Principles of Laparoscopic Surgery

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With Foreword by
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Principles of Laparoscopic Surgery

Basic and Advanced Techniques

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Foreword

In the five years since laparoscopic methods have gained widespread use in general surgery, a wealth of experience has accumulated. The surgical pioneers who recognized the potential value of laparoscopy for treatment many years previously certainly deserve a great deal of credit for their farsightedness. In a sense, however, the changes of the past few years amount to the development of a whole new branch of surgery. The rate of change has produced an intense demand for the surgical community to gather, structure, and disseminate the newly acquired knowledge. The safety and efficacy of this enormous shift in surgical practice hinges on this process.

In *Principles of Laparoscopic Surgery,* the editors have asked a select group of expert surgeons to present what amounts to an encyclopedic account of current laparoscopic surgical practice. The detailed but varying opinions on the management of gallbladder and complex pancreaticobiliary disease are unique to this volume. Not only are varying surgical viewpoints presented, but gastroenterologists and radiologists also describe alternative methods of management. Because laparoscopic cholecystectomy is the most developed and most common procedure, Chapters 11 and 12 give an especially detailed overview, including clinical data to support each author's views. The editors have also included information from related fields in evolution, including minimally invasive urology, gynecology, and vascular and cardiovascular surgery. Aiming to be comprehensive, the coverage includes advances as well as basic instrumentation and techniques. Potential complications are described to help surgeons avoid the pitfalls that lead to complications. The new scientific information concerning electrocautery, fiberoptics, the rod-lens system, video cameras, lasers, and shock wave technology is presented in detail.

Thus, this reference book thoroughly covers the indications, technique, and results of surgical laparoscopy. It is a detailed, authoritative work that should be of great use to both the novice and advanced laparoscopic surgeon.

January 1995
San Francisco, California

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Preface

Laparoscopic cholecystectomy *is* today's gold standard for managing symptomatic cholelithiasis. This technique represents a milestone in the management of a common surgical disease. Globally, millions of patients have benefited. More importantly, however, it symbolizes a change in the mindset of general surgeons from that of traditional followers to that of innovative thinkers willing to take the challenge of progress in a field of medicine which had grown staid. This redemption of thought and spirit represents the renaissance of general surgery which has created a new essence for progress that has spread like wildfire throughout the world to include not only wealthy industrialized societies, but also encompassing less advantaged countries with limited economic reserve. This new raison d'etre has inspired the applications of minimally invasive surgery to other organs and disease processes, creating an avalanche of ideas and techniques designed to correct or ameliorate surgical diseases in a more humane manner.

Thousands of surgeons internationally have taken courses and precepted to learn laparoscopic methods. Numerous textbooks, journals, newsletters, videotapes, and now CD-ROMs have been produced to provide the information surgeons thirst for. To date, most of these textbooks have been written in "cookbook" fashion providing a step-by-step description of "how I do it." Because most of these early textbooks have been written at a time when little clinical data had accumulated and only few surgeons had significant experience, they were appropriate. Unlike these earlier books, *Principles of Laparoscopic Surgery* is a complete textbook on basic and advanced techniques in minimally invasive surgery. This textbook not only describes the techniques used, but it presents the rationale for their use and clinical material to support it. Because minimally invasive techniques have truly been developed in a worldwide arena, internationally renown experts have been invited to contribute. Moreover, because minimally invasive techniques are used in various specialties, innovators in vascular surgery, cardiology, radiology, urology, and gynecology have been asked to share their ideas and experiences. Laparoscopic cholecystectomy and laparoscopic common bile duct explorations exemplify our borrowing equipment developed for gynecologic and urologic purposes, and adapted to general surgical problems. Likewise, knowledge of techniques and technology developed in other fields may find application in other problems faced by the general surgeon or other specialists working with minimally invasive approaches.

Section I provides essential information on equipment and basic techniques. Nursing and anesthetic considerations are covered in detail. Credentialling, training concepts and guidelines are developed. In Section II, the various organ systems are approached with minimally invasive techniques that include not only different laparoscopic approaches, but also the options of endoscopic and radiologic approaches which are presented by both surgical and nonsurgical colleagues. These various alternative techniques are described by experts who defend their rationale with extensive clinical data. These approaches are also compared with the traditional open methods to try to place the newer techniques in perspective. Section III looks at the important developments in the specialty areas, with an extensive look into gynecology and urology. Angioscopy in venous and arterial intraluminal surgery provides a window to potential developments that may find applications in abdominal surgery. Three-dimensional ultrasound reconstruction of arterial plaques provide a titillating preview of an exciting new imaging modality. Section IV deals extensively with the technology presently being used and provides an insight into potentially useful future technology. The surgeon will have the opportunity to better understand the mechanisms of tissue ablation with laser and electrocautery, the dynamics of stone destruction with electrohydraulic and shock wave lithotripsy, as well as the physics of light and image transmission necessary to couple intraperitoneal images to the video screen.

The editors hope that this textbook will provide the surgeon with the techniques, and clinical and scientific information necessary to advance his or her skills in this modern era of surgery.

Maurice E. Arregui

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Section I
Basic Laparoscopic Techniques

1
A History of Endoscopic Surgery

Chad J. Davis and Charles J. Filipi

Introduction

Surgery has experienced a revolution in the eight years since the introduction of laparoscopic cholecystectomy. This procedure was followed rapidly by the development of laparoscopic appendectomy, herniorrhaphy, bowel resection, and other abdominal procedures, and by a resurgence of interest in thoracoscopy, a procedure which had decreased in popularity after the introduction of chemotherapeutic agents for tuberculosis in the 1940s.

Technological advances in most fields are the result of both slowly progressing research and major breakthroughs or discoveries of the missing pieces of the puzzle that make rapid advancement possible. The development of endoscopic surgery in the last 100 years is a case in point. Although physicians in ancient times and in the Middle Ages attempted endoscopic examinations of sorts, it was not until the 1800s that development of practical endoscopes began in earnest. Three periods of breakthrough mark the development of endoscopic surgery in the last 100 years, each of which has made rapid progress possible: first, the invention of the incandescent light bulb by Thomas Edison and the development of lens systems for scopes in the 1870s and 1880s; second, the invention of the rod-lens system by Hopkins in the late 1950s together with the development of fiberoptic cold-light transmission in the early 1960s; and finally, the introduction of the computer chip video camera in the 1980s.

This chapter will focus on the major breakthroughs and the people responsible for them, as well as on the profound influence these innovations have had on the practice of endoscopic surgery. It will also look at the other smaller advances and the unsung heroes who persisted despite technical limitations and, sometimes, the condemnation or skepticism of their colleagues.

The manuscripts written by the pioneers in endoscopy and endoscopic surgery are fascinating reading. These people had a clear grasp of the clinical problems they were trying to study and uncommon foresight concerning the instruments that were needed to study them. In developing their own instruments, they displayed extraordinary ingenuity and were usually held back only by technical constraints, some of which would not be overcome for many years.

Early History (400 B.C.–A.D. 1805)

Endoscopy was first described by Hippocrates of Greece (*circa* 460–375 B.C.), who made reference to a rectal speculum: "Then lay the patient backwards and look with the rectal speculum to see where the rectum is affected . . ."[1] The first simple specula for gynecological endoscopy date from about the same time.[2] The problems with these early instruments—inadequate light and a shallow depth of penetration—are the same problems that would plague endoscopy for more than 2,000 years.[3] Roman medicine also produced instruments with which to inspect internal organs: a very advanced three-bladed vaginal speculum was found during excavations of the ruins of Pompeii, which was destroyed in A.D. 70. This instrument was similar to the modern-day vaginal speculum. Archigenes, a Syrian physician who practiced in Rome from A.D. 95 to 117, developed a vaginal speculum and outlined how the patient and physician should be positioned for an examination. He was also the first to emphasize adequate illumination and recommended "that good light from the south."[1] Soranus, an Ephesian who practiced obstetrics in Rome at about the same time, also described a vaginal speculum. In the Babylonian Talmud, the compendium of Rabbinical writings completed around A.D. 500, the Niddah Treatise mentions a device called a "siphopherot." This siphopherot consisted of a lead tube with a bent tip and wooden "mechul" at the tip to make insertion into the vagina less painful. The uterine cervix could then be inspected directly.[1,2]

According to Avicenna (A.D. 980–1037), the learned and eminent chief physician at the hospital in Baghdad, reflected light was probably introduced by the Arabian physician Abulkasim (A.D. 936–1013) about A.D. 1000. He used a mirror to reflect light into the vagina and cervix.[1,2,4] More sophisticated light sources were produced during the later Middle Ages and the Renaissance. In 1587 Giulio Caesare Aranz suggested applying the camera obscura to medical use. In his treatise *Tumores Praeter Naturam* he described how light shining through a window-shutter could be projected into the nasal cavity by means of a spherical glass flask filled with water. For an overcast day he suggested using an artificial light source, although it is unclear what light source he had in mind.[1,2,5]

In the 1600s Peter Borell of Castres, France, developed a concave mirror to reflect and focus light on the object being examined. The following century the gynecologist Arnaud adapted a small lantern used by burglars—the thief lantern—to illuminate the cervix, giving new impetus to the use of the vaginal speculum. He described this innovation in his publication *Mémoires Gynécologiques* in 1768.[1,2,5]

FIGURE 1.1. Philipp Bozzini. A self-portrait *circa* 1805 from the Frankfort town archives. (From Rathert P, Lutzeyer W, Goddwin W. Philipp Bozzini (1773–1809) and the Lichtleiter, Figure 3(D). In: *Urology*. 1974; III (1). With permission.)

The Modern Era (1805–Present)

Philipp Bozzini (1773–1809) (Figure 1.1) deserves most of the credit for the birth of modern endoscopy. Until the early 1800s, examination of the interior of the body was hindered by the perennial problems of inadequate illumination and a shallow depth of penetration. Bozzini attempted to overcome these deficiencies with his invention, the "*Lichtleiter,*" or light conductor. This early endoscope directed light rays into the internal cavities of the body and redirected them to the eye of the observer. It saw only limited clinical use, but imperfections in its design or construction were only partly responsible for this. Professional rivalries and politics in the medical community of Vienna ultimately sealed the fate of this brilliant invention.[3]

The development of Bozzini's invention and the events surrounding its evaluation by the Viennese medical community are worth reviewing in detail for two reasons. First, the instrument was truly ingenious and, second, the reaction of some physicians in Vienna was not unlike the reaction of some physicians to today's laparoscopic procedures—skeptical at best and hostile at worst.

It is important to know something of Bozzini's early years in practice to understand why he developed the *Lichtleiter* and why he made the fateful decision to submit his invention to Archduke Karl of Austria in 1805.[6] Bozzini completed his medical studies in Mainz in 1796 and started practice there at the age of 23. The French conquered Mainz in 1797, and the city later came under the control of the French government. Bozzini was allowed to continue practicing medicine but did not want to become a French citizen. He therefore tried to find a new position in another part of Germany and settled in Frankfort. At about this time, from 1799 to 1802, he served in the War of the Second Coalition as an army physician under the command of the Archduke Karl, brother of the Austrian Emperor Franz I. He served with great distinction as head of a military hospital. On his return to Frankfort, he applied for citizenship there but for some reason his application was rejected. He sought the help of Archduke Karl, who wrote a letter of recommendation to the local government of Frankfort. As a result, Bozzini became a citizen in 1803.

Bozzini had only a small private practice in Frankfort, which allowed him to devote his energies to scientific work and investigation. He invented several instruments, of which the *Lichtleiter* is the most famous (Figure 1.2). The instrument was a vase-shaped lantern, about 13 in. high, 2 in. deep, and 3 in. wide. Its body was made of tin covered with leather and its parts consisted of a candle, a reflecting mirror, and several specula for examining the urethra, bladder, rectum, and vagina. The light was conveyed from a lamp through a tube into the vagina to illuminate it. The cervix was viewed through a second channel.[7] In February 1805 Bozzini published a short announcement in one of the German daily newspapers describing the device, and in June of that year he sent the first full description of the *Lichtleiter* to Archduke Karl

FIGURE 1.2. Original *Lichtleiter* with various speculae. This is the only *Lichtleiter* in existence in America and is in the possession of the American College of Surgeons, Chicago, IL. (From Rathert P, Lutzeyer W, Goddwin W. Philipp Bozzini (1773–1809) and the Lichtleiter, Figure 1. In: *Urology*. 1974; III (1). With permission.)

of Austria. He did this out of gratitude to the Archduke and probably also because he hoped that the Archduke, as commander of the armed forces and therefore of all military hospitals, might encourage the acceptance of the *Lichtleiter* in Vienna and elsewhere.

Archduke Karl was impressed with the *Lichtleiter* but knew that it could be introduced in the military hospitals only if it was approved by the Josephs-Academy of Vienna, the ultimate authority in matters of military medicine. The Josephs-Academy was progressive, unlike its arch rival, the Vienna Medical Faculty, headed by Joseph Andreas Stifft. Stifft was "on principle an enemy of all new ideas." The Josephs-Academy was extremely interested in the instrument and commenced experiments on it immediately. However, in those days of absolute authority, it was necessary to gain permission from Emperor Franz himself before offering the light conductor for general use. Franz also was skeptical of innovations and consulted on the matter with his personal physician, who was none other than Joseph Andreas Stifft. Stifft was not about to let the Medical Faculty be outdone by the Josephs-Academy, so he suggested that the Vienna Medical Faculty give its own expert opinion on the device after the Josephs-Academy completed its experiments. Emperor Franz followed his advice and signed a resolution to this effect.

In February 1807, nearly two years after Bozzini sent his manuscript to Archduke Karl, the Josephs-Academy completed its studies on the *Lichtleiter* and declared the invention ingenious and the inventor a gifted person. It then sent the light conductor to the Medical Faculty for further studies. Only nine days later, the Medical Faculty made public its "expert opinion"—inspired by Stifft, no doubt. It reported no experiments but simply announced that the device was "a mere toy." It warned doctors not to buy it and reprimanded Bozzini for his "undue curiosity."[8,9] So Bozzini's ingenious invention became a victim of professional jealousy in the Viennese medical community and of political intrigue at the court of Emperor Franz. Nevertheless, time has vindicated Bozzini because his *Lichtleiter* established the principles that guided the development of endoscopes, and it inspired others to forge ahead in this new field.

There was little recorded activity in endoscopy until 1826, when Pierre Salomon Segalas (1792–1875) introduced his "speculum urethro-cystique" to the Académie des Sciences in Paris.[3] It is unclear whether Segalas knew of and was inspired by Bozzini's work or whether his invention was independent. Nevertheless, Segalas's instrument employed the same principles as Bozzini's and was more clinically useful. The *Lancet* reported that "M. Segalas informed the Institute that the light accumulated at the extremity of the urethral tube would enable a person to read the smallest printing type at the distance of fifteen inches, and that in the most obscure place."[3]

In America, John D. Fisher (1798–1850) of Boston described an endoscope initially developed to inspect the vagina but later modified to examine the bladder and urethra.[8] He may have been inspired by reports of Bozzini's and Segalas's instruments, although he seemed to imply otherwise in a letter to Professor Horner of Boston: "an instrument involving the same principles as Segalas, was thought of by me three years ago [in 1826], when a student of medicine. I then had under my charge a woman who had a disease of the neck of the uterus, and so great were her feelings of delicacy that I could not prevail upon her to suffer me to make an examination with a common speculum."[3] As a result of this quandary, Fisher constructed an endoscope that not only afforded him a better view than was possible with an ordinary vaginal speculum "but also placed him at a sufficiently discrete [sic] distance to satisfy the patient's modesty."

In spite of the ingenuity of Bozzini, Segalas, and Fisher there was again a lull for about 25 years. Then in 1853 Antonin J. Desormeaux (1815–1881) (Figure 1.3) introduced a versatile new endoscope. He presented it to the Académie des Sciences on November 29, 1855, and

FIGURE 1.3. Antonin Desormeaux (1815–1881). (Courtesy of Dittrick Museum of Medical History.)

shared the Argenteuil Prize for the design of the instrument.[3,5,8,9] The endoscope burned a mixture of alcohol and turpentine, which Desormeaux called "gazogene," and the light rays were reflected into a tube by means of mirrors. A genitourinary speculum allowed him to inspect the urethra, bladder, and vagina[9] (Figure 1.4). By inserting a lens, the light could be condensed to form a narrower, more intense spot.[10] Desormeaux had initially contemplated using electricity but abandoned that idea: "before I settled upon this lamp, I thought of the electric light, but it is too cumbersome to be carried around, and requires an assistant [to regulate the batteries]. It would, moreover, double the price of the instrument."[3] (The instrument was already expensive. In the 1872 catalogue for George Tiemann & Co., an American surgical instrument distributor, the Desormeaux endoscope cost $150, making it the second most expensive item in the catalogue. Most surgical instruments cost much less.[3])

Desormeaux's clinical investigations with his invention were aided by his appointment as surgeon at the Necker Hospital in Paris in 1862. There, he diagnosed and treated urologic diseases in numerous patients using his endoscope. He also wrote his monograph *De l'endoscopie,* published in 1865, which was even more influential than his endoscope itself.

The search for a brighter, more intense light source continued, and in 1867 the first internal light source was invented by Julius Bruck, a dentist from Breslau. All earlier instruments had an external source whose light was transmitted inward through a system of mirrors and lenses. Bruck developed a method of examining the mouth that he called "stomatoscopy" and used as his light source a loop of platinum wire heated to white-hot brilliance by an electric current. This dramatically improved illumination, but it also increased the risk of burning a hole in the tissue being examined. Bruck developed a water jacket for cooling the wire, but this made the device cumbersome, and it did not gain widespread acceptance.[8,9,11] Nevertheless, a decade later Nitze used this method of illumination in his first cystoscope.[8]

The First Major Breakthroughs

The next developments, which occurred independently but almost simultaneously, were the first major breakthroughs for endoscopy and led to a flurry of activity and to the production of endoscopes that were the forerunners of present-day instruments. The first of these advances was the incorporation of lenses into the endoscope tube to sharpen and magnify the image. The second was the invention of the incandescent light bulb.

Maximillian Nitze (1848–1906) (Figure 1.5) developed a cystoscope with a series of lenses and reported it in 1879 in the *Wiener Medizinische Wochenschrift.*[13] In this article, he noted the shortcomings of Desormeaux's scope and described the improvements he had made in his new instrument. Nitze wanted, first, a wider angle of vision and, second, a brighter internal (not external) light that would move with the scope and would thus produce no shadow. To tackle the first problem, he worked with Reinecke, a Berlin optician, and developed a lens system that had three parts: an objective lens; a middle, or inverting, lens; and an ocular lens, or eyepiece. This system produced the wider angle of vision desired, corrected image inversion, and magnified the image.[8] This was the basic design, with some variation, used by endoscope manufacturers for the next 70 years. To solve the second problem—that of illumination—Nitze used an electrically heated platinum wire similar to Bruck's, which was cooled with a continuous stream of water. This wire generated enough natural light that Nitze suggested taking photographs through the scope. He also appealed to technicians for help in perfecting the design of the instrument, since he considered his own cystoscope to be rather crude.[8,13] Not long after this, he sought the help of Josef Leiter (1848–1892), the leading instrument maker in Vienna.[3,8] Aided by Leiter's mechanical ability, this collaboration soon produced a practical cystoscope, models of which were offered in a Viennese medical catalogue published in 1880.[8]

"Widespread acclaim for the ingenuity of the instrument brought Nitze and Leiter to blows, each claiming personal credit for the design and its success."[3] They parted company and Leiter teamed up with Johann von

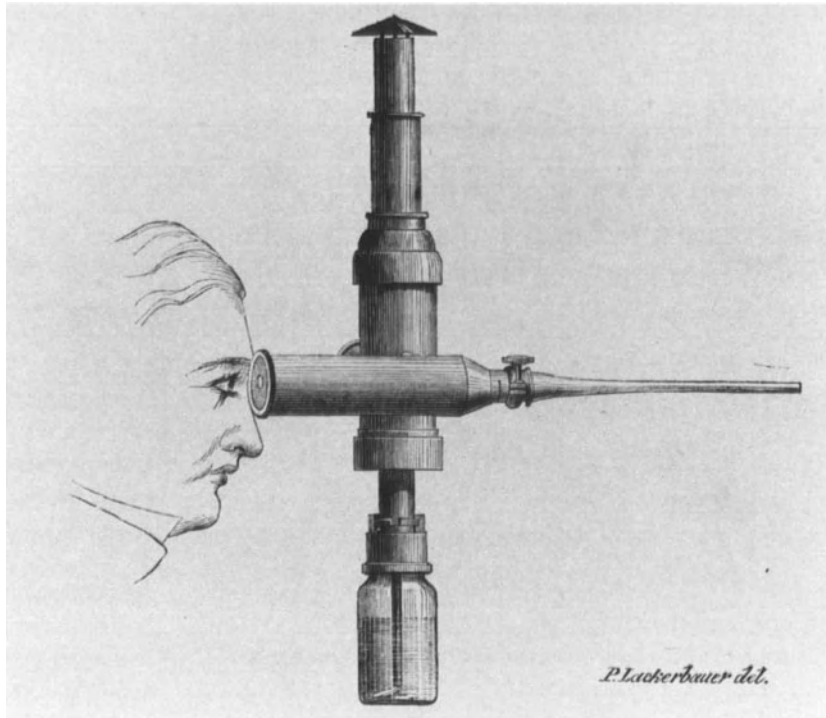

FIGURE 1.4. Desormeaux endoscope used as a cystoscope. (From Davis CJ. A history of endoscopic surgery, Figure 9. In: *Surgical Laparoscopy & Endoscopy*. 1992; 2 (1). With permission.)

FIGURE 1.5. Maximillian Nitze (1848–1906). (From Belt AE and Charnock DA. The cystoscope and its use, Figure 9. In: *Modern Urology*. Lea & Febiger, 1936.)

Mikulicz in 1880 to design a gastroscope and esophagoscope. Rudolf Schindler, the famous gastroscopist of the twentieth century, who worked closely with the German instrument maker Georg Wolf, reminded his endoscopic colleagues of this quarrel in his textbook *Gastroscopy* in 1950. He emphasized that collaboration between physicians and instrument makers was crucial to the development of workable endoscopes:

> The cornerstone of endoscopy was laid by Joseph Leiter, an electro-optician of Vienna, who worked with Nitze and built the first cystoscopes. Together with Mikulicz, he also inaugurated the second phase of gastroscopy . . . It is useless to ask whether the technician or the physician has the greater merits . . . The ugly disagreement between Nitze and Leiter is well known. It would have been unnecessary if both men had considered that the one cannot exist without the other.[3]

The other major breakthrough of this period was the invention of the incandescent light bulb in October 1879 by Thomas Edison. Only four years later, in 1883, Newman of Glasgow described using a miniaturized version of the incandescent bulb in a cystoscope. Two cells powered the bulb, which produced light equal to that of one candle. The bulb was placed within a cannula, which was then introduced into the bladder. Although this cystoscope was limited to use in women, Newman "was able to carry out numerous procedures and recognized many bladder lesions."[8]

Josef Leiter first saw the Edison electric lamp at the 1883 International Electrical Exhibition in Vienna. He miniaturized the bulb and incorporated it into the distal end of the cystoscope, introducing his instrument in 1886.[3] This "mignon lampchen" eliminated the platinum wire illumination system with its cumbersome cooling jacket. Independently, in 1887, Nitze introduced his cystoscope with a miniature incandescent bulb.[8,9]

In the remaining years of the nineteenth century other innovations included a prismatic lens system for angled viewing and incorporation of an operating channel into the cystoscope. However, none of these changes improved Nitze's basic design[2,8] (Figure 1.6). The cystoscope helped establish urology as a viable specialty and at the "close of the 19th century, other open cavity endoscopic procedures such as proctoscopy, laryngoscopy, and esophagoscopy, were well-established in daily clinical use."[9] "Closed cavity" procedures had not been tried, but the stage was set for the innovations of the twentieth century.

The First Laparoscopy

Georg Kelling, a surgeon from Dresden, was the first to perform laparoscopy, introducing a cystoscope into a living dog before the Seventy-third Congress of German Naturalists and Physicians in Hamburg on September 23, 1901. He named the procedure "*Kölioskopie*" and described it in a report in the *Münchener Medizinische Wochenschrift* in January 1902.[14]

He anesthetized a small area of abdominal wall and introduced a Fiedler puncture needle through which room air, filtered through sterile cotton, was injected into the abdomen to produce a pneumoperitoneum. He then inserted a larger trocar and introduced a Nitze cystoscope through it. He could see the internal viscera clearly and could palpate them with the tip of the scope or with a probe inserted through a second trocar.[11,15] In his article he gave instructions for the preparation of the patient and recommended enemas to clear the colon so that if bowel perforation occurred, contamination would be minimal. He also considered intra-abdominal adhesions a contraindication for the procedure. He promised a more detailed report, which did not appear.[14,15]

He was not heard from again until late 1910, after H. C. Jacobaeus of Stockholm published his report on laparoscopy and thoracoscopy in humans in *Münchener Medizinische Wochenschrift.* A response by Kelling appeared two months later in the same journal, disputing Jacobaeus's claim to be the first to perform the procedure in humans and stating that he had successfully used celioscopy in two humans between 1901 and 1910.[16] Unfortunately, unlike Jacobaeus, Kelling had made the mistake of not publishing his work and he therefore did not receive the publicity or attention he deserved.

In a 1923 article, published after 13 years of silence, Kelling reported that the dire economic situation in Germany after World War I had compelled him to use celioscopy liberally as a diagnostic method, because it saved his patients the prolonged and costly stay in the hospital an exploratory laparotomy entailed. He advocated its use in the diagnosis of intra-abdominal conditions, including cirrhosis of the liver and abdominal adhesions, and in the diagnosis and staging of gastric carcinoma. He also used celioscopy and gastroscopy—although not concurrently—to evaluate gastric ulcers. In all these conditions, this less invasive procedure did indeed result in a shorter hospital stay, a smaller abdominal wound, and a quicker recovery. Also in this article, he described a new trocar with a lengthwise groove that housed a small tube through which air could be passed.[15,17]

The followers of Jacobaeus were prone to overlook the achievements of Kelling. It is possible that Kelling's reply to Jacobaeus was sour grapes, but given Kelling's other achievements in esophagoscopy and gastroscopy and his integrity as an investigator and clinician, it is also possible that he performed laparoscopy on humans prior to Jacobaeus. And one could understand Kelling's frustration and disappointment when Jacobaeus published his work first. So, to avoid detracting from the achievements of either man or impugning their honesty, both should be recognized as the progenitors of modern laparoscopy.

At this point, some confusion exists about the achievements of Dimitri Oskarovich Ott, a gynecologist from St. Petersburg. He is credited by a number of authors with performing the first laparoscopy, albeit without the aid of

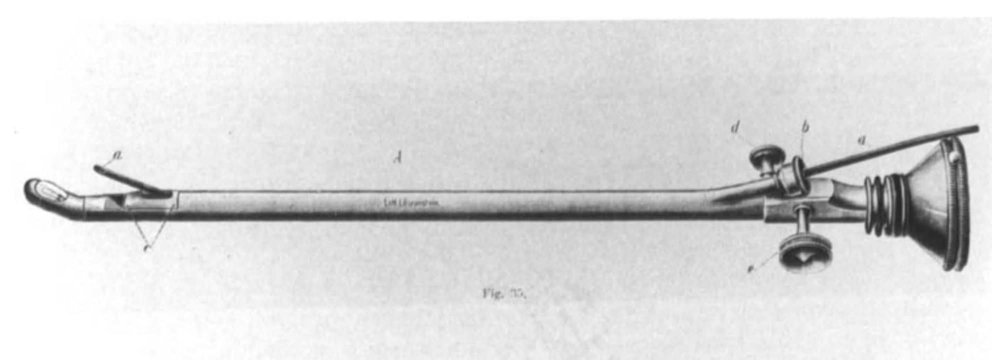

FIGURE 1.6. Nitze cystoscope with incandescent globe and instrument channel for ureteral probe. (Courtesy of National Library of Medicine, Bethesda, MD.)

the optics of the type Kelling used.[2,3,9,11,15,18] He supposedly inserted a speculum into the abdomen through a small anterior abdominal wall incision and inspected the cavity using a gynecologist's head mirror and an incandescent bulb. However, according to Ott's own articles, which were published both in Russian and German in 1901, this was not the case.[19,20] What he actually did was make an incision in the vagina posterior to the cervix and insert a speculum into the cul-de-sac, a procedure that allowed him to inspect the pelvic and abdominal viscera. No mention was made, in either of his articles, of an incision in the anterior abdominal wall. So what he actually performed was the first culdoscopy, not a laparoscopy as we know it. The confusion probably resulted from the fact that he called his procedure "ventroscopy," implying that the incision would have been made in the ventral portion of the abdomen (that is, in the abdominal wall). Nevertheless, he showed extraordinary foresight about the eventual uses of intra-abdominal endoscopy: removal of the uterus, dissection of "adhesions and fixations of the uterus and adnexae," diagnosis and treatment of ovarian cysts and tumors, treatment of "infections in the tubes and of ectopic pregnancies," and conservative operations on the uterus, such as enucleation of fibromas.[20]

Hans Christian Jacobaeus (1879–1937) (Figure 1.7), professor of medicine at the Caroline Institute in Stockholm, Sweden, reported the first laparoscopy and thoracoscopy in the human. He described several cases of laparoscopy and two cases of thoracoscopy in October 1910 in his article "Concerning the possibility of using cystoscopy in the examination of serous cavities."[21] Jacobaeus was a conscientious and respected investigator, as evidenced by this tribute to him by Sven Ingvar upon his death: "Jacobaeus possessed a great capacity for work, inflexible industry, meticulous care in planning and execution, and independence and originality in the interpretation of the observations made."[22]

FIGURE 1.7. Hans Christian Jacobaeus (1879–1937). (From Bottiger LE, ed. *Acta Medica Scandinavica.* 1938; 93. With permission.)

Jacobaeus coined the term "thoraco-laparoscopy." After experimenting on 20 cadavers with a trocar he designed, he performed laparoscopy on 17 patients with ascites and thoracoscopy on two patients with suppurative exudates of the pleura.[15,21] He did not use a separate needle to produce a pneumoperitoneum, as had Kelling, but instead insufflated air through the trocar through which the Nitze cystoscope was then introduced. The following year, in 1911, he reported his experience with 115 laparoscopies and thoracoscopies in 72 patients, 45 of whom had abdominal problems and 27 of whom had pleural diseases. Only one patient had a serious complication (bleeding).[23]

Interestingly, in his 1911 paper Jacobaeus viewed thoracoscopy as a more promising procedure than laparoscopy. He later concentrated on thoracoscopy for the evaluation and treatment of tuberculosis.[11,15] With the aid of the thoracoscope, he lysed pleural adhesions in these patients in order to produce an artificial pneumothorax. In 1913 a French doctor named Rosenthal, commenting on Jacobaeus's work, acknowledged the value of laparoscopy but, like Jacobaeus, thought thoracoscopy the more important method because it opened "a new field of attack, whereas laparoscopy had to compete with the more traditional exploratory laparotomy."[15] This, of course, was in the days before endotracheal intubation and therefore before thoracotomy was technically feasible.

The first laparoscopy in the United States was performed in 1911 by Bertram M. Bernheim, an assistant surgeon at Johns Hopkins, before he learned of the work of Kelling and Jacobaeus. In two patients, he inserted an ordinary proctoscope of ½-in. bore through an epigastric incision and used an electric headlamp for illumination. He used no pneumoperitoneum but was able to inspect the stomach, gallbladder, liver, and the parietal peritoneum. One of the patients was deeply jaundiced and laparoscopy showed a distended gallbladder. At laparotomy a pancreatic carcinoma was found to be obstructing the common bile duct.[3,9,11,15,24]

Advances in Europe and America

Developments in laparoscopy and thoracoscopy over the next several decades fell within three areas of specialty: gastrointestinal disorders, gynecologic conditions, and thoracic diseases. Laparoscopic investigations into disorders of the gastrointestinal organs, especially those of the liver and stomach, predominated from 1920 through the 1940s, but some work was also done in gynecologic laparoscopy. Culdoscopy was a distinctly American development, introduced around 1940 because of the disenchantment of American gynecologists with laparoscopy. It remained the preferred mode of intra-abdominal endoscopy in the United States until the late 1960s. Thoracoscopy was very popular for division of pleural adhesions in patients with tuberculosis and was used mostly for this purpose. Several authors reported series of hundreds, and sometimes thousands, of patients so treated between 1920 and 1950.

B. H. Orndoff, an internist from Chicago, reported the first large series of "peritoneoscopies" in the United States in 1920.[24] His article appeared, surprisingly, in the *Journal of Radiology* and described 42 cases.[25] Orndoff's innovations were a sharp pyramidal trocar point, which facilitated trocar introduction through the abdominal wall, and the use of fluoroscopy, which he contended decreased the chance of injuring the abdominal viscera with trocars or instruments.

R. Korbsch of Munich extended the indications for laparoscopy to any disorders of the abdominal cavity that could not be diagnosed in any other way in a 1922 article.[26] He wrote and published the first textbook and atlas on laparoscopy and thoracoscopy in 1927.[1,5]

One of the most notable proponents of peritoneoscopy at this time was the brilliant investigator Heinz Kalk of Berlin. His primary contribution was to champion and improve on a forward oblique (135°) viewing system that had been introduced by Kremer around 1927.[27] This endoscope had a more "natural angle of vision" (that is, a more-forward alignment) that made it easier for the examiner to orient himself with respect to the abdominal surroundings. It also decreased the blind spot to 10°, small enough, in Kalk's opinion, to be easily tolerated when performing an examination. This ingenious development was largely responsible for the widespread acceptance and growth of laparoscopy in Europe.[9,11] The optical system of the laparoscope remained essentially unchanged until Hopkins introduced the rod-lens system 30 years later.

Pneumoperitoneum

Many workers realized that pneumoperitoneum was crucial to the success of laparoscopic examination. Early on, however, the methods for producing one were crude, the needles were somewhat dangerous, and there was no consensus about whether filtered air, oxygen, or some other type of gas should be used. In addition, once produced, the pneumoperitoneum was difficult to maintain because of air leakage through the cannula around the laparoscope.

Otto Goetze of Germany reported in 1918 developing an insufflation needle for use in diagnostic radiology. He suggested in his article that the needle could be used in laparoscopy.[28] In 1938, Janos Veress of Hungary introduced his spring-loaded needle for draining ascites and evacuating fluid and air from the chest. The barrel of the needle contained a blunt obturator, which would retract during puncture of the abdominal wall and spring forward, ahead of the needle, once the fascia was penetrated to protect the abdominal viscera from the sharp needle. He used it in over 2,000 cases.[29] He did not suggest that it be used for laparoscopy, but it later became the preferred needle for establishing a pneumoperitoneum and is still the most popular needle today.

Richard Zollikofer of Switzerland recommended that CO_2 be the preferred insufflation gas in an article published in 1924. He used CO_2 rather than filtered air or nitrogen to avoid explosions inside the abdomen and to promote more rapid absorption of gas into the peritoneum.[2,9,11,15,30]

Therapeutic Laparoscopy

The diagnostic capabilities of laparoscopy were becoming well-established but, unlike thoracoscopy, laparoscopy had not yet found a role in treatment. Oscar Nadeau and Otto Kampmeier of Chicago recognized the therapeutic possibilities of laparoscopy and stated they could not agree with Jacobaeus that "[a]bdominoscopy does not have the practical possibilities that thoracoscopy has." In a remarkably prescient statement—especially considering the development of therapeutic laparoscopy in the 1960s and 1970s—they predicted that abdominoscopy would: "outstrip thoracoscopy in the extent of its application and in its development. The separation of certain types of peritoneal adhesions, the internal application of drugs, or the execution of other therapeutic measures with the guidance of the endoscope, represent the direction which the further clinical development of the method probably will take."[15]

C. Fervers, a general surgeon from Germany, was the first to report on the lysis of intra-abdominal adhesions laparoscopically (in 1933).[2,31] In several patients, he used the coagulating sound of a cystoscope to cauterize and cut the adhesions under direct vision.

Fervers used oxygen to insufflate the peritoneal cavity and reported an incident where some smouldering, carbonized abdominal adhesions ignited the oxygen and caused an intra-abdominal explosion. There was a big flash of light throughout the abdomen, which could be seen through the abdominal wall by those in the operating room. It frightened the surgeon more than it hurt the patient, who escaped with a few minor complaints that disappeared after several days. Needless to say, Fervers never insufflated the abdomen again using oxygen. From then on, he used filtered air.[31]

There is some question as to who actually performed the first laparoscopic tubal sterilization. Techniques were developing simultaneously in several countries during the 1930s, but because of the constraints imposed by the politics of the day, free exchange of scientific information was not possible.[2] It is therefore difficult to ascertain the exact sequence of events. However, Boesch of Switzerland is credited with the first tubal sterilization in 1936.[5]

In 1937, independently of Boesch, E. T. Anderson of Texas suggested that women could be sterilized by endothermic coagulation.[2,9] It is not clear, however, whether he actually performed the operation or merely described it.[9] In 1941 Power and Barnes of Ann Arbor, Michigan, described performing a laparoscopic tubal sterilization, which probably was the first American case reported.

Laparoscopy in America

In America in the 1930s John C. Ruddock and Edward B. Benedict were the most outspoken proponents of laparoscopy.[3] Ruddock was a surgeon who worked with American Cystoscope Manufacturers, Inc. (ACMI), and perfected his own "peritoneoscope" using the foroblique vision system promoted by Kalk. He also designed a pneumoperitoneum needle, a cannula and trocar, a fluid aspirator, and biopsy instruments. In his hands, peritoneoscopy was safe and very successful: he reported 500 cases in 1937 with a mortality of 0.2% and a diagnostic accuracy of 92% (compared to 64% without peritoneoscopy).[3,11,32] He was a vigorous champion of the procedure. In 1939, Benedict of Boston published his experience with peritoneoscopy in 48 patients. He had only one fatality, which he attributed to the pneumoperitoneum. He subsequently published five papers on peritoneoscopy, dealing mostly with gastroenterology. He showed that it was useful for diagnosing liver diseases, ascites, neoplasms of the stomach and colon, and gynecologic disorders.

John M. Waugh, a Mayo Clinic surgeon, was also very active in the field of peritoneoscopy, from the time he joined the Mayo Clinic. He used it primarily for the diagnosis of liver disease and intra-abdominal malignancies. There were 396 diagnostic examinations performed at Mayo between 1938 and 1946 and, of these, Waugh did 273. Peritoneoscopy was 93% accurate in cases where it was done to confirm a clinical diagnosis and 71% accurate when the purpose of the procedure was to establish a diagnosis. Waugh concluded that any patient with ascites who had a doubtful diagnosis "should be examined at least once by peritoneoscopy. This should be done to establish definitely the diagnosis in the hope that benign disease amenable to treatment may be found."[33]

Culdoscopy

Peritoneoscopy was used extensively in Europe because of Kalk's influence, but the technique was not widely accepted in America, although it had a few proponents, such as Ruddock, Benedict, and Waugh.[9] American gynecologists, especially, became disenchanted with laparoscopy because of the lack of satisfactory instruments and the resultant technical difficulties, so a different technique was tried. In 1939 TeLinde of the Johns Hopkins University attempted to examine the pelvic organs via the vaginal route with the patient in the lithotomy position. He found this method difficult, however, because the small bowel behind the uterus obstructed the view, and he abandoned it. In 1944 Decker and Cherry overcame the problems encountered by TeLinde by placing the patient prone on her knees and elbows. This created a negative intra-abdominal pressure, which induced a pneumoperitoneum when the needle was introduced into the cul-de-sac. Decker and Cherry were the first to name the procedure "culdoscopy" and used only local anesthesia in most cases. Because of their efforts and those of Doyle and Clyman later on, culdoscopy remained the primary gynecologic endoscopic procedure in America until the late 1960s.[2,9,11,34]

Post-War Developments

After World War II most of the impetus for laparoscopy came from European gynecologists. One of its main proponents was Raoul Palmer of Paris, who used culdoscopy to study infertility, as had Decker, but preferred the abdominal approach, which he called "gynecologic celioscopy."[9] He was the first person to emphasize the importance of monitoring the pressure of the pneumoperitoneum, determining that it should not exceed 25 mm Hg in a patient under general anesthesia.[11,35]

Another advocate was H. Frangenheim of Konstanz, Germany. Starting in the early 1950s, he modified and designed many laparoscopic instruments and introduced a prototype of the modern carbon dioxide insufflator.[36] He encouraged the use of laparoscopy for a wider array of clinical indications and was one of the first to identify the sources of complications, such as emphysema, air embolism, intestinal perforation, hemorrhage, thermal injury to the bowel, cardiopulmonary problems, and infection. He suggested these complications could be avoided if general anesthesia was used, care was taken while introducing the pneumoperitoneum, and the pneumoperitoneum needle or trocars were not placed through previous abdominal scars.[9,11] In the late 1950s Palmer and Frangenheim independently developed methods of electrocoagulation for tubal sterilization.[36] Frangenheim, who has published a textbook and numerous articles on laparoscopy, is largely responsible for the trend toward laparoscopy in Germany from 1958 on.[5,9,11,34]

The Second Wave of Breakthroughs

At the same time that Palmer and Frangenheim were championing gynecologic laparoscopy, two major developments in laparoscopy were emerging: the rod-lens endoscope and fiberoptic light transmission.

The Rod-Lens Endoscope

Professor Harold H. Hopkins (Figure 1.8), now of the University of Reading, England, was responsible for the two most important inventions in endoscopy after the war: the rod-lens system and fiberoptics. The rod-lens system, from its inception to its realization, was solely Hopkins's pursuit, whereas his invention of and experimental work with fiberoptic bundles provided the groundwork for clinically usable flexible endoscopes.

In the late 1940s Hopkins, who was working at the Imperial College of Science and Technology in London, met the late Hugh Gainsborough, a gastroenterologist then at St. George's Hospital of London.[37] Gainsborough and others hated the rigid (or "semi-flexible") gastroscopes then in existence and pressed the case for a completely flexible instrument. Hopkins became interested in solving this problem and received a research grant in 1952 to work on a flexible tube that could transmit images. In 1954 Hopkins and his graduate student N. S. Kapany described the "fiberscope," as they called it, in an article in *Nature*.[38] This fiberscope was constructed of a bundle of similarly oriented (or coherent) glass fibers, which could convey an optical image along a flexible axis. Others had demonstrated this principle before, but there had been no practical application of it, nor had a method been devised for making such a bundle.[12,38,39] Their work led to the development by others of fiberoptic endoscopes that could transmit images from the body to the eye, as well as of fiberoptic bundles that could transmit intense light from an outside source into the body cavity being examined.

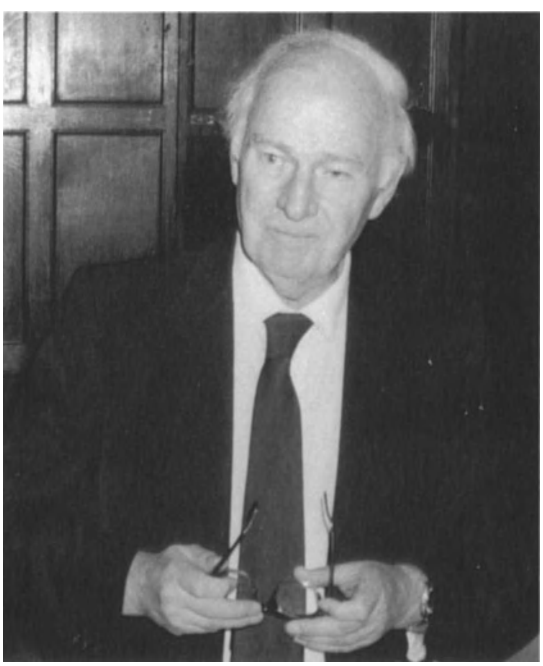

FIGURE 1.8. Professor Harold H. Hopkins. (Courtesy of Prof. Harold H. Hopkins.)

More importantly for urology and laparoscopy, however, this work on fiberoptics led Hopkins to measure the light transmission and image aberrations of the existing cystoscopes. He found that these telescopes had very poor light transmittance and poor image quality and color. He laid aside his work with fiberoptic bundles and pursued this different optical problem. At about the same time (in the mid-1950s) James Gow, a urologist in Liverpool, was interested in taking color photographs through a cystoscope and he sought out Hopkins. Hopkins said to Gow that an appreciable increase in light transmittance would require a whole "new idea," to which Gow replied, "Well, couldn't you have one?" And indeed, Hopkins could . . . and did. The result was the rod-lens system, a radical departure from the lens systems of the previous 80 years and a system which, to date, has not been improved upon.

The design of the Hopkins telescope is described in Chapter 35.1, "The Hopkins Rod-Lens System," which also contains pertinent diagrams. Suffice it to say here that Hopkins took advantage of two principles of light transmission and of the new multiple-layer antireflection coatings for the surfaces of lenses and produced an astonishing result: 80 times the light transmission of the traditional telescopes.[40,41]

Hopkins traveled to Ann Arbor every summer for two or three weeks to lecture at the University of Michigan. One summer in the late 1950s he took a prototype of his rod-lens scope and some color slides of the urinary bladder with him. The faculty and students seemed impressed, but when he offered the prototype to a well-known American endoscope manufacturing firm, it was not interested. Hopkins felt that the reason was the NIH (Not Invented Here) syndrome.

In about 1960 Hopkins was invited to an international conference on medical photography in Düsseldorf, Germany, by a professor from Munich who specialized in medical physics. Hopkins showed color slides of the interior of the bladder, made with James Gow using the rod-lens cystoscope, and attendees were eager to learn what kind of cystoscope had been used to obtain such clear photographs. Shortly after this, Hopkins received a telephone call from Karl Storz, a surgical instrument maker in Tuttlingen, Germany, who at the time ran a relatively small factory. It turned out that someone who had attended the meeting in Düsseldorf had contacted Storz about the new rod-lens technology and Storz wanted to develop it. Hopkins made several trips to Germany to help with the design and manufacture of a cystoscope, and within six months, Storz had produced a prototype. Hopkins's original light source was a distal tungsten filament bulb but Storz used a fiberoptic light transmitter in his prototype instrument, with a further appreciable increase in the amount of light forming the image.

Hopkins patented his "pre-Storz" rod-lens scope in the United Kingdom in 1960 and, later, after development of the endoscope by Storz, he and Storz negotiated a license agreement. The Storz system was a great advance, and it was appreciated as such by the world's urologists. Some though, still used the older cystoscopes with the tungsten filament light bulbs at the distal tip of the instrument—with cool water constantly circulating through the bladder, it made little difference whether or not the light source generated heat—and these continued to be manufactured until the late 1960s and early 1970s. However, in the field of laparoscopy the story was different, for finally there was a laparoscope that could produce a clear picture, with true color rendition, and with a bright light that did not generate heat inside the abdomen that might damage tissues. The stage was thus set for the great advances in gynecologic laparoscopy over the next two decades.

Fiberoptic Light Transmission

In 1899 D. D. Smith first described transmission of light from an external source through a glass rod into the viewing chamber. At about the same time, Thompson described use of a fused quartz rod for a similar purpose.[11] However, the practical clinical application of this principle did not come until 50 years later when, in 1952, N. Fourestier, A. Gladu, and J. Valmière, of the Optical Institute in Paris published a paper in which they presented a method of transmitting an intense but "cool" light along a quartz rod from the proximal to the distal end of a rigid bronchoscope.[42] Previously lamps had been introduced into the body cavity at the distal tip of the endoscope, imposing the risk of injury from heat or electrical faults. Fourestier's external light source removed this danger.[9,34] He suggested that this improvement was applicable to other types of endoscopes. However, despite its advantages, the Fourestier quartz light rod did not gain universal acceptance because it was expensive and fragile. It was only with the development of fiberoptics that a cold light source became practical, and for that story we must turn to the field of gastroenterology.

Basil Hirschowitz, a fellow in gastroenterology at the University of Michigan in Ann Arbor in 1954, was intrigued by the description of Hopkins's and Kapany's fiberscope in *Nature,* as well as by another article in the same issue by a Dutchman named A. C. S. van Heel.[43] In this paper van Heel reported that coating glass fibers with a material of lower refractive index prevented light from escaping from the fiber and kept it traveling down the length of the fiber.[12,43]

This prompted Hirschowitz to visit Hopkins and Kapany at the Imperial College in London to discuss the practical application of fiberoptics to gastroscopy. Hirschowitz realized that the fiber bundles Hopkins had used, which were only a few inches long, could not be used to make a practical endoscope. So he returned to the University of Michigan to start a three-year collaboration with C. Wilbur Peters, a professor of physics, and Lawrence Curtiss, a physics student, to develop a glass fiber bundle suitable for use in a gastroscope. Critical to achieving this goal was Curtiss's invention of a special method of drawing out long glass fibers and coating them with a layer of glass of lower refractive index. In December 1956 he finally succeeded in producing a glass fiber with the necessary qualities for a gastroscope, and one month later the team assembled the coherent bundle of fibers used to build the first fiberoptic gastroscope.[3,12] (A coherent fiber bundle was necessary to maintain the orientation of the image along the length of the endoscope.) The prototype was demonstrated by Hirschowitz, Pollard, and Curtiss as an "add-on paper" at the annual meeting of the American Gastroscopic Society in May of 1957.[12] Three years later, after close collaboration between this team and American Cystoscope Makers, Inc., the first commercial gastroscopes were produced and tested. Incidentally, these endoscopes had an incandescent light bulb at their tips. Advances were rapid and in another three years, in 1963, the first endoscopes using cold light transmitted from an outside source by a second fiberoptic bundle were introduced by Hirschowitz[44] (the first fiberoptic esophagoscope) and Karl Storz (the Hopkins rod-lens cystoscope). This bundle of fibers did not have to be coherent because it was transmitting only light and not images. It was this development, of a light-transmitting bundle of fibers, that was so important for laparoscopy, because it eliminated the risk of thermal injury to the bowel and other abdominal organs caused by incandescent lighting. This, coupled with the vastly improved optics of the rod-lens system, gave pioneers such as Kurt Semm the support they needed to develop new laparoscopic instruments and procedures.

1960–1985

From about 1964 on, Professor Kurt Semm played a key role in the development of laparoscopy. He called his procedure "pelviscopy" to dissociate it from gynecologic "laparoscopy," which continued to encounter opposition in German medical centers because of numerous mishaps.[4] He developed many new instruments over the next 15 to 20 years and other investigators added their own instruments and techniques (Table 1.1).

With these more advanced instruments, surgeons were able to perform more advanced procedures (Table 1.2). Laparoscopy lent itself to more than fimbriolysis, simple tissue biopsy, and lysis of adhesions. Tubal sterilization, salpingostomy, and enucleation of myomas could be performed using Semm's method of endocoagulation or with bipolar cautery. Advanced methods of knot-tying and suturing led to laparoscopic operations on the bowel and appendix (Table 1.2).

TABLE 1.1. Development of instruments and techniques by Semm and others, in chronological order.

1935	High-frequency coagulation (monopolar)
1966	Automatic insufflator
1968	Hook scissors
1969	Uterus vacuum mobilizer
1971	High-frequency coagulation (bipolar)
1972	Endocoagulator
1976	EndoLoop applicator (Roeder loop)
1979	Endoligation technique
	Tissue morcellator
1980	Endosuture techniques
	Suction-irrigation systems
1982	Myoma enucleator (cutting coagulator)
1985	Pelvitrainer

(Modified, with permission, from Semm K. History. In: Sanfilippo JS, Levine RL, eds. *Operative Gynecologic Endoscopy,* New York: Springer-Verlag, 1989. p. 1–18.)

TABLE 1.2. Chronological listing of procedures developed or perfected by Semm.

Before 1972	Cautious lysis of adhesions
	Ovarian biopsy
	Fimbriolysis
1972	Tubal sterilization by endocoagulation
1974	Salpingostomy by endocoagulation
1975	Myoma enucleation by endocoagulation
1976	Tubal pregnancy
1977	Omental adhesiolysis
	Salpingectomy
	Oophrectomy
1980	Bowel suturing
1982	Incidental appendectomy

(Modified, with permission, from Semm K. History. In: Sanfilippo JS, Levine RL, eds. *Operative Gynecologic Endoscopy.* New York: Springer-Verlag, 1989. p. 1–18.)

The British gynecologist Patrick Steptoe was another contemporary innovator. He wrote the first textbook on laparoscopy in English in 1967, entitling it *Laparoscopy in Gynaecology.* He demonstrated the safety and effectiveness of laparoscopic sterilization and, together with R. G. Edwards, developed techniques of laparoscopic ovum recovery from the late 1960s through the late 1970s, thus establishing the field of *in vitro* fertilization.[9,11,45]

In 1970 Melvin Cohen wrote the first American textbook on laparoscopy, which helped reintroduce the technique in the United States.[9,11] Also in 1970, H. M. Hasson pioneered "open laparoscopy," in which he made an abdominal incision and viewed the peritoneal cavity directly before introducing the trocar and cannula. This avoided the complications associated with blind percutaneous trocar entry.[46] These developments and the improvement of lighting techniques using fiberoptics accounted for the widespread acceptance and use of laparoscopy in the United States in the early 1970s.

Computer Chip Video Camera—The Third Major Breakthrough

With all of this activity in laparoscopy in the last 30 years, one might ask why general surgeons did not operate through the laparoscope until eight years ago. The answer is that they did—in laboratory settings—but the equipment was too cumbersome and made operations too tedious. The primary difficulty was that laparoscopic visualization of the peritoneal cavity was restricted to the operating surgeon. A single assistant could observe through an articulated attachment that split the image, but he also had to hold the laparoscope and the teaching scope. Obviously, no one else in the room could see to help in any useful way, so procedures were restricted to a few simple operations (Figure 1.9).

This all changed, however, in 1985, with the introduction of the first computer chip TV camera made by Circon Corporation. This development was a "by-product of technical advances in microelectronics" in the prior two decades.[3] The camera head had inside it a silicon chip which was, in actuality, a miniature solid-state camera. In most cameras this sensor was a charge-coupled device (CCD) consisting of an area of the silicon chip divided into discrete picture elements.[41] The solid-state image sensor picked up the image from the laparoscope and transmitted it electronically through a cable to a video processor, which then projected the image on a television screen.[3]

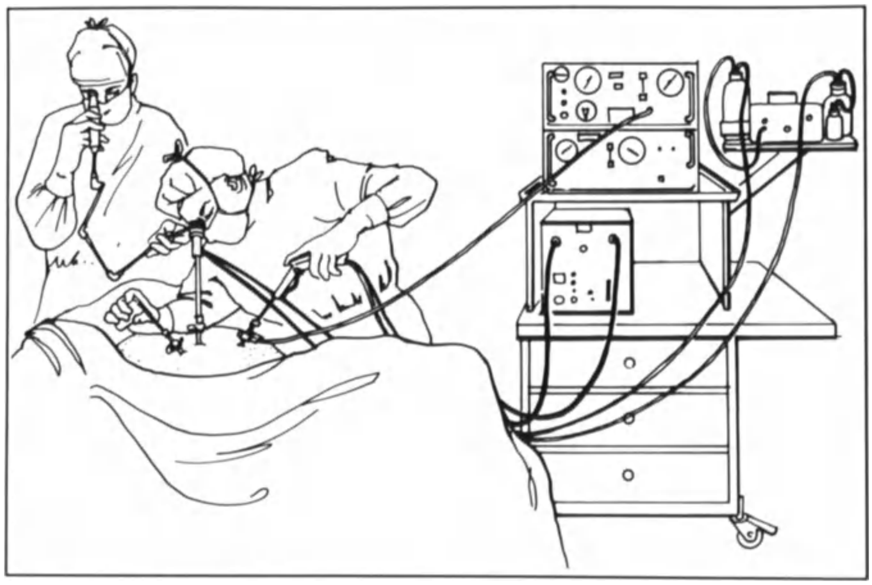

FIGURE 1.9. Laparoscopic operation performed with assistant looking through "teaching scope." (From Filipi CJ, Fitzgibbons RJ, Jr., Salerno GM. Historical review: Diagnostic laparoscopy to laparoscopic cholecystectomy and beyond. In: Zucker KA, Bailey RW, Reddick EJ, eds. *Surgical Laparoscopy*. St. Louis: Quality Medical Publishing, Inc., 1991. p. 13.)

This was the missing piece of the puzzle, and so began the era of video-guided surgery. Others in the operating room could see what the surgeon was seeing and could assist effectively, and therefore the laparoscope could be used for more difficult operations. It was only a short time until the first laparoscopic cholecystectomy in a human was performed in 1987 by Philippe Mouret in Lyon, France (Figure 1.10). Within a year, Dubois (Paris), Perissat (Bordeaux), Nathanson and Cuschieri (Scotland), McKernan and Saye (Marietta, Georgia), and Reddick and Olsen (Nashville, Tennessee) had performed laparoscopic cholecystectomies at their respective institutions.[4,18] McKernan and Saye were the first to perform the procedure in the United States. The procedure spread like a brushfire worldwide, driven not only by patient demand but by a desire on the part of surgeons to be at the forefront of surgical innovation. Laparoscopic cholecystectomy also started a revolution in surgery, and operating endoscopes were soon used for a number of other procedures such as appendectomy, inguinal herniorrhaphy, bowel resections, staging for intra-abdominal and intrathoracic malignancies, antireflux operations, pleural biopsy, wedge resections of the lung, and treatment of spontaneous pneumothorax. The explosion of interest in these techniques has been one of the major success stories of surgery in recent years.

FIGURE 1.10. Philippe Mouret. First to perform laparoscopic cholecystectomy in the human. (Courtesy of Dr. Philippe Mouret.)

Laparoscopic Cholecystectomy

In 1985, Dr. Charles Filipi and Dr. Fred Mall performed the first known laparoscopic cholecystectomy in a dog. A laparoscope with an attached collapsible retractor was designed to obtain exposure, and the gallbladder was dissected from the liver bed with a specially devised suction cautery. An arthroscope was introduced through a separate puncture site, but adequate visualization was impossible because of the inability to maintain a pneumoperitoneum. A 1 L/min insufflator could not compensate for the large air leaks at instrument entry sites. Lori Roosma, R.N., an operating room supervisor, familiarized the surgical team with several standard laparoscopic techniques, including application of the fallop loop for ligation of the cystic duct stump, and two dogs subsequently underwent laparoscopic cholecystectomy. In spite of the success of these two operations, the laparoscope with the collapsible retractor did not provide satisfactory exposure. Video systems suitable for the laparoscope were not available at the time, and the technique was considered unsafe. The instrument company supporting the development of this procedure was unwilling to continue funding investigation, so work was suspended.

After the introduction of the silicon chip camera in 1985 and Mouret's first successful laparoscopic cholecystectomy in 1987, other problems, such as management of common bile duct stones became an issue. Surgeons, led by Petelin and Phillips, advocated laparoscopic common bile duct exploration, which avoids the additional procedure of endoscopic retrograde cholangiopancreatography (ERCP) and the low but definite risks associated with that procedure.[47,48]

Laparoscopic Appendectomy

Dekok performed a laparoscopically assisted appendectomy in 1977. He dissected the appendix using the laparoscope and removed the appendix from the abdomen through a small laparotomy.[4] Semm reported the first incidental laparoscopic appendectomy in 1983; he accomplished the operation entirely with the laparoscope. He suture-ligated the mesoappendix, tying the knot extracorporeally, and ligated the base of the appendix with a pre-tied Roeder loop.[4]

Patrick O'Regan, a general surgeon from Vancouver, British Columbia, was the first to perform a laparoscopic appendectomy for acute appendicitis in 1986.[49] The operation took place at University Hospital, Shaughnessy Site. He videotaped the procedure using a laparoscope and a camera with a beam splitter, because he did not have a silicon chip camera. The tape was presented in March 1986 at the hospital's annual presentation of research projects, but the case was not published. Subsequently, O'Regan performed an occasional laparoscopic appendectomy using an elaborate teaching arm (referred to earlier in this chapter). After obtaining his first computer chip camera, he started doing the operation routinely. Since then, he has performed 95 consecutive appendectomies laparoscopically, 60 of which were for acute appendicitis.[50] Schreiber published his experience with 70 laparoscopic appendectomies in 1987; seven of these were in patients with acute inflammation.[4]

Laparoscopic Herniorrhaphy

Since the advent of the Bassini repair in 1884,[50] many surgeons have advocated variations on the theme of high sac ligation and inguinal floor reinforcement for inguinal hernia repair. Recently the preperitoneal prosthetic repair for inguinal hernias has reduced the incidence of recurrent hernia to 1 to 2%.[51–53] Because of the apparent adaptability of this approach to laparoscopic herniorrhaphy and because of the overwhelming popularity of laparoscopic cholecystectomy, a number of surgeons started to investigate the value of laparoscopic preperitoneal herniorrhaphy.

In 1982 Ger reported the first laparoscopic inguinal hernia repair using a prototype stapler.[54] In his paper, he described the open transabdominal approach to inguinal hernias employing stainless steel clips to close the internal peritoneal opening of the sac. But in the last patient in the series, Ger used the laparoscope to guide the placement of the clips. Shultz and Corbitt in 1990 independently initiated studies using a stuffing technique, in which mesh plugs and sheets were inserted into the hernia defect and the preperitoneal space.[55,56] Arregui first reported his experience with a laparoscopic preperitoneal mesh repair similar to that of Stoppa, Nyhus, and Rignault in May 1991.[57] Advocating a true anatomic dissection, he skeletonized the transversalis fascia, the iliac vessels, the spermatic cord, and Cooper's ligament and sutured a large piece of nonabsorbable mesh into the preperitoneal space to cover the defect and the surrounding tissues. His initial results were excellent, and in many respects he established the standard for laparoscopic hernia repair.

Also in 1990 Fitzgibbons, Filipi, and Salerno investigated an intraperitoneal onlay mesh repair in pigs using polypropylene mesh.[58] They measured the percentage of mesh surface area that was subsequently involved by adhesions and preliminary data suggested that the operation was a safe and effective approach for humans. The onlay technique was then utilized clinically, and the initial results were satisfactory.

Edward Phillips and Jean L. Dulucq developed a totally preperitoneal laparoscopic approach for inguinal hernia repair. They found that adequate exposure could be obtained by insufflation of CO_2 gas into the preperitoneal space. A large piece of mesh was then stapled to the inguinal floor after the indirect or direct sac was reduced. Their early results were excellent.[59]

Advanced Abdominal Laparoscopy

Katkhouda's series of seromyotomy for sectioning the gastric branches of the vagus nerve, first reported in 1991, established the feasibility of the laparoscopic approach to peptic ulcer disease.[60] Pre- and postoperative gastric analysis demonstrated a marked decrease in acid secretion and early follow-up endoscopy revealed satisfactory results. Bailey and Zucker in the United States popularized the anterior highly selective vagotomy combined with a posterior truncal vagotomy in 1990.[61] Their approach simplified the operation, but long-term follow-up data is required to validate this operation. Additional early laparoscopic procedures for peptic ulcer disease included truncal vagotomy with pyloric balloon dilatation[62] and stapled anterior vagotomy.[63]

Dr. Bernard Dallemagne of Liege, Belgium, was the first to successfully perform a highly selective anterior and posterior vagotomy for peptic ulcer disease.[64] The technique he developed for ligating the short gastric vessels for laparoscopic Nissen fundoplication was undoubtedly helpful in performing the meticulous dissection required for ligation of the lesser curvature vessels for a highly selective vagotomy.

Dallemagne also performed the first-known human laparoscopic Nissen fundoplication in January of 1991. His innovations included methods for safe anterior retraction of the distal esophagus, a technique for establishing the necessary opening behind the gastroesophageal junction and, as already mentioned, successful ligation of the short gastric vessels, a significant accomplishment at the time.[65] Full mobilization of the gastric fundus with vessel ligation proved to be the most technically challenging portion of the procedure. Dr. Dallemagne's clinical results have been outstanding at long-term follow-up, and he has the world's largest recorded series of laparoscopic antireflux procedures.

Thoracoscopic Surgery

The history of thoracoscopy can be divided into three eras: the period of enthusiastic use (1910–1950), the period of neglect (1950–1989), and the period of renaissance (1989–present). The factors that have influenced the development of endoscopic surgery in general have also influenced thoracoscopy, but other factors unique to thoracic diseases have played important roles as well.

Professor Hans Christian Jacobaeus, as outlined earlier in the chapter, was the first person to perform thoracoscopy in a human. He performed the operation in 1910 at the Serafimerlasarettet Hospital in Stockholm, Sweden.[21] He published his further experience with laparoscopy and thoracoscopy in 1911[23] and shortly thereafter turned his attention solely to thoracoscopy, realizing the great therapeutic value of the procedure, which could be used to lyse tuberculous adhesions of the pleura to produce an artificial pneumothorax. At the time, there was a great deal of interest in this treatment for tuberculosis. In 1882 (the year Koch discovered the tubercle bacillus) an Italian physician named Forlanini had observed that tuberculous cavities would collapse and heal after the occurrence of a spontaneous pneumothorax or a massive pleural effusion. Wishing to accomplish this same effect in his patients, Forlanini inserted a needle into the chest and injected air or nitrogen into the pleural cavity to produce a "pneumotorace artificiale." The technique became very popular, but was unsuccessful in many cases because of incomplete collapse of the cavities due to persistent pleural adhesions.[66] Jacobaeus saw very quickly the utility of thoracoscopy in solving this problem and developed a two-cannula technique, using "galvanocautery" to dissect and burn pleural adhesions under direct vision through the thoracoscope. With this treatment, he was able to collapse the lung successfully in 75% of patients and produce a good clinical result in 67%. His complication rate was surprisingly low, and there were no deaths.[15,22,66] In 1921 he reported 40 cases of intrapleural pneumolysis to treat tuberculosis[67] and in 1925 he published a series of 120 cases, most of which were pneumolysis but some of which were diagnoses of pleural tumors.[68] From the time of Jacobaeus's reports in the 1920s until the early 1950s many articles from both sides of the Atlantic reported large series of thoracoscopic intrapleural pneumolyses.[68]

Although most of the work during this time was with tuberculosis, a few investigators used thoracoscopy for other reasons: for pleural biopsy, to evaluate penetrating injuries to the chest, and to stage thoracic malignancies.[68] When the antituberculous drugs were introduced, starting with streptomycin in 1945, thoracoscopy fell into disuse as a therapeutic tool. During this "period of neglect," from about 1950 to 1989, a few surgeons and internists used thoracoscopy, but mostly for diagnostic purposes. Articles reported its use in diagnosing pleural effusions and malignancies, staging lung cancers, evaluating chest trauma,[68,69] treating spontaneous pneumothorax, evaluating pulmonary disease in children,[70,71] and treating empyema.[68,72]

Lately thoracoscopy has undergone a renaissance. Relegated to a diagnostic modality for almost 40 years, thoracoscopy has now regained its position as a true therapeutic procedure. This renaissance was dependent on the invention of the computer chip camera and on the impetus provided by the widespread popularity of laparoscopic cholecystectomy. As surgeons gained confidence with the laparoscope, they ventured into the chest. New instruments also resulted from work in the abdomen, namely the 30-mm linear stapler and angled thoracoscopic scissors and grasping forceps. The value of the linear stapler has been most apparent in the case of wedge resections of peripheral pulmonary nodules. A number of surgeons are investigating techniques, such as wire localization or ultrasound, for the preoperative or intraoperative localization of deep lung nodules, to aid thoracoscopic wedge resection.[73,74] Thoracoscopically assisted lobectomy has been described[75,76] as has thoracoscopic bullectomy in patients with severe chronic obstructive lung disease.[77]

Conclusion—The Future

What can we conclude about the advances made so far in endoscopic surgery and about what lies ahead? First, the concepts behind most new developments were proposed long ago—the technical wherewithall was the missing ingredient. Second, technical advance is often not linear and clean, even though hindsight makes it appear that way.[3] There are fits and starts, backtracking, and lag periods when nothing new is developing or appears to be developing. Having said this, however, much development is surprisingly logical and proceeds as far as it can given the current state of knowledge. Third, in order for a procedure to catch on and become popular, it must be straightforward and the technical support for it must be easy to obtain. Very few surgeons in private practice or in smaller hospitals have the energy or persistence to pursue innovative procedures that require an inordinate amount of their time. It simply is not practical. Fourth, collaborative efforts are crucial to technical advancement,[3] and the importance of the creative alliance of the clinician and the instrument maker cannot be overemphasized, witness the advances that came out of the collaborations of Nitze and Leiter, Mikulicz and Leiter, and Hopkins and Gow. As Schindler said, the clinician and the instrument maker cannot do without one another. These types of collaborations will continue to form the basis for further advances. Finally, "important changes in instrumentation have been prompted by technical advances outside the domain of . . . medicine."[3] Examples are Edison's invention of the light bulb, Hopkins's and Kapany's work with fiberoptics, and the development of charge-coupled devices and video processing. All started as innovations outside the realm of medicine and led to great advances in endoscopy. So external developments are sometimes more important than what is going on inside medicine. One need only remember that computed tomography came from the "same company that produced the music of the Beatles."[3] There is no predicting where the next major breakthrough in surgical endoscopy will come from—it may come from a source that is just as improbable.

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2
Basic Equipment and Instrumentation

Harry Reich and J. Barry McKernan

Introduction

Operative laparoscopy requires skills, facilities, and equipment far beyond those required by the laparoscopic diagnostic and sterilization procedures standard in the 1970s and 1980s. A suction/irrigator (aquadissector), angled scopes, special forceps, scissors, a high-flow insufflator, a 30° tiltable operating-room table, and an electrosurgical generator are indispensable tools for these advanced surgical procedures. The video camera and monitor facilitate assistance and documentation. Just as no surgeon would contemplate performing a laparotomy with two clamps and a single pair of scissors, the surgeon using laparoscopic techniques needs a full selection of instruments and ancillary equipment to carry out these procedures safely and effectively.

In this chapter, we present in detail the basic equipment and instrumentation for operative laparoscopy. This discussion presupposes ideal circumstances, and it is recognized that each hospital and clinic needs to assess its unique needs with regard to laparoscopic surgery set-up and instrumentation based upon the types of procedures performed, the surgeon's preferences, and financial considerations.

Operating Room Set-Up and Equipment

Camera, Light Sources, and Recorders

An operating room dedicated to video endoscopic surgery has large carts for monitoring equipment close to the operating table, so that the light and camera cables can reach the operative field. Equally acceptable is a movable, overhead platform for the video monitor, camera, and light source, with multiple heads for different light cables. The video signal can also be sent to a VCR recorder or color printer at a distance from the operating table. Two tapes may be recording continuously: one for the patient and the other for the surgeon. Today's camera, light source, and monitor function as an integral unit, a design that allows maximum visual resolution (Figure 2.1).

Video Positioning

Video enables the surgeon to stand comfortably while watching the monitor rather than bending awkwardly and

FIGURE 2.1. Typical video set-up, including light source, VCR, and mavigraph.

painfully to look directly through the optics. The special demands for space near the patient have led to a variety of practical arrangements.

Video opposite the surgeon. Only one monitor is necessary with this set-up. The monitor is on one side of the patient, the surgeon on the other, and the assistant is between the patient's legs, where the monitor can be viewed. Both the surgeon and assistant have access to instrument tables beside or behind them. A scrub nurse is not necessary if a specially trained assistant is available. The circulating nurse tends to the video recorder, the irrigation supply, and the laser, if used. This arrangement requires some adjustment of hand-eye coordination on the surgeon's part because the monitor is often at a 90° angle from the plane of surgery. This positioning, however, avoids the neck and back strain that result from twisting to see a monitor placed between the patient's legs, especially if the surgeon operates with instruments in the left hand and laparoscope in the right, that is, in the same plane as the surgeon and the monitor. Hand-eye coordination is extremely difficult for the assistant, for whom the image is almost a mirror image and he often assumes a passive role, maintaining retraction or grasper positions achieved by the surgeon. Mirror-image operating skills are attainable with extensive training and will greatly increase the efficiency of the surgical team.

Double video monitor. This arrangement is preferred by most surgeons for cholecystectomy and advanced procedures. Two monitors are placed on either side of the patient, allowing the surgeon (usually on the patient's left) and the first assistant (opposite the surgeon) to have comfortable views cephalad or caudad and across the patient. A second assistant can hold the camera or retractor.

Video at foot of table. Some pelvic surgeons prefer the video monitor to be at the foot of the table because this allows the assistant (opposite the surgeon) an equally good view. Such positioning eliminates the hand-eye coordination problems for the surgeon and assistant that arise when a single monitor is opposite the surgeon. A scrub nurse is necessary with this arrangement.

Surgeon between patient's legs. Some surgeons performing biliary and gastric procedures find that, with the patient in the reverse Trendelenburg position, the table can be lowered enough for them to sit between the patient's legs and operate looking cephalad at the monitor with both hands comfortably positioned over the patient's abdomen. The first and second assistants are on the patient's left and right.

Operating Table and Positioning for Pelvic Surgery

The patient is flat until the umbilical trocar sleeve has been inserted and is then placed in a steep Trendelenburg position (20 to 30°). Lithotomy position with the hip extended (thigh parallel to the abdomen) is obtained with Allen stirrups or knee braces, which are individually adjusted for each patient before anesthetization. Anesthesia examination is always performed prior to prepping the patient.

Extensive pelvic surgery may require a steep Trendelenburg position for a prolonged period of time, as well as rapid reversals of position for irrigation and aspiration. The table should be capable of a 30° tilt and preferably should be electric. For the past 16 years, one of the authors (Reich) has used a steep Trendelenburg position (20 to 40°) with shoulder braces and the patient's arms at his sides. No adverse effects have been experienced.

Because these positions are extreme and the surgeon inevitably leans on the patient's limbs, special precautions are necessary. The surgeon should not lean against the patient's extended arm. Rather, prior to the induction of general anesthesia, bilateral ulnar pads can be applied, and both arms should be tucked at the patient's sides, the right one on a padded arm board. Shoulder braces are placed over the acromioclavicular joint to prevent brachial plexus injury. Legs should be positioned while the patient is awake to check for comfort. Knee stirrups can be used, with careful lateral padding to protect the peroneal nerve and avoid foot drop, or Allen stirrups can be used to support the heel, avoiding pressure points around the free knee.

Anesthesia

Most laparoscopic surgical procedures are done under general anesthesia with endotracheal intubation. The routine use of an orogastric tube is recommended to diminish the possibility of a trocar injury to the stomach and to reduce small-bowel distension. No preoperative medication is given, but intravenous sedation is considered if indicated. For prolonged surgery, an end-tidal CO_2 monitor is emplaced and an orogastric tube is inserted to empty the stomach contents.

Insufflators

High-flow CO_2 insufflation (up to 15 L/min) is used to compensate for the rapid loss of CO_2 during suctioning. Insufflator models are available that filter the CO_2 gas, allowing it to recirculate after removal of smoke produced by electrosurgery or laser surgery. The ability to maintain a constant intra-abdominal pressure between 10 and 15 mm Hg during long laparoscopic procedures is essential. Higher pressure settings may be used during the initial insertion of the trocar. The setting is then lowered to diminish the development of subcutaneous emphysema. High-pressure settings may be used to control venous bleeding, but only for short periods. Sustained high pressure raises the possibility of CO_2 embolism or delayed bleeding (Figure 2.2).

Gasless Laparoscopy

Abdominal-wall subcutaneous emphysema occurs frequently during anterior abdominal wall adhesiolysis because peritoneal defects result in free communication with the rectus sheath. This compromises the peritoneal-cavity operating space. A useful technique is to insert an anterior-abdominal-wall retractor once the umbilicus has been cleared of adhesions (Figure 2.3).

Instruments

Optics

Three laparoscopes are essential for pelvic surgery: a 10-mm straight-viewing laparoscope; a 10-mm laparoscope with 5-mm laser channel and 5-mm operating-channel adaptor; and a 5-mm straight-viewing laparoscope for introduction through a 5-mm trocar sleeve. If possible, the laserscope should be aligned prior to surgery and kept on a separate table ready for use, and a second operative laparoscope should be available. For general abdominal procedures, 10-mm 0°, 30°, and 45° laparoscopes are essential.

Trocar Sleeves

Trocar sleeves are available in many sizes and shapes. For most cases 5.5-mm cannulas are adequate. Newer electrosurgical electrodes, which eliminate capacitance and insulation failures, require 7- or 8-mm sleeves. Laparoscopic stapling is performed through 10- to 14-mm ports; fascial closure is often necessary to prevent incisional hernias if the incision is 10 mm or longer.

Traditional lower-quadrant trocar sleeves are too long to permit free access to pelvic structures with available instruments. The trocar sleeve falls into the operative field and must be lifted before scissors or biopsy forceps are opened when operating on structures directly beneath it. Slippage out of the peritoneal cavity is a concern during intraoperative instrument removal and results in additional time spent re-establishing the second puncture site. The traps or valves interfere with efficient instrument exchange and prohibit the introduction and removal of suture material and the evacuation of tissue.

Short trapless trocar sleeves with a retention-screw grid around the external surface are available. These trocar sleeves facilitate efficient instrument exchanges and eliminate time spent reinserting sleeves removed during these exchanges. They also allow greater freedom of movement during extracorporeal suture tying.

Irrigators (Aquadissectors)

Aquadissector pump and accessories. The aquadissector pump is best positioned behind the surgeon with its handle either draped over the patient's left leg or on a sterile table within easy reach of the surgeon. Depending on the experience of the surgeon's assistant, it may be easier for the surgeon to make his own instrument exchanges from a sterile table behind him.

The usual irrigant is lactated Ringer's solution. A screw cap facilitates bottle exchange; trocar-puncture tube caps should be avoided.

Proficient aquadissection often requires many bottles of Ringer's solution and specially trained surgical personnel to change them. Fortunately, many hospitals in the

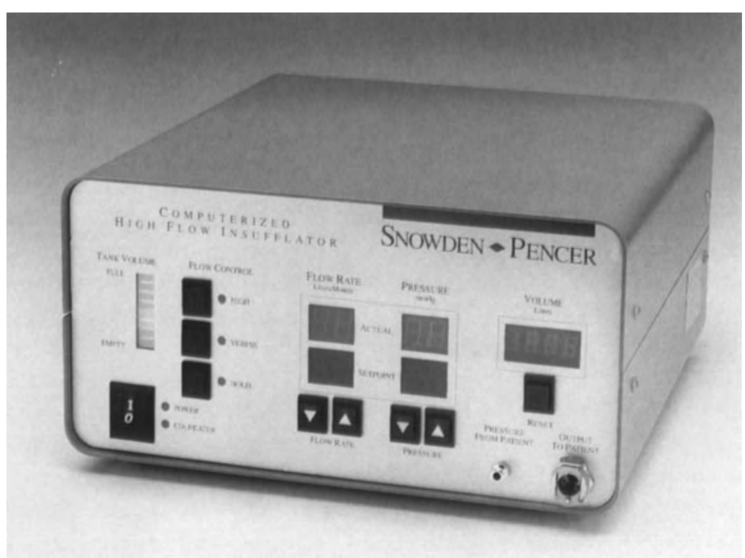

FIGURE 2.2. High-flow insufflator.

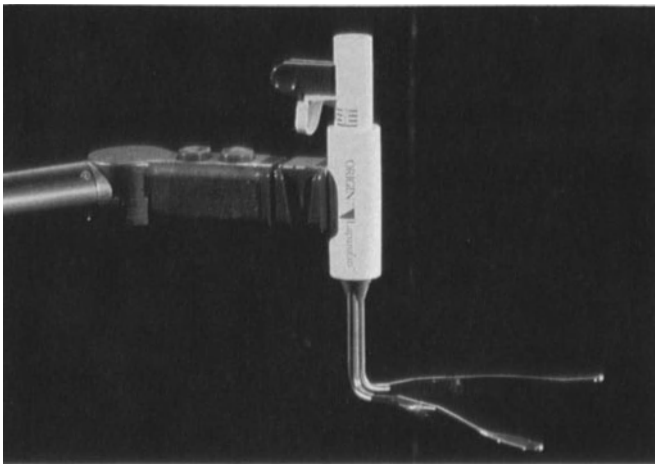

FIGURE 2.3. Abdominal-wall retractor for gasless laparoscopy.

United States require a dedicated nurse to be in the operating room throughout laser procedures. In addition to turning the laser on and off, this nurse changes bottles of Ringer's solution. On average 10 L of lactated Ringer's are used per case; over 30 L have been used on occasion. The recent development of compatible irrigant bottles with larger capacities (3-L bags) makes this task easier.

Aquadissectors. Aquadissectors (suction/irrigators with the ability to dissect using pressurized fluid) should have a single channel to maximize suctioning and irrigating capacity. Separate suction and irrigation channels, either side-by-side or concentric, result in diminished suction capacity and reduced hydraulic pressure. Clots stuck at the bifurcation of the single channel are dislodged by flushing the channel with a 50-cc syringe.

The aquadissector should be designed so that the surgeon can operate with minimal upper-arm and shoulder strain. Complicated finger movements rapidly lead to fatigue, so large buttons are preferable to small valves. Comfort is essential if the aquadissector is to convey the "feel" of the tissue.

An aquadissector with a solid (not perforated) distal tip is necessary to perform atraumatic suction-traction or retraction, to irrigate directly and to develop surgical planes (aquadissection). Small holes at the tip impede these actions and serve no purpose. In addition, the shaft of the aquadissector should be bead-blasted to minimize reflection when operating the CO_2 laser.[1]

The Aqua-Purator (WISAP, Sauerlach, Germany, or Tomball, TX) was the first of the aquadissection devices. It delivers fluid at a pressure of 200 mm Hg and a rate of 250 mL/10 s. One liter can be instilled in 35 seconds. In the handle of the Aqua-Purator are large staples used to occlude separate suction and irrigation tubes, which funnel into a single-channeled tube. Problems frequently arise from malocclusion of the tubing, resulting in persistent leaking of irrigant or suctioning of the pneumoperitoneum. It is not uncommon to require more than one handle to complete a difficult laparoscopic surgical procedure, and multiple handles should be available to ensure that one is in proper working order.

Other aquadissection devices are available, including some disposable ones. Many companies offer probes with an irrigation channel inside a suction channel studded with openings. Although these devices provide more efficient smoke evacuation for CO_2 laser surgery, they hinder suction-traction and aquadissection.

Several versions of combined suction device exist, consisting of 5-mm channels through which a 3-mm needle electrode or scissors can be passed for combined cutting, coagulation, irrigation, and aspiration.

Pulsatile water-jet irrigators use compressed nitrogen (at a recommended pressure of 80 psi) to generate high-pressure liquid pulses for aquadissection. Pulsatile aquadissection may also be possible with ultrasonic dissectors. These devices vibrate at 23 kHz and an amplitude of as much as 350 μm. They can selectively fragment soft, firm, and even tough, fibrous tissue. They have suction, irrigation, and electrosurgical cutting and coagulation abilities.

The Harmonic Scalpel

Another ultrasonically activated device is the harmonic scalpel, which moves at an imperceptible 55,000 vibrations per second, cutting tissue with a cool blade. The mechanical action denatures collagen molecules, forming a coagulant and instantly sealing very small vessels with minimal thermal damage.

Forceps

Self-retaining atraumatic forceps are the retractors of operative laparoscopy, maintaining exposure and position for surgery. At least two such instruments should be available. Blunt atraumatic graspers are used to retract the small bowel. Strong atraumatic ovarian forceps, solid or ring-tipped, are applied to the utero-ovarian ligament to stabilize or retract the ovary. Smooth-tipped smooth-bodied atraumatic grasping forceps are used for ureteral dissection (Figure 2.4).

Single-tooth cupped biopsy forceps or ovarian punch-biopsy forceps with teeth have been used extensively in laparoscopic surgery for over 20 years and still grasp and hold tissue better than most other forceps. They are used to grasp the ovarian-cyst wall firmly for dissection and avulsion. Two of them work well to separate the normal ovary from cyst walls. The forceps with teeth are used for grasping and pulling specimens through trocar sleeves.

Laparoscopic 5-mm corkscrews are the best instrument to place large solid masses in traction during myomec-

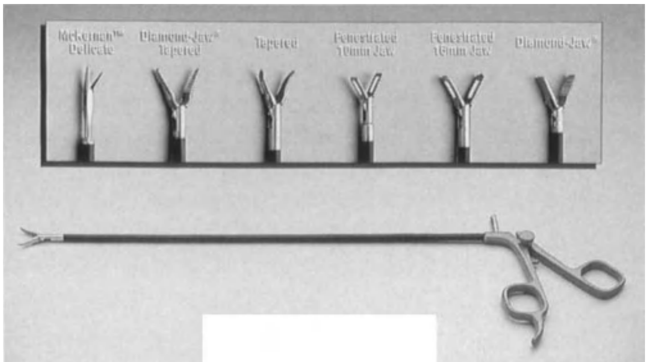

FIGURE 2.4. Grasping forceps.

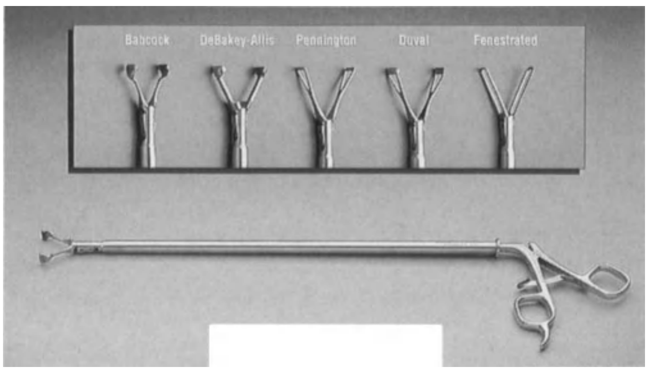

FIGURE 2.5. Bowel graspers.

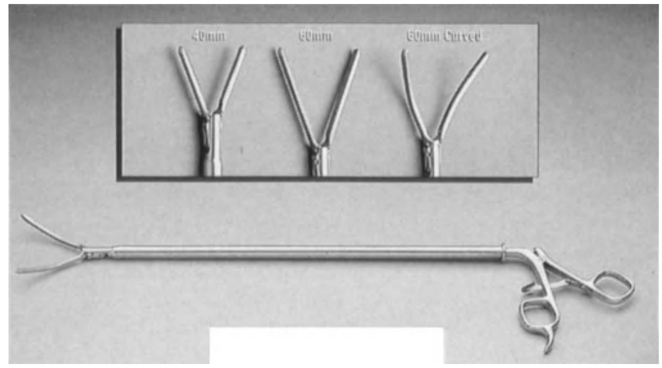

FIGURE 2.6. Bowel instruments.

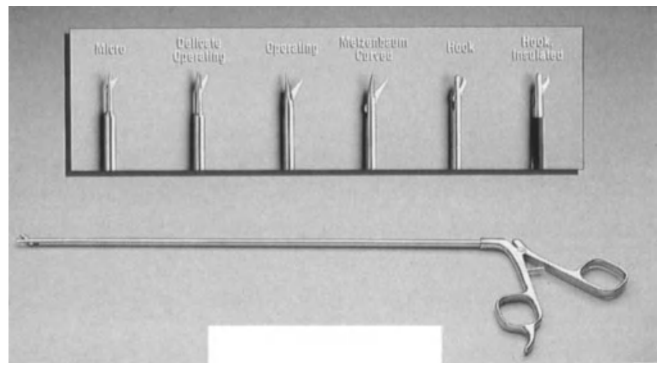

FIGURE 2.7. Laparoscopic scissors.

tomy or hysterectomy. The 11-mm corkscrew inserted vaginally aids in all morcellation procedures.[2]

Babcock, bowel, and Allis graspers are essential for bowel surgery (Figures 2.5 and 2.6).

Scissors

Sharp dissection is the primary technique used for adhesiolysis because it diminishes the potential for adhesion formation; electrosurgery and laser are usually reserved for hemostatic dissection of endometriosis or dissection of adhesions where anatomic planes are not evident or vascular adherences are anticipated. Scissors that cut are new laparoscopic instruments. Surgeons should select scissors that feel comfortable in their hands. To be maneuverable, scissors should not be too long nor should they be encumbered by an electrical cord. Although laparoscopic scissors have improved, the surgeon should have at his or her disposal a large number and variety of scissors to ensure one suited to the procedure at hand. Scissors are the best instrument to use to cut avascular or congenital adhesions and peritoneum. Blunt or rounded-tipped 5-mm scissors with one stable blade and one moveable blade are used to divide thin and thick bowel adhesions sharply (Figure 2.7).

Electrosurgical Instruments

Electrosurgery is the mainstay of laparotomy surgery today. Because techniques for laparoscopic surgery are patterned on those of laparotomy, it seems logical that the instruments should be similar.

Monopolar cutting current is safe. Cutting current is used to cut or coagulate (desiccate), depending on the portion of the electrode in contact with the tissue. The tip cuts, whereas the wide body tamponades and coagulates. The voltage is too low to arc or spark over a gap of 1 mm. For lysing adhesions or draining cysts, nonmodulated cutting current (40 to 80 W) is used. Cutting current passed through a knife, hook, or button electrode is used for coagulating individual blood vessels or hemorrhagic ovarian cysts. A vessel should be compressed to occlude it before coagulation. A quick application of cutting current after coagulation often prevents the char from pulling off with the electrode.

Monopolar coagulation current with conventional electrodes and electrosurgical generators can arc or spark approximately 1 to 2 mm. The electrode is placed close to tissue but not in contact with it, and the current fulgurates diffuse venous and arteriolar bleeders. It takes 30% more power to spark or arc in CO_2 than in room air; thus, at the same electrosurgical power setting, less arcing occurs during laparoscopy than during laparotomy. Coagulation current is modulated so that it is on only 6% of the time; the voltages are more than 10 times those of cutting current.

The argon-beam coagulator can be used to provide more powerful fulguration. It uses argon gas at a rate of 2 L/min and high-voltage coagulation current to increase the spark or arc and yet penetrates tissue very superficially. Coagulation current at 80 W will spray arc approximately 1 cm through the argon gas causing superficial charring and achieving hemostasis. Uses include intraovarian bleeding after cystectomy and uterine hemostasis after myomectomy. It is rarely used during adhesiolysis.

Electrode insulation defects or capacitive coupling can cause electrosurgical injury to the bowel beyond the surgeon's field of view during laparoscopic procedures. While the surgeon views the tip of the electrode, electrical discharge may occur from its body (insulation failure) or from metal cannulas surrounding the electrode if they are separated from the abdominal wall by plastic retention sleeves. For this reason, monopolar electrosurgery should be avoided when working on the bowel unless the surgeon is well versed in this modality. The expert laparoscopic surgeon can use monopolar electrosurgery to safely cut or fulgurate tissue, but desiccation (coagulation) on bowel should be performed with bipolar techniques.

Bipolar desiccation for large-vessel hemostasis was first reported in 1985.[4,5] Bipolar forceps use high-frequency low-voltage cutting current (20 to 50 W) to coagulate vessels as large as the cystic, ovarian, and uterine arteries. Bipolar electrocoaptive desiccation seals arterial blood vessels effectively, so that they withstand the pulsating arterial pressure until permanent fusion of collagen and elastic-tissue fibers is accomplished through the healing process. Large blood vessels are compressed and bipolar cutting current passes until complete desiccation is achieved, that is, the current depletes tissue fluid and electrolytes to the point that it ceases to flow between the forceps.[6–9] Coagulating current is not used because it might rapidly desiccate the outer layers of the tissue, producing superficial resistance that would prevent deeper penetration.

For large-vessel hemostasis using bipolar forceps, the current flow must be monitored with a meter to ensure total coagulation of the tissue between the tips of the forceps. The bipolar forceps must be so applied that the vessels between its tips are completely occluded. If the vessels are not occluded, current will continue to flow between the tips of the instrument as heat is carried away from the site by the blood flow, and the tissue will not become completely desiccated. Current flow between the tips of the bipolar forceps ceases only when complete desiccation (dehydration) has occurred. Then, and only then, is it safe to divide the vessel.

Excision of structures is most easily and safely accomplished by repeatedly grasping and cutting small amounts of pedicle, following each cut with thorough desiccation. This technique closely parallels good open surgical technique: hemostat (bipolar forceps) grasping is followed by suturing (desiccation) until the pedicle is divided. If too much tissue is grasped the current spreads laterally beyond the forceps tips and may damage sensitive adjacent structures. Division of the desiccated pedicle should be close to the border of the intended specimen, so that the compressed and sealed vessels in the area of desiccation remain to provide hemostasis.

Finally, when discussing electrosurgery, it is important to emphasize that cautery, thermocoagulation, or endocoagulation refer to the passive transfer of heat to tissue from an instrument heated by electrical current. The temperature rises within the tissue until cell proteins begin to denature and coagulate, causing cell death. No electrical current passes through the patient's body.

Laser

Most laparoscopic procedures can be performed without a laser. The major advantages of the CO_2 laser is its 0.1-mm depth of penetration and the fact that the energy is rapidly absorbed by water, factors which provide a greater margin of safety when working around the bowel, ureter, and major vessels. Another key advantage is that the laser need not be in contact with the target and can instead be at a distance. Backstops are rarely necessary, especially if the operator learns to use the tissue to be lased as the backstop, because the laser has a superficial depth of penetration and the surgical field is wet. It must be emphasized, however, that a zone of thermal necrosis surrounds treated tissue and, in susceptible patients, adhesions will form. Lasers do not result in less adhesion formation than other thermal energy sources.

The main effect of the CO_2 laser on tissue is to vaporize it. It can be used to vaporize lesions, but it is more often used to divide or separate adhesions and to excise tissue, much as scissors might be used. As in the case of electrosurgery, blood vessels less than 1 mm in diameter are often coagulated in the process, but application of the beam to an actively bleeding vessel usually results in "burnt, black blood."

Use of the CO_2 laser through a laser laparoscope converts the umbilical incision into a portal for performing surgery, making an additional incision unnecessary. This delivery system allows the surgeon a panoramic field of view, and he can cut or ablate tissue in otherwise inaccessible locations in the deep pelvis perpendicular to and in the middle of this field. The invisible CO_2 laser beam, composed of electromagnetic radiation with a wavelength of 10.6 μm, is delivered to the laparoscope through mirrors fixed in an articulating arm. This beam then travels down the 5- to 8-mm-diameter operating channel, comes to a focus approximately 2 cm from the end of the laparoscope, and remains in focus for several centimeters beyond this point. This beam is moved with a standard coupler or one with a micromanipulator joystick until it coincides with the 1-mm spot of a helium-neon aiming beam; the tissue effect will be slightly larger than 1 mm. A useful technique is to center the beam and its surrounding symmetrical halo in the operating channel by placing transparent tape or the cuff of the surgeon's glove over the scope tip to visualize the beam exit.

Major problems encountered with a CO_2 laser in the operating channel of a laparoscope are jumping, blooming, and loss of the beam. If the laser/laparoscope coupler does not connect with the laparoscope at precisely 90°, the beam will be off-axis in the operating channel. The beam energy will heat the CO_2 purge gas unevenly, causing it to act as an asymmetric lens and to refract the CO_2 laser energy to a location other than the helium-neon spot. Most new laser couplers correct this problem.

Tension on the laser laparoscope as it traverses the trocar sleeve will alter the beam spot, as will the extent of hydration of the tissue being vaporized, irrigant on the scope tip, and smoke in the peritoneal cavity. The mirrors in the articulating arm mirrors may require frequent realignment to ensure a reproducible tissue effect. An ice pack between the laserscope coupler and the surgeon's hand may be necessary to prevent skin burns when using lasers with large raw beams and beam/coupler mismatches.

An effect similar to a blended current is accomplished when the CO_2 laser is used at power settings above 50 W. At high power settings, the spot is large (2 to 4 mm), extremely coagulative, and provides hemostatic cutting.[10] A similar tissue effect is obtained with a defocusing coupler.

The passage of CO_2 gas through the laparoscope lumen, presently a necessity to purge this channel of debris, reduces both the power delivered to tissue and the power density (the concentration of laser energy) at the tissue. This occurs because the CO_2 purge gas absorbs and is heated by the laser beam. Power to tissue is reduced by 30 to 50% in the case of a 7.5-mm laparoscopic operating channel (12-mm scope) and by 60% in the case of a 5-mm operating channel (10-mm scope). A 12-mm laparoscope has a smaller spot size and higher power transmission than a 10-mm operating laparoscope because of the optics of opaque tubes of given lengths and diameters, an effect independent of the laser itself. Although it is desirable to operate at high power density to minimize operating time and damage to surrounding tissue, heating of CO_2 gas in the laparoscope lumen results in an increase in spot size and, thus, a reduction in power density.

Some new terms need defining. Superpulse mode implies very high power (500 W) released in brief surges (< 50 mJ), theoretically allowing tissue to cool between spikes and reducing surrounding thermal effect. Even higher energy pulses (> 200 mJ) are possible with some lasers, allowing longer cooling intervals between pulses and char-free vaporization.

For continuous-wave laser operation, the power-density threshold at which cutting and ablation are achieved with minimal thermal damage is generally accepted to be 5,000 W/cm^2. It is not possible to produce power densities higher than 1,500 W/cm^2, however, with conventional CO_2 lasers and CO_2 purge gas; this power-density threshold can be achieved only with the isotopic $^{13}CO_2$ laser.

Fiber lasers have limited use because they lack the versatility of electrosurgical electrodes for cutting, coagulation, or fulguration. The energy from these lasers is absorbed by the tissue protein matrix and converted to heat. A much larger volume of tissue is involved in the laser thermal effect, which is coagulation initially and vaporization only after protein is heated to temperatures higher than 100°C. In contrast, because the energy from the CO_2 laser is absorbed by water, it is converted to thermal energy in a much smaller volume of tissue. Fiber lasers offer greater hemostasis and may have significant use in liver or other highly vascular tissues.

Suture Instruments

Laparoscopic needle holders, introduced through abdominal puncture sites, are used to manipulate sutures, needles, and involved tissue. Conventional laparoscopic needle holders have grooves at right angles to their longitudinal axis and can securely grasp only straight needles. These straight needles are introduced by grasping the suture 2 cm from the needle and pulling the needle flat against the needle holder through a 5-mm cannula. The suture is tied outside the peritoneal cavity using a knot pusher and pushed to the desired tissue. The average operating time for placing and tying a suture is less than 5 minutes.

An endoscopic curved-needle driver is designed to hold a curved needle at 90° to the shaft with little lateral motion. Oblique versions—right and left—hold the needle at a 45° angle to the shaft and are especially valuable for abdominal surgery because the fixed positions of the abdominal puncture sites make suture placement difficult (Figure 2.8).

A pelviscopic loop ligature consists of a 0-gauge chromic catgut with a pre-formed slipknot at its end.[11] The device is introduced through a 5-mm second-puncture trocar sheath.

Retractors

Abdominal retractors may be of great benefit for liver and abdominal-wall retraction (Figure 2.9).

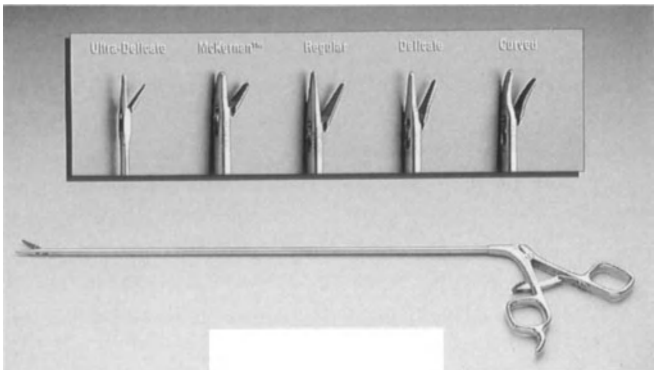

FIGURE 2.8. Laparoscopic needle holder.

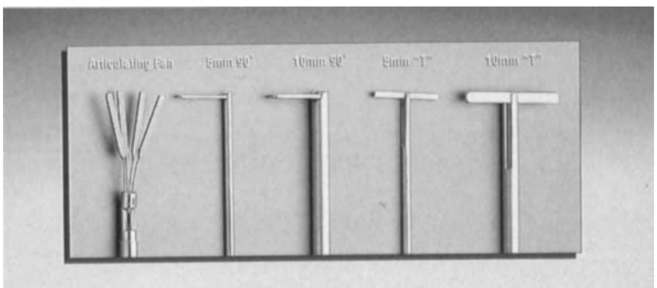

FIGURE 2.9. Intra-abdominal retractors.

Staples

Disposable stapling instruments for laparoscopic surgery are available. These devices are used for large-vessel hemostasis during laparoscopic splenectomy, oophorectomy, and hysterectomy. Currently available variations include an automatic clip applier for medium- to large-size clips (9-mm long when closed), a laparoscopic stapler that simultaneously places clips and divides the clamped tissue, a right-angle clip applier with a hooked tip that pulls the duct or vessel away from adjacent tissue before clip application, and a circular multiple-staple applicator intended for rapid end-to-end anastomosis of the rectosigmoid.

Sterilization of the Camera

The easiest and quickest way to ruin a good camera is to sterilize it between cases. Laparoscopy was never thought to be a sterile procedure before the incorporation of video with the laparoscope, because the surgeon operated with his head in the surgical field, looking through the laparoscopic optic. Since 1983 one of the authors (Reich) has maintained a policy of not scrubbing for laparoscopy and of not sterilizing or draping the camera or laser arm. Infection has been rare. This author attributes the lack of infection to his policy of absolute hemostasis (verified by underwater examination), copious irrigation and clot evacuation, and the practice of leaving 2 to 4 L of Ringer's lactate in the peritoneal cavity at the end of each operation. Bacteria grow poorly in Ringer's lactate solution, especially if all blood clot is evacuated from the peritoneal cavity. The umbilical incision is closed with a single 4–0 Vicryl suture apposing deep fascia and skin dermis, with the knot buried beneath the fascia to prevent the suture from acting like a wick and transmitting bacteria into the soft tissue or peritoneal cavity.

Bacteria and other particulate matter as large as 10 μm are removed from the peritoneal cavity principally by the diaphragmatic lymphatics. Small openings called stomata connect the peritoneal cavity with the diaphragmatic lymphatics. Increased intraperitoneal pressure accelerates the clearance of particulate matter (10 to 20 μm). It is possible that Fowler's position, which interferes with rapid bacteria clearance, may increase the incidence of postoperative abscesses. The rapid absorption of bacteria from the peritoneal cavity may constitute the first line of defense against intraperitoneal infection. Bacteria reach the thoracic duct in less than 10 minutes. They are filtered out in the retrosternal lymph nodes or passed into the systemic circulation, where the reticuloendothelial system clears them from the blood.[12–18] *Prophylactic antibiotics are recommended for most laparoscopic procedures because of this physiologic activity.*

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3
Electrosurgery Techniques of Cutting and Coagulation

Mohan C. Airan and Sung-Tao Ko

With the advent of laparoscopic cholecystectomy[1] a new era dawned for electrosurgical devices. Initially whether electrosurgical units (ESUs) should be used at all in laparoscopic cholecystectomies was a matter of debate. Reddick proposed the use of lasers. However, in the last three years monopolar electrosurgery has established itself as a cost-effective safe modality of laparoscopic surgery.

General Remarks

Monopolar Surgery

In this form of electrosurgery, the patient is placed in the path of the current flow and his tissue completes the circuit. Precautions must be taken to prevent electrical burns due to leakage currents, alternate current flow, and return-electrode problems (pad burn).

In laparoscopic surgery the exposed electrode tip must be visible whenever the unit is operating. The minimal current and power settings needed to achieve desired results should be used. The power used is chosen by the operator. The longer the current is on, the higher the energy flow through the patient. *It is imperative that the current be turned on only long enough to achieve the desired result.* It should then be turned off. Accidental triggering of current is signaled by an audible tone. *This alarm should never be disabled or turned off.*

Bipolar Surgery

In this form of electrosurgery, the patient does not complete the circuit. Therefore, the chance of electrical burns is reduced. The surgeon must be cognizant of the signs of *thermal* damage when using this modality; however, bipolar electrosurgery is definitely safer than monopolar surgery. However, the ability to cut is reduced, and monopolar electrical current has therefore remained the energy source of choice.

Achieving Cutting, Coagulation, and Fulguration Using Monopolar ESUs

Open Surgery

Monopolar ESUs are designed with switches that allow the units to be operated in either of the above modalities.

Cutting Current (Figure 3.1)

In this mode, electrons flow constantly, leading to a rapid rise in the temperature and instantaneous vaporization of the water in the cells, resulting in disruption of the cells, and dissipation of the heat. This results in a quick cut, but tissues bleed because the capillaries are cut rather than coagulated. There is less thermal damage in the cutting mode than in other modes because the heat is instantly dissipated when the water is converted to steam. Typically, the voltage is lower than in other modes but the current is continuous.

Blended Cutting Current (Figure 3.2)

In this mode, the current is produced in a chain of pulses. This leads to slower heating of tissues and slower disruption of cells. This results in mild coagulation of tissues, especially capillaries, with less blood loss. Cutting of tissues is achieved together with mild to moderate coagu-

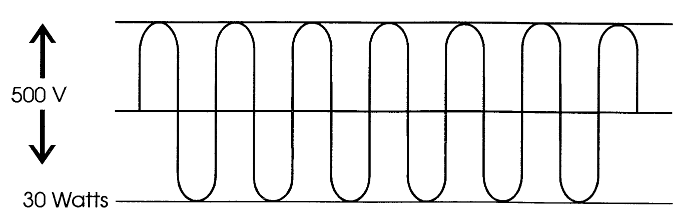

FIGURE 3.1. Typical cutting waveform. Unmodulated constant current; high current, low voltage.

lation, depending on the setting of the ESU. Typically, the voltages are slightly higher than in the cut mode, but the current is intermittent.

Coagulating Current (Figure 3.3)

In this mode, the current is interrupted for a longer period, leading to even slower heating of tissues, more coagulative thermal necrosis of tissues, and less vaporization. Typically, because a certain amount of current has to be driven through the tissues, the voltages are higher. The coagulative thermal tissue damage in this modality depends on the length of *time* the ESU is activated. This is controlled by the surgeon.

Fulguration (Figure 3.4)

In this mode, the voltages are extremely high, and there is low current flow. The coagulative necrosis of tissues is achieved by the sparking of the electrode, which is not in contact with tissues. The result is a charring of tissues. The burns are superficial. This is useful for fulgurating skin lesions. However, in laparoscopy it is sometimes used to control diffuse liver-bed hemorrhage. The electrode should never touch the tissues to be coagulated. Because the voltages must be *very high* to cause the electrode to arc, this ESU setting is the most dangerous one. If there is an insulation failure, there might be a burn the surgeon does not observe.

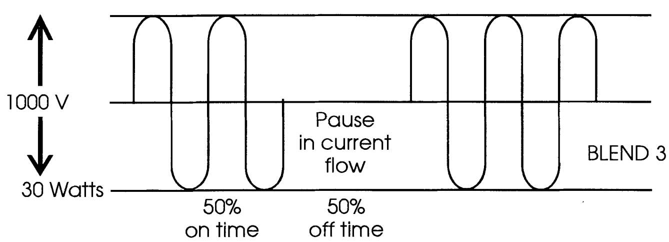

FIGURE 3.2. Blended or modulated cutting waveform. Modulated or interrupted current; high current, low voltage.

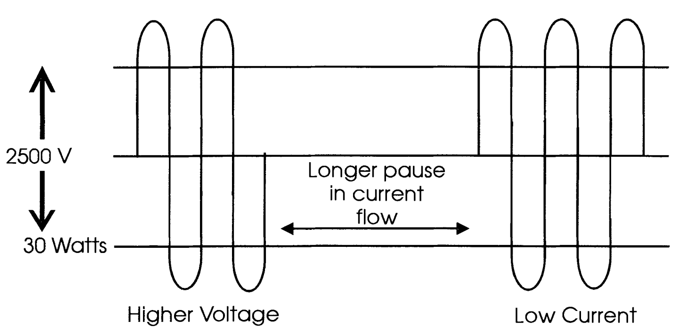

FIGURE 3.3. Typical coagulating-current waveform. Low current, higher voltage.

Concept of Current Density

In monopolar electrosurgery, the patient is *intentionally* placed in the path of the electrons. This means that each time the ESU is turned on, there is a flow of current through the patient's body. Safeguards against "short circuits" should be scrupulously observed.

The literature on electrosurgery can be very confusing. However, the principles can be understood without the need to commit to memory the complicated formulas that describe the electrical power or current density delivered by the ESU settings.

Simplified Concept

Figure 3.5 depicts a body placed in the path of a current of 100 W. The two electrodes have a surface area of 100 cm^2 each. The amount of current going through the patient's body is 1 W/cm^2. This is a low current density.

Figure 3.6 represents a similar configuration, but one of the electrodes (the active handpiece) has a surface area of 1 cm^2. Therefore, the current density at this site is 100 W/cm^2. This is a high current density.

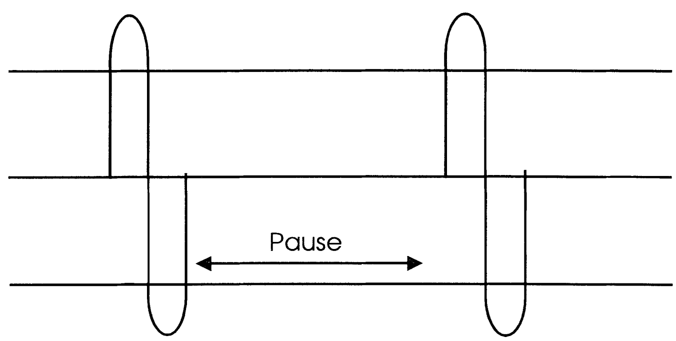

FIGURE 3.4. Fulgeration current. Highest voltage, longest pause. Sparks to surface of tissue. Superficial damage, or charring, seen on tissue. Works by coagulation of tissue and fluid.

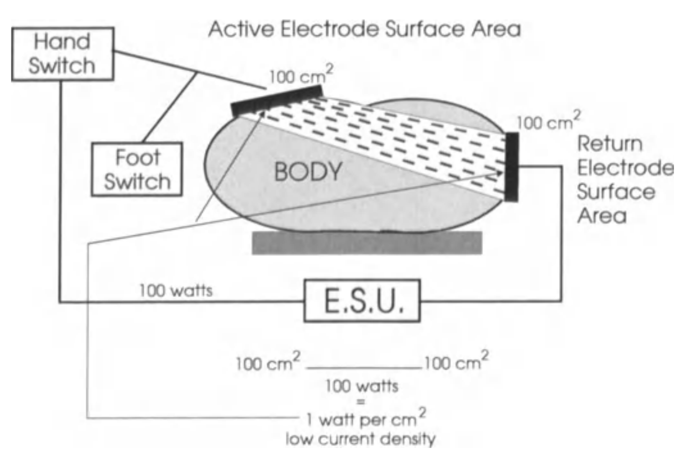

FIGURE 3.5. Low current density.

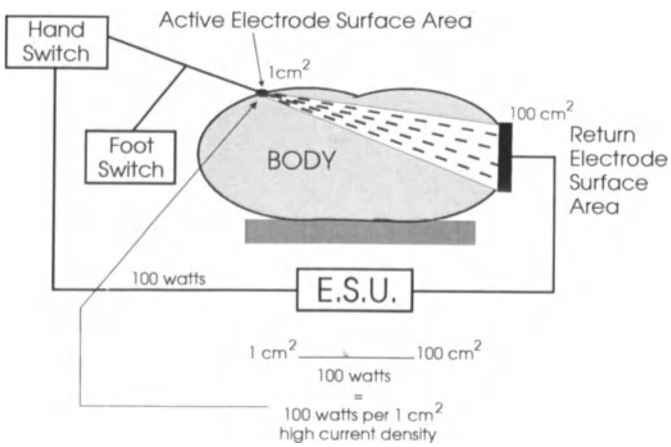

FIGURE 3.6. High current density.

If current density is low, the heating that occurs due to passage of current through the body is slow. Clinically, such a setting might be used for diathermy treatments of sprains, etc.

If the current density is high, there is a rapid rise in temperature in the area of contact. Depending on the rate of rise, cutting or coagulation will be achieved.

If cutting of tissue is desired, the tissue has to be placed on tension, and a high current density applied to the desired area. Higher current density can be achieved by means of a smaller surface area, such as a wire tip (Figure 3.7). The same instrument can be used to coagulate if a larger surface is applied to the tissues, by using the body of the wire (Figure 3.8). Cutting can be safely achieved by placing the ESU in the coagulation mode and using the tip or point of the wire electrode. The thinner the wire electrode, the less current is needed to cut. The thinner the wire electrode, the more efficient it is.

Guidelines for the Use of Electrosurgery in Laparoscopic Applications

1. Avoid using over 30 W of power.
2. Use only the coagulation mode with wire electrodes. If the cutting mode is used, there is more bleeding, and this can obscure the operative field. Because wire electrodes are so thin, one can achieve satisfactory cutting (similar to that achievable at a blend setting) in the pure coagulation mode. The authors have used this setting in conventional surgery. Tissue damage can be reduced by reducing the "on" time of the current. This is controlled by the surgeon using either a handpiece or a foot pedal.
3. Use electrode geometry to achieve precise coagulation or cutting. Choose a smaller contact patch to achieve cutting and a larger contact patch to achieve coagulation (Figure 3.9).
4. The tissue has to be placed on tension to achieve cutting (Figure 3.7).
5. Use the thin wire electrodes to cut. Thick wire electrodes perform poorly because they tend to cause coagulation, and cutting and coagulation cannot be

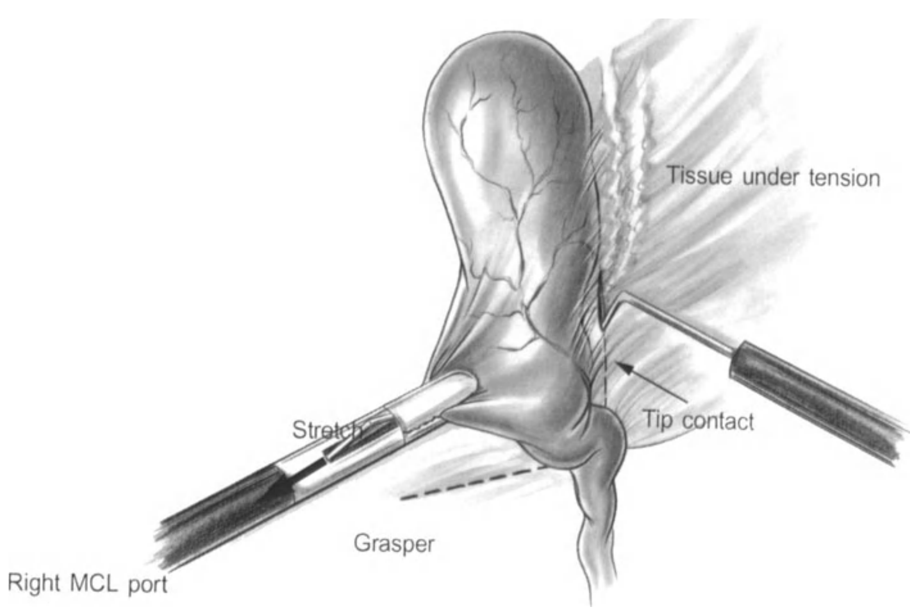

FIGURE 3.7. High current density used to make V-shaped cut in peritoneum. 25 W coagulation current using tip of wire electrode results in high current density that cuts when tissues are stretched.

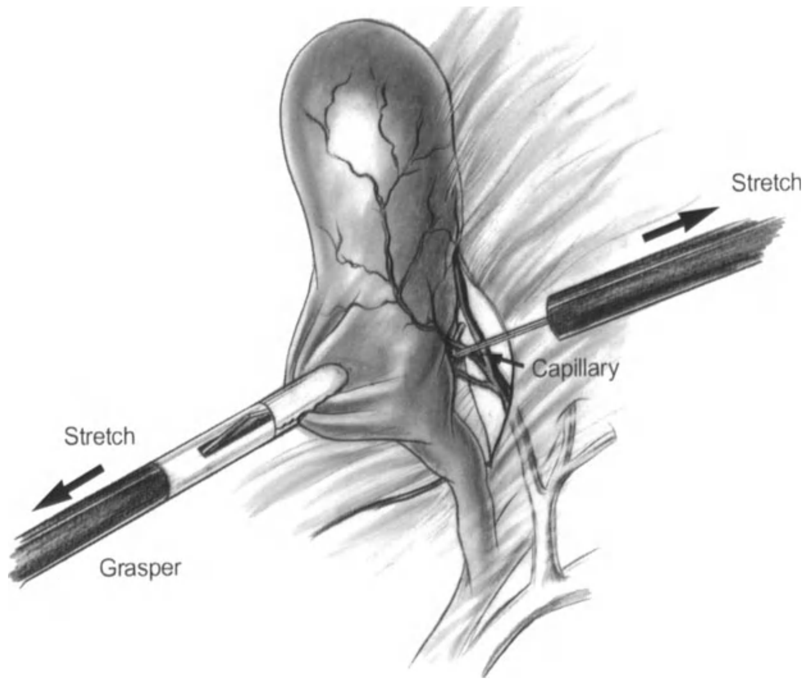

FIGURE 3.8. Capillary lifted by L-wire electrode and tugged in the angle of electrode is exposed to a larger surface area of the electrode. This technique achieves precise coagulation of a small capillary.

properly achieved (Figures 3.7, 3.8, and 3.10). Thinner wire electrodes can be used for precise bloodless dissection.

6. The foot switch or hand switch should be activated for short periods only. If the current is on long, the chance of remote-site electrical injury is increased (in the event there is an unrecognized insulation failure).
7. If the surgeon observes blanching of tissue, a precursor of charring, too much power is being used. Charring should be avoided. In the liver bed, this will result in the liver tissue adhering to the electrode and, when the electrode is moved, it will tear the liver tissue.

Fulguration in the Liver Bed

This modality can be used occasionally to stop bleeding. The electrode should not be in contact with the liver tissue, as the goal is to achieve hemostasis by sparking. Sixty watts should be the maximum power setting. Because voltages are very high in the fulgurating mode there is a risk of burns within the abdomen, which may not be recognized at the time of surgery.

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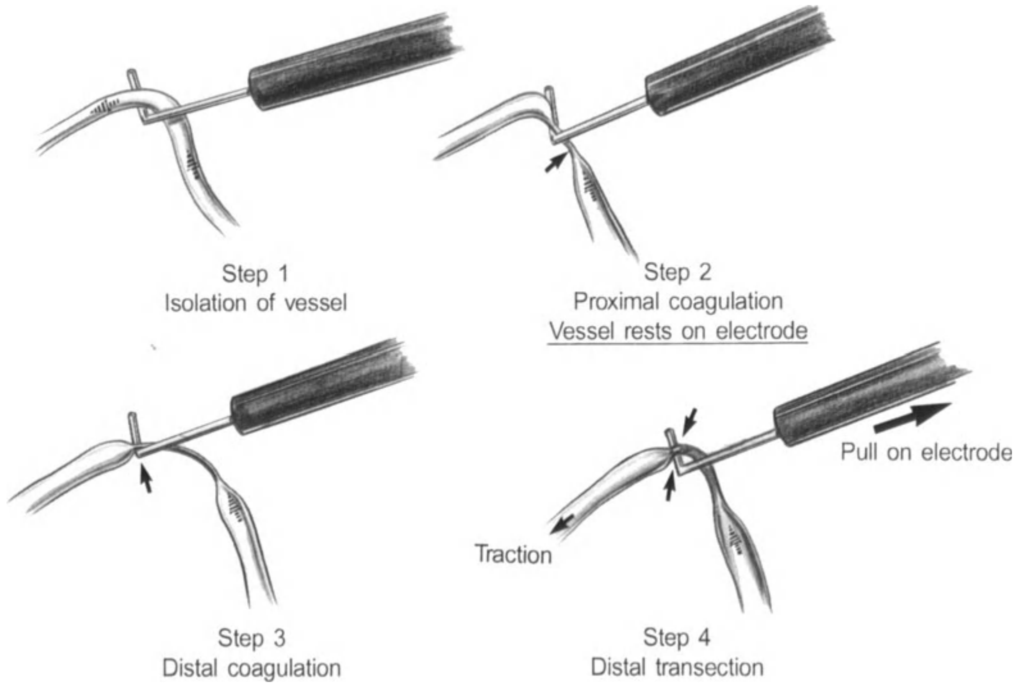


FIGURE 3.9. Method of coagulating and cutting a small vessel.

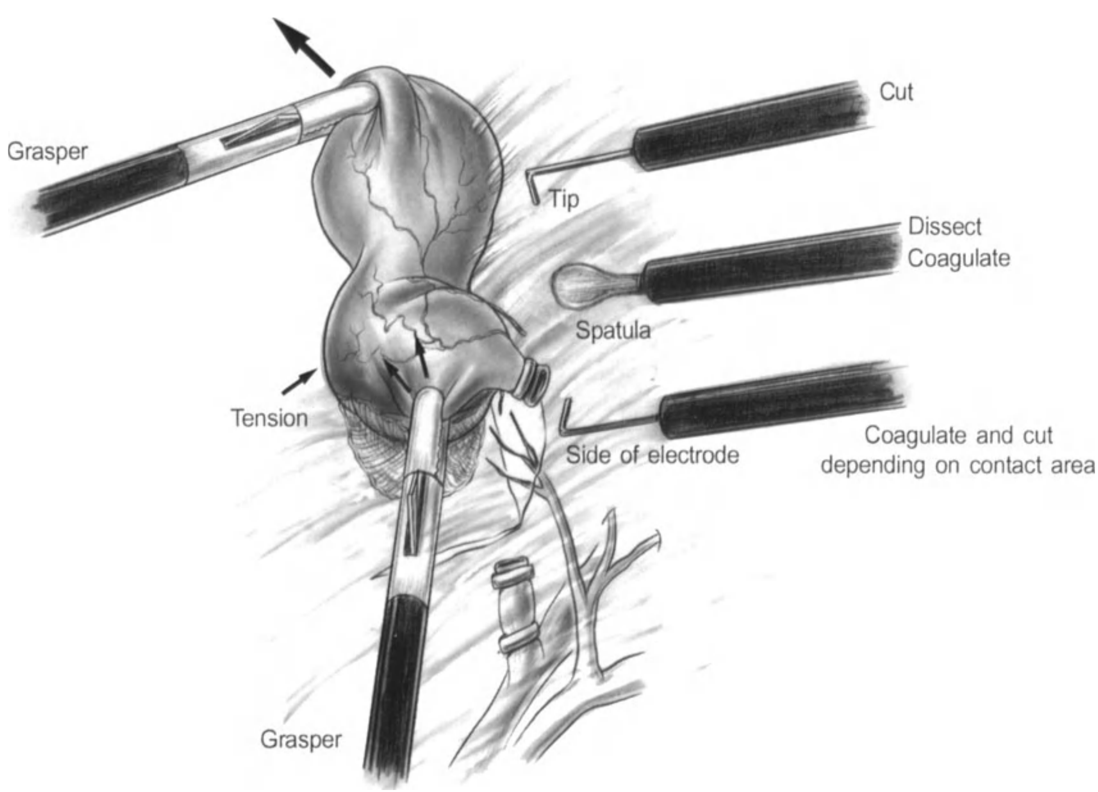


FIGURE 3.10. Whether tissues are cut or coagulated depends on the contact surface area and on the tension on the tissues. Thinner electrodes require less current to cut. Thicker electrodes require high current to achieve the same result.

4
Suturing Techniques

Henry L. Laws

The skilled endoscopic surgeon must be able to tie or sew when these techniques will make the operation more efficient or practical. Indeed, many advanced procedures are not feasible without sewing and tying.

The first surgeons to do video-directed laparoscopic cholecystectomy used thread and ties, but the modification of clip appliers led most surgeons to do these operations without suture material. More complex restorative procedures, however, still require suturing and knot-tying. Consequently, the master surgeon must be adept with threads and knots, and every surgeon should be capable of passing and tying ligatures, placing a stitch, or beginning, running, and ending a suture line. In the writer's judgment, all laparoscopic surgeons must be capable of the following:

Suturing

1. Passing a tie
2. Taking a single suture
3. Running a continuous suture line

Tying

1. Using an Endoloop
2. Performing an external tie
   a. complete tie plus tightening with a plastic pusher
   b. placing individual external throws and effecting an internal tie
3. Performing an internal tie
   a. single
   b. performing the initial tie for a running suture line and terminating a running suture

All of these maneuvers can be practiced on inanimate models.

Equipment

Suture Material

Permanent and absorbable materials are used in laparoscopic surgery in the same way they are used in open procedures. The operator needs to be familiar with the characteristics of the suture material. For instance, a Roeder knot requires fewer loops if the material is chromic catgut than if it is PDS or polypropylene. Polypropylene is so slick that the knot may slip unless additional throws are taken or a clip is used to secure the ends.

Needle Holders

The dominant (right) needle holder should have a lock the surgeon can activate or inactivate at will (Figures 4.1 and 4.2). It should be strong and preferably should have only one moving jaw (to reduce suture snagging). The lock on the nondominant needle holder, which is used much as are tissue forceps in open surgery, preferably should be inactivated. The writer prefers to use a 3-mm needle holder on the left and a 5-mm needle holder on the right. When a smaller needle holder is used, it should be passed through a 5-mm-to-3-mm reducer. The needle carriers should have jaws that will not fray suture material. An instrument with smooth atraumatic jaws should be available for the assistant, who may need to grasp the suture material from time to time.

Throw Pushers

The surgeon should have available both 5-mm and 3-mm throw pushers to lay external throws (Figure 4.3).

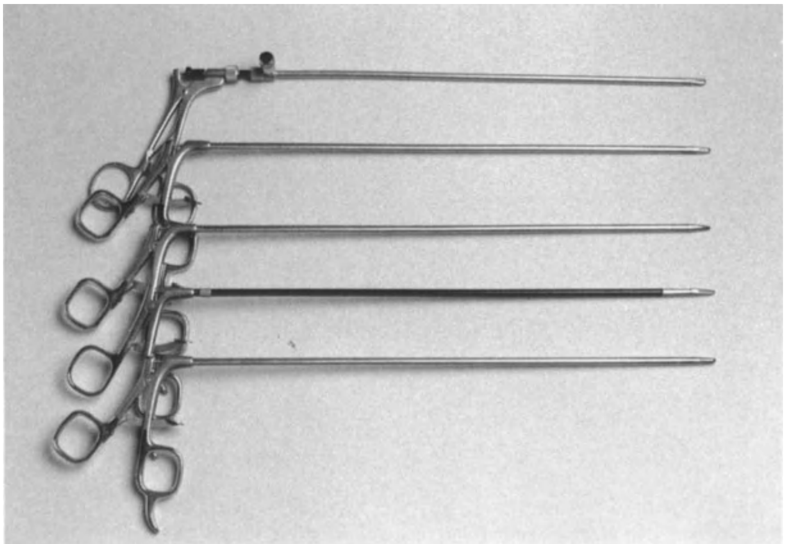


FIGURE 4.1.

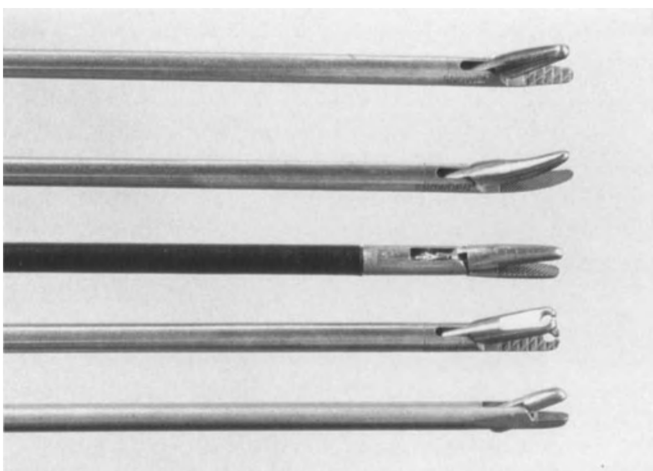


FIGURE 4.2.

FIGURES 4.1 and 4.2. Several different needle holders are shown. Many others are available. In selecting one the surgeon should consider its strength, the reliability with which it holds the needle, the ease with which the shaft can be rotated, its usefulness for holding thread, and whether the jaw hinges catch on the thread. For many procedures, such as working around the esophageal hiatus, many needle holders are simply too short. The writer prefers a needle holder with one moving jaw, relatively smooth surfaces, and great strength. There are special needle holders for curved needles.

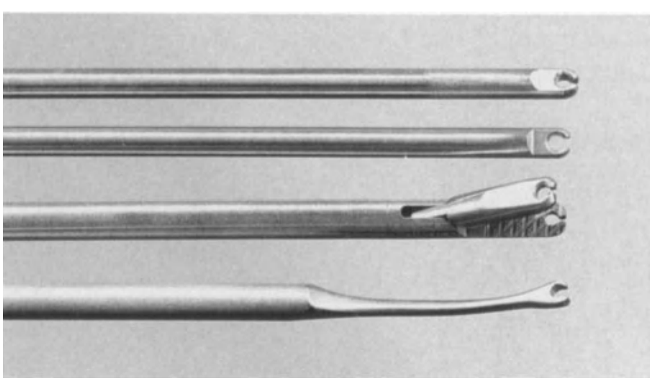


FIGURE 4.3. Throw pushers may be 3 mm or 5 mm in size. Some needle carriers have a throw-pusher slot. The surgeon should withdraw the thread from the abdomen for tying via a cannula or reducer of appropriate size.

Plastic (or metal) pushers are commercially available that are designed to push external ties of 0 and 2–0 suture material inside the body cavity. However, finer material may be needed, which may require a "throw" pusher.

Endoloops

An Endoloop is a convenient prefashioned ligature for tubular structures that have already been transected. The Endoloop is drawn backward into a 5-mm-to-3-mm reducer, because the plastic pusher is 3 mm in size. After the Endoloop is introduced into the abdominal cavity, a grasper is passed through it and holds the tubular structure until the Endoloop knot is pushed into position. A ligature can also be applied with a commercially available suture and a plastic pusher. The thread is passed into the body cavity through a 5-mm-to-3-mm reducer, then maneuvered around the structure and back out through the reducer. A knot is effected externally and pushed into position with the plastic pushing device. A thread with a preapplied needle can also be used. The needle is passed through the tissue and brought out through the reducer. The knot is fashioned externally and then pushed back inside.

As a general rule, sutures that must be under tension or be very secure probably should be tied externally because more force can be applied. Internal ties may be best for delicate sutures or those that do not have to be under tension.

Commercially available suture materials that have a preapplied plastic pusher and pre-tied knot provide a convenient way to place the tie quickly (Figure 4.4). An absorbable suture clip, which can be placed with a special applier through a 10- to 12-mm cannula, is also available (Figure 4.5).

Needles

Commonly used needles include a straight needle, a Ski needle, and a curved needle (Figure 4.6). Nonswedged needles are laborious to use and, because they can easily be lost within the body cavity, probably should not be used. To introduce a large curved needle, a cannula can be briefly removed and a carrier that holds the thread just above the needle used to pass the needle through the body wall. To position a curved needle or Ski needle for grasping with the needle carrier, the surgeon should hold the pointed end of the needle in the left hand. The thread should be grasped about 1 cm behind the needle, which can then be rotated into the proper position.

Trainer

A trainer with a self-stabilizing camera is essential for practice (Figure 4.7).

Technique

Passing a Needle into the Abdominal Cavity

The needle holder should grasp the thread just behind the needle. The holder can then be pulled into the 5-mm-to-3-mm reducer and passed into the surgeon's left-hand port. In the case of an internal tie, for which the appropriate length of thread would be 5 or 5½ in., the needle and suture can be pulled back up into the reducer with the needle holder before the reducer is passed into the cannula (Figure 4.8).

Creating a Slip Knot

If a suture with a prefashioned slip knot is to be passed into the abdominal cavity, the 3-mm needle driver should be used to grasp the suture material just behind the needle and above the slip knot pull and to pull it back up into the reducer before the reducer is introduced into the cannula (Figures 4.9–4.11). The slip knot may be created so that the shorter thread or the longer thread slips. This writer prefers the former, but either is effective.

External Ties

The classic Roeder knot was popularized in America by Dr. Kurt Semm (Figures 4.12–4.14). This is the writer's preferred external knot.

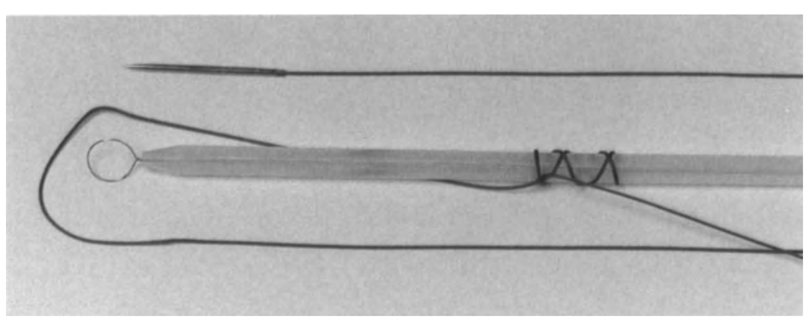


FIGURE 4.4. Some commercial suture materials have a preapplied pusher and pretied knot. The needle and thread are carried inside, passed through the tissue, and brought back out of the abdomen. The thread immediately behind the needle is then passed through a wire loop, which is pulled up through the plastic pusher. The pretied knot is then slipped over the thread, and the pusher is used to tighten it.

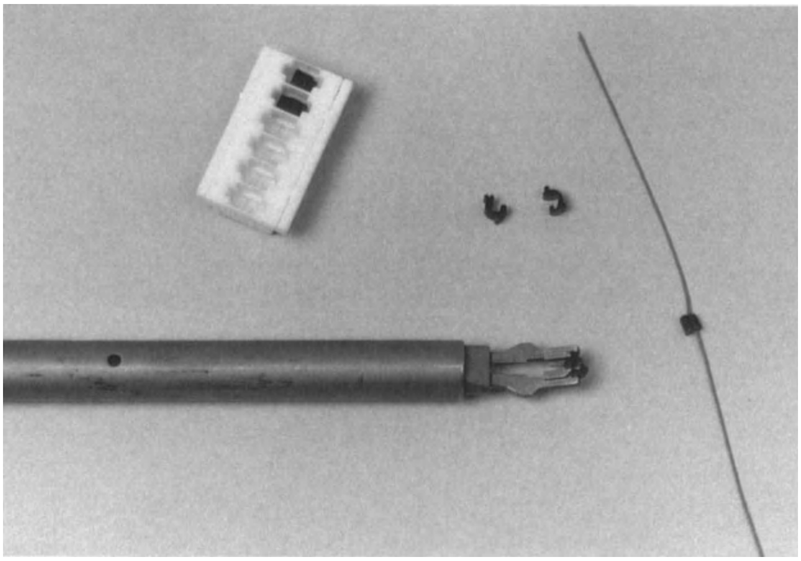


FIGURE 4.5. A commercial absorbable suture clip will hold a suture without tying.

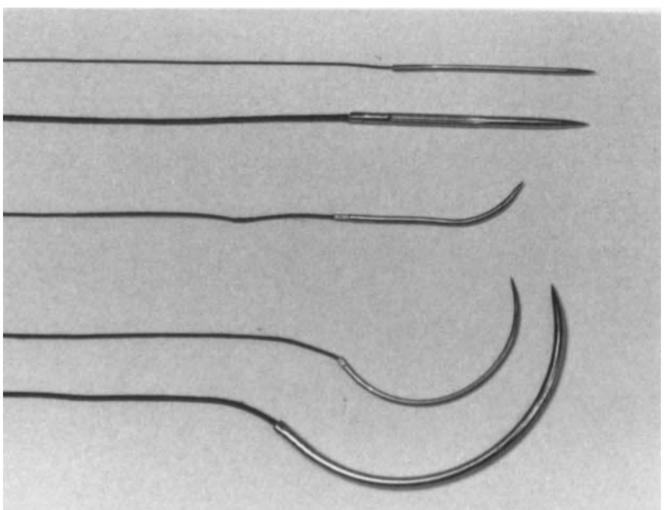


FIGURE 4.6. The most popular needle is a straight needle that is essentially a short Milner needle. The curved needles are useful but are more difficult to set in the needle holder and require more finesse on the part of the surgeon.

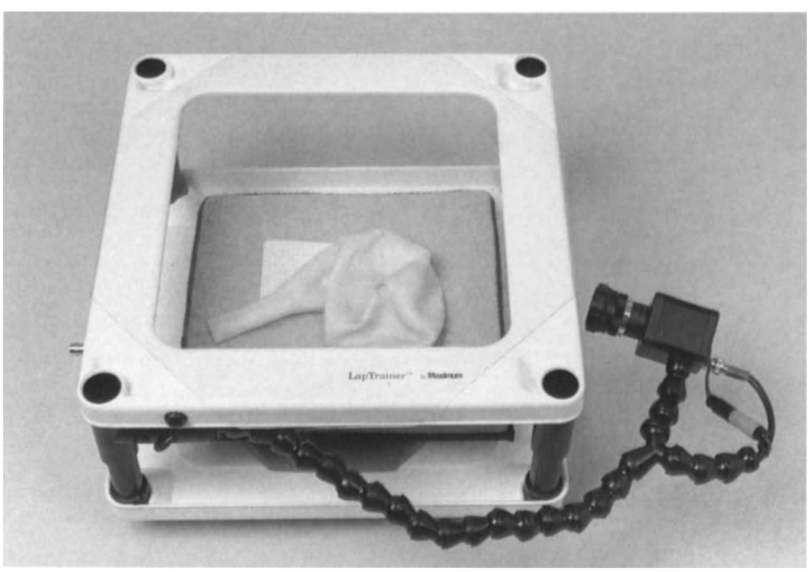
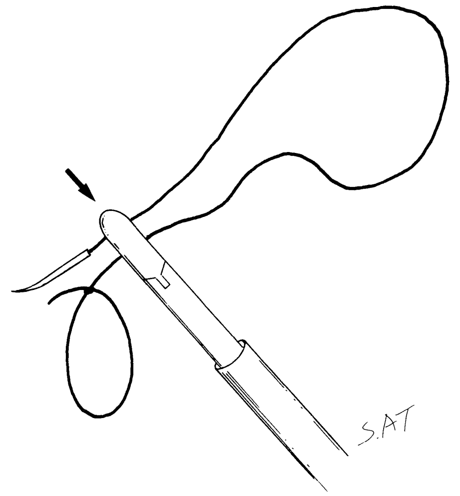


FIGURE 4.7. A trainer, such as this one by Maximum Design & Mfg., Inc., which is portable, has a self-holding camera, a clear or opaque cover, and can be connected to any TV screen, is useful for practice.

FIGURE 4.8. To pass a needle into the abdominal cavity, the thread immediately behind the needle and, in the case of a slip knot, the thread immediately before the slip knot, are grasped in the tip of the needle holder after the holder is passed through a 5-mm-to-3-mm reducer. The thread and suture are pulled back up into the reducer as it is slipped into the cannula for insertion into the abdominal cavity.



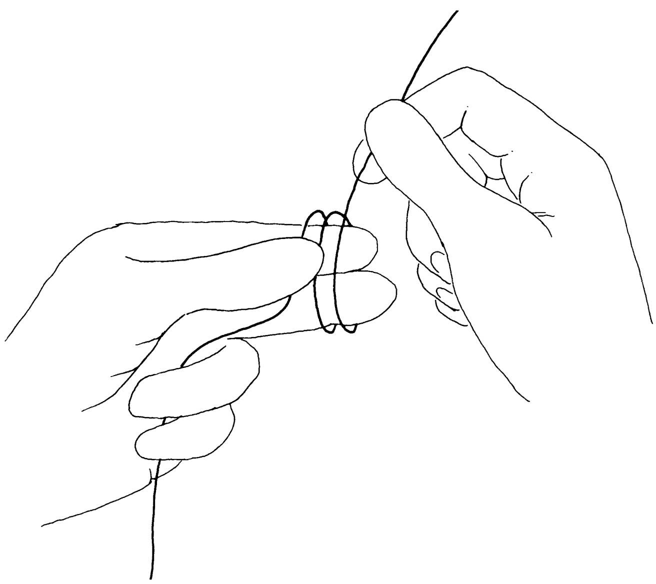


FIGURE 4.9.

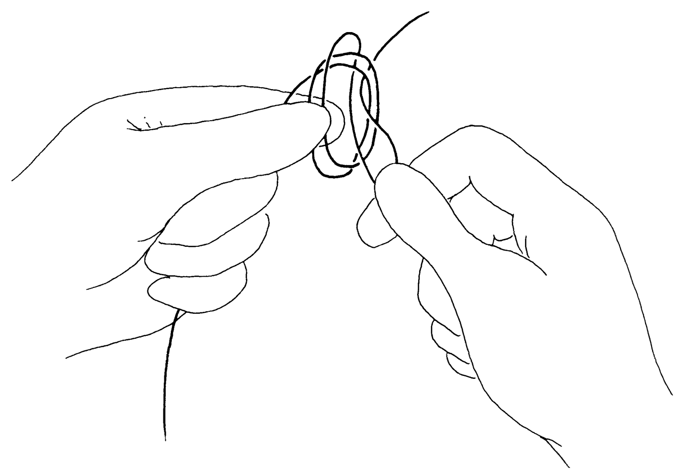


FIGURE 4.10.

FIGURES 4.9–4.11. A slip knot is made by encircling two fingers twice, then passing the thread through the double loop. The loops are pulled tight. If a single suture is to be tied with a slip knot, there should be about 5 in. of thread between the needle and the slip knot.

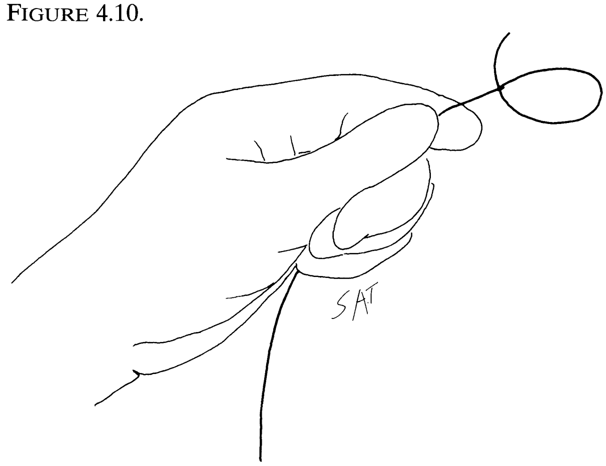


FIGURE 4.11.

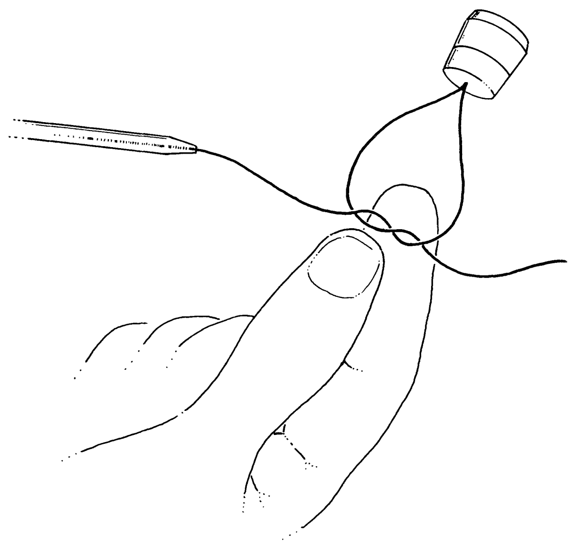


FIGURE 4.12.

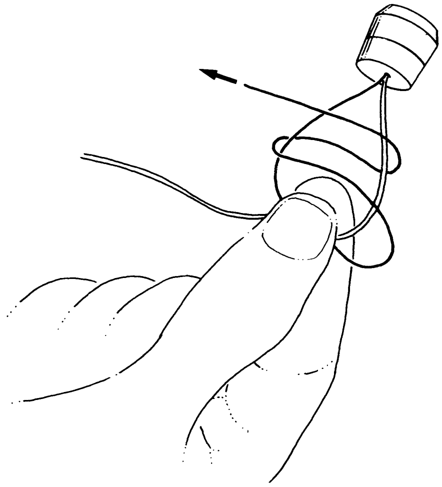


FIGURE 4.13.

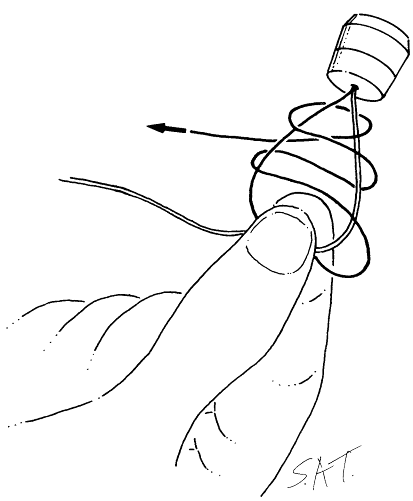


FIGURE 4.14.

FIGURES 4.12–4.14. When the surgeon ties a Roeder knot, an assistant's finger should occlude the cannula orifice and keep the two threads separated. A single throw is taken and held between the finger and thumb (Figure 4.12). The short thread is wound around the long thread three times, and then passed between the two threads exiting the cannula and under itself (Figures 4.13 and 4.14).

The Texas Endosurgery Institute (TEI) knot can be tied in several ways, is somewhat difficult to tie, but may be useful for slicker material, such as PDS (Figures 4.15–4.22). It is convenient to use a thread with a preapplied plastic pusher to create either a Roeder or a TEI knot. The preapplied pushers are 3 mm in diameter and, therefore, the suture material should be passed into and out of the abdomen through a 5-mm-to-3-mm reducer. Such suture comes in 0 or 2–0 sizes. Finer sutures must be tied in some other fashion.

Suture material of any fineness can be tied by making individual throws, which are then slipped into the abdominal cavity with a throw pusher (Figures 4.23 and 4.24). The throw pushers come in 5-mm or 3-mm sizes. The surgeon must insert and remove the suture material through a cannula of a size that will allow proper function of the throw pusher.

To effect a Roeder or TEI knot requires a length of thread at least 42 in. long. The thread for individual throws tied externally should be at least 36 in. in length, although a 30-in. thread can usually be tied.

Internal Ties

Internal ties can be effected simply by tying the knot internally (Figures 4.25–4.29). A slip knot created outside may be tightened into position. To end a continuous suture line, the Aberdeen knot is most effective (Figures 4.30–4.34).

Sewing

The common mistake in sewing is to work with too long a piece of suture material. For a single stitch, the thread

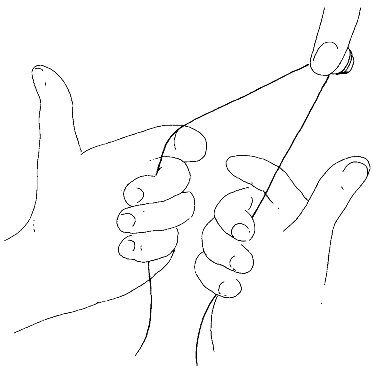


FIGURE 4.15.

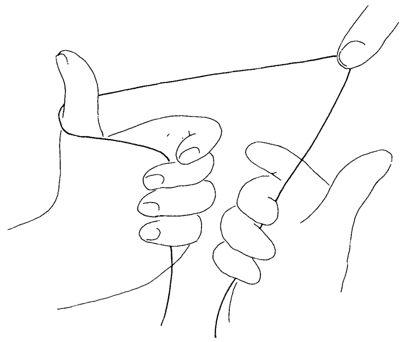


FIGURE 4.16.

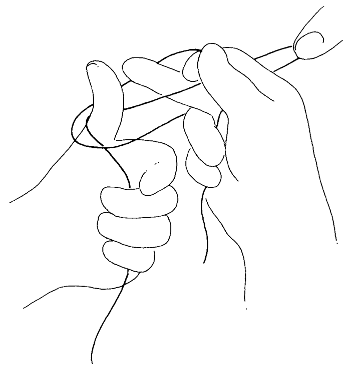


FIGURE 4.17.

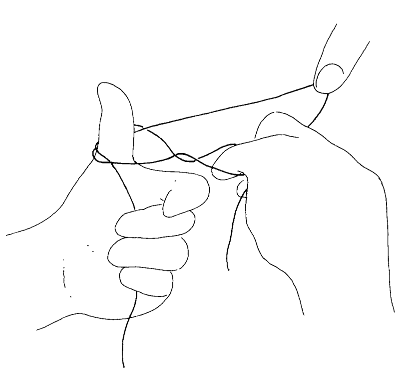


FIGURE 4.18.

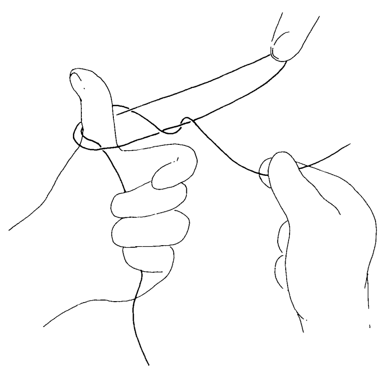


FIGURE 4.19.

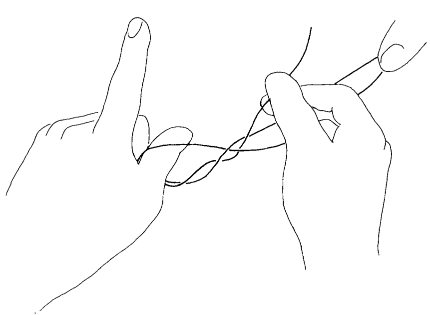


FIGURE 4.20.

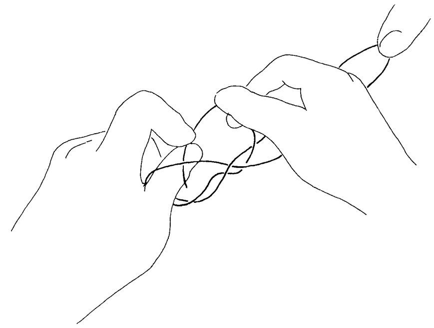


FIGURE 4.21.

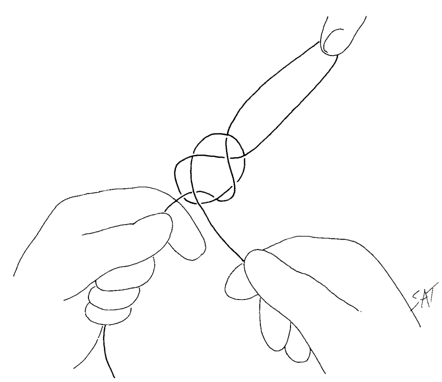


FIGURE 4.22.

FIGURES 4.15–4.22. When the surgeon ties a TEI knot, an assistant's finger should occlude the cannula orifice and separate the two threads. The surgeon should assume a horns-out position, with the thread lying over either index finger (Figure 4.15). Next the left thumb is tucked under the thread, so that the thread encircles the thumb (Figure 4.16). The thread in the right hand is brought around this posted thumb, then pulled under one of the threads exiting the cannula and over the second (Figures 4.17–4.19) The left hand is then rotated so that the suture can be picked up and rotated about 180° (Figure 4.20). The right hand then lays the thread between the thumb and index finger of the left hand (Figure 4.21). The thread is then pushed through the loop held by the thumb and pulled snug (Figure 4.22).

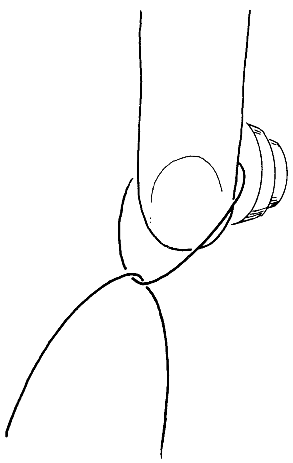


FIGURE 4.23.

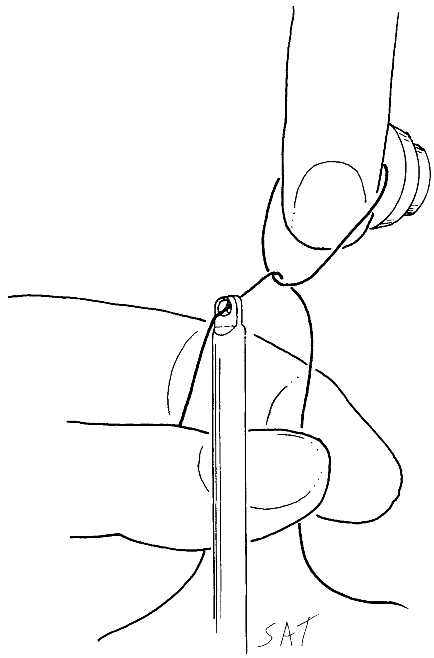


FIGURE 4.24.

FIGURES 4.23 and 4.24. For a single throw, an assistant should occlude the cannula orifice and separate the two threads. A single throw is made at the surgeon's preference (Figure 4.23). The two ends are held by the assistant (Figure 4.24). The throw pusher is then braced on the assistant's index finger, catches one thread, and slips the throw inside the body cavity to accomplish the tie. Both threads need to be kept taut as the throw pusher is advanced.

should be approximately 5½ in. A good rule of thumb for a running suture is to allow 5½ in. for the first stitch and ½ in. for each additional stitch. To effect a single stitch, the suture material is grasped immediately behind the needle with a 3-mm needle holder and pushed into the abdominal cavity (Figure 4.8). The suture is then passed through the structure, which is stabilized with the left-hand carrier. Generally, the needle is pulled out of the tissue with the right-hand needle carrier. The tie is effected as shown in Figures 4.25–4.29. It may be wise to use a piece of thread approximately 5 in. in length with a pre-tied slip knot (Figures 4.35 and 4.36). Then, after the slip knot is pulled tight, another throw(s) can be tied to reinforce it.

The suture material for a continuous suture line is pulled up into the 5-mm-to-3-mm reducer, which is then passed into the cannula to allow entry into the abdominal cavity. After the initial stitch is taken, the slip knot is tied as shown (Figures 4.35 and 4.36). As further running sutures are taken, the needle should be pulled part way through the tissue after each stitch with the right-hand carrier. Then, the carrier can be re-locked on the needle while it is still stabilized by the tissue. For the final suture, the needle should be pulled out of the tissue with the left-hand needle driver, leaving a loop about 1 cm in diameter for the Aberdeen knot. This knot anchors the continuous suture line. The knot will be easier to tie if an assistant with a smooth instrument holds the thread where it comes out of the sutured organ so that the suture line is taut as the surgeon effects the tie. The assistant can then grasp the thread as it comes out after each throw until the final throw is made.

Most laparoscopic surgeons will not be called on to sew and tie frequently enough in clinical practice to keep their skills honed and may need to take practice regularly with a trainer.

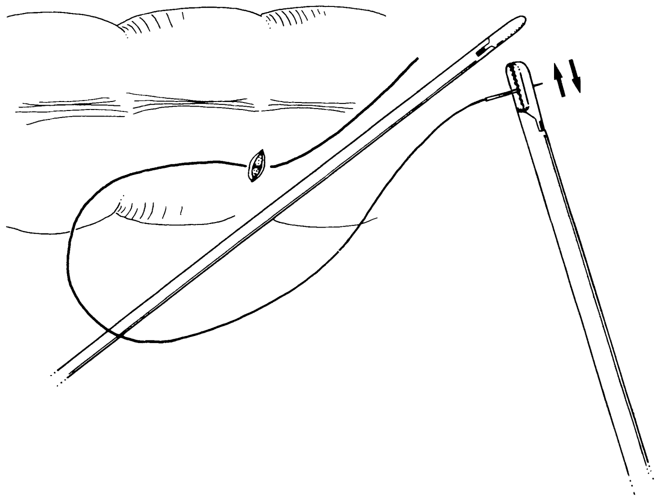


FIGURE 4.25.

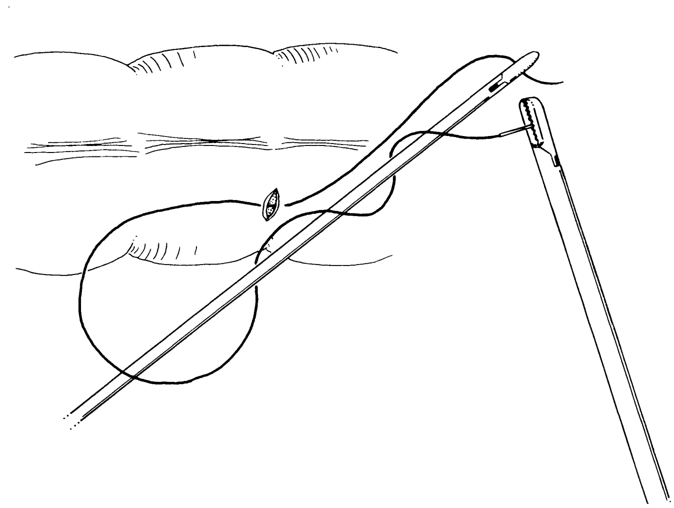


FIGURE 4.26.

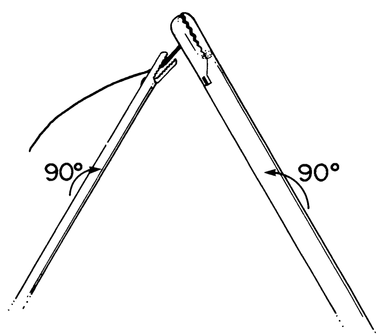


FIGURE 4.27.

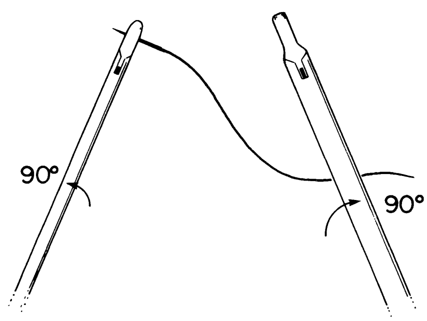


FIGURE 4.28.

FIGURES 4.25–4.29. To tie a single suture, the needle point is grasped with the right-hand carrier and brought back to the right adjacent to the short end of the thread. The left-hand carrier is then placed across the field near the short end of the thread. The needle is then passed down and up twice, encircling the empty carrier (Figure 4.25). The tail of the thread is grasped with the left-hand carrier and brought back across the field. Then the thread is made snug by pulling the right-hand carrier in the opposite direction (Figure 4.26). The needle is then transferred to the left-hand carrier with both carriers in vertical (Figure 4.27). The same maneuvers are repeated on the left (Figures 4.28 and 4.29).

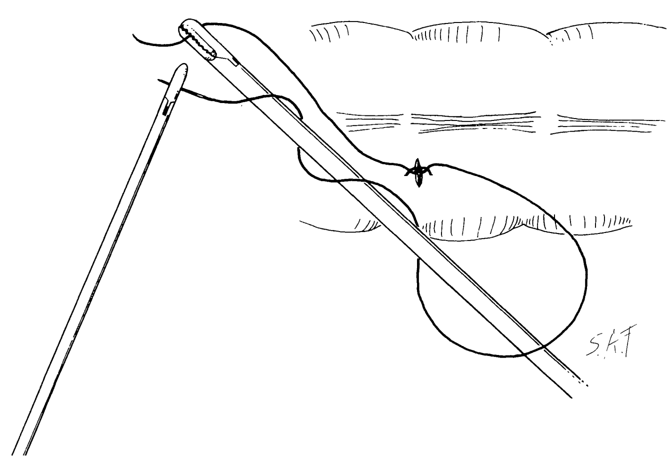


FIGURE 4.29.

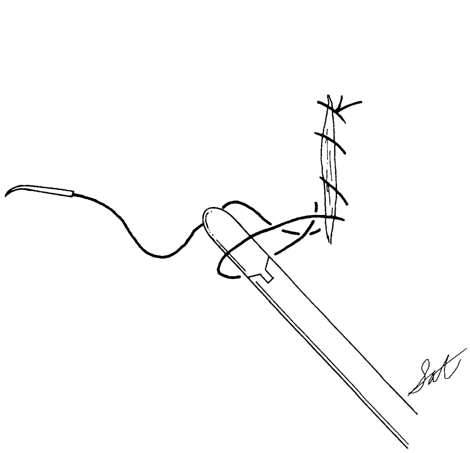


FIGURE 4.30.

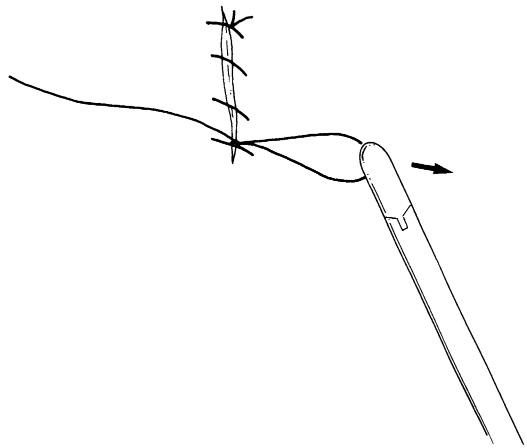


FIGURE 4.31.

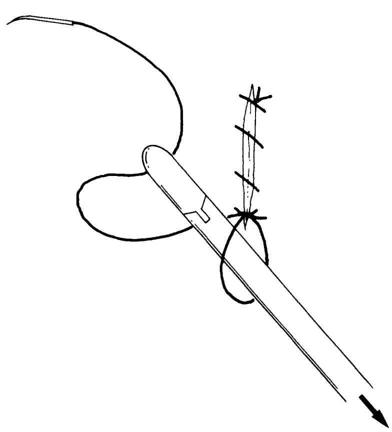


FIGURE 4.32.

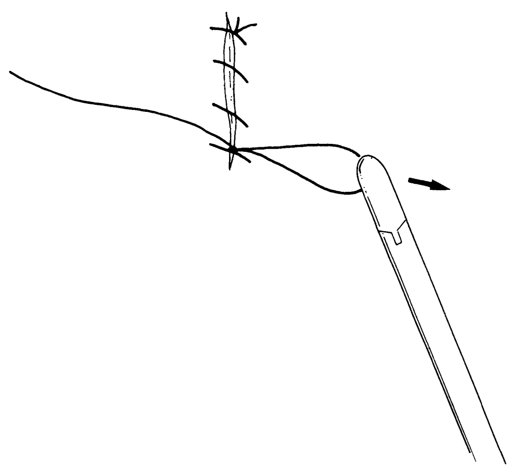


FIGURE 4.33.

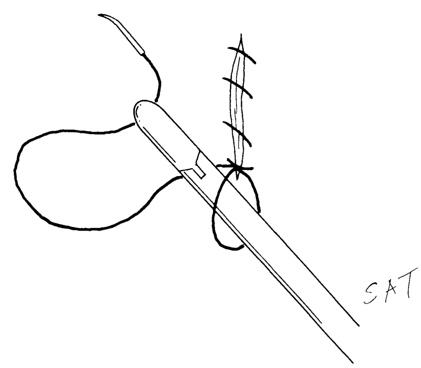


FIGURE 4.34.

FIGURES 4.30–4.34. After the last stitch is taken, leave the loop from the previous stitch open for about 1.5 cm. Reach through this loop, grasping the suture as close to where it comes out of the tissue as possible (Figure 4.30). Pull the suture back through the loop, tightening it up and creating a second loop (Figure 4.31). Go back through this loop, grasping the suture again (Figure 4.32). Pull this suture through the second loop, creating a third loop (Figure 4.33). Go back through this third loop, grasping the suture near the needle, and pull the entire suture through this loop, cinching this loop down and completing the tie (Figure 4.34).

FIGURES 4.35 and 4.36. The stitch may also be taken with a thread that has a slip knot at the end. One needle carrier can then be passed through the slip knot, grasping the thread immediately behind the needle and pulling it back through the loop. The other needle can then be used to grasp the short end of the thread. By pulling in opposite directions with the two needle carriers, the slip knot can be tightened.

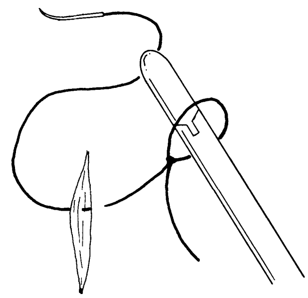


FIGURE 4.35.

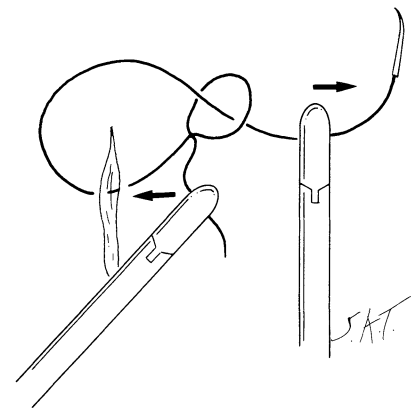


FIGURE 4.36.

5

Current Concepts in Operative Surgery Using Videoendoscopically Assisted Mechanical-Suture Techniques

Felicien M. Steichen, Roger Welter, Hee Yang, Edward B. Sottile, and Vito A. Marrero

As surgeons have gained experience with state-of-the-art stapling instruments and techniques, it has become obvious that mechanical sutures did not simply replace manual sutures. They elevated operative surgery to a higher level of sophistication and reduced the need for physically wearing prolonged or repetitive maneuvers, allowing the surgeon to concentrate on the design and execution of standard and complex reconstructive procedures. What appeared at first to be a simple conversion from manual to mechanical sutures evolved into a system of new techniques made possible by the staples.

When they were first introduced, some of these techniques, such as the everting, mucosa-to-mucosa closure of hollow viscera, ran counter to accepted practice. (In fact, Benjamin Travers had shown in 1812 that everting manual sutures would heal.) Crossing and overlapping staple lines represented a radical departure from traditional sewing, because it is not safe to cross manual sutures. Crossing made possible the functional end-to-end anastomosis, constructed with linear instruments. In time this technique led to the variable anastomotic cross section, or techniques for increasing the anastomotic aperture to avoid the danger of stenosis or stricture.[6]

A further, major advance was the recognition by Charles Knight that circular and linear staple lines could safely intersect. All of these techniques are used in various combinations in complex reconstructive procedures, such as the sequential anastomosis-resection (anastomose-résection intégrée of Welter),[7] that are used to create substitute organs and restore function after major extirpative operations.

Manual sewing in laparoscopy and thoracoscopy is at best tedious, perhaps soon to become a relic of a romantic surgical past, and is certainly not in harmony with the space-age technology of videoendoscopically guided operations. The adaptation of stapling instruments to minimally invasive surgery has given an added importance to these techniques, which were developed during the open age. One hopes other methods, such as safe and reliable tissue glues and compression anastomotic devices, will soon become available to facilitate the reconstructive phase of procedures done laparoscopically or thoracoscopically.

Like stapling, the state of the art in endoscopically guided or assisted procedures within the abdomen, pelvis, or chest reflects the availability of new materials and technology.

The availability of fiberoptic endoscopes and of smaller and smaller cameras, both incorporated into a television and video system, has elevated the one-man mostly diagnostic procedure of coelioscopy to a therapeutic procedure conducted by a team whose members are guided in their operative roles by the image projected on a TV monitor. The participation of the entire operating team, including the nurses and the anesthesiologist, has made operating with minimal access to the body cavity, once a *tour de force,* a safe surgical undertaking that has opened progressively more and more therapeutic avenues.

Operations became more advanced as a reconstructive phase was added to the excision of tissue and organs. The established surgeon must decide how many of the procedures he or she cares to learn. As more and more young surgeons, fully trained in all videoscopic techniques, join the ranks of clinical practitioners, this problem will disappear.[8]

To demonstrate the usefulness of mechanical devices and sutures in laparoscopic and thoracoscopic surgery, I will discuss the techniques used in different clinical situations.

In diagnostic procedures and biopsies by incision or excision, as well as in the ablation of diseased organs, clips and everting or crossing staple lines are the most useful mechanical techniques.

For operations where partial or total *resection of an organ* requires *anatomical repair and restoration of function,* overlapping and intersecting staple lines are useful. They are employed, for example, in the creation of functional end-to-end and triple-stapled end-to-end anastomoses, as well as in the repair of pulmonary hilar structures and parenchyma.

For *complex reconstructive procedures ("anastomose-résection intégrée") and the creation of substitute organs* done with minimal body-cavity access, mechanical sutures, but also, one hopes, other labor-saving devices and materials now only a dream or on the drawing board, will play a dominant role in the future.

Stapling in Thoracoscopically Guided and Assisted Operations

Indications and Contraindications

Thoracoscopy, *in general,* is indicated in the diagnosis and treatment of thoracic conditions if the lesion can be seen or exposed by pleuroscopy and manipulated by videoscopically guided or assisted means without compromising uninvolved anatomical structures, altering the long-term prognosis (especially in the case of malignancies), exacerbating existing co-morbidity factors, or threatening immediate patient survival.[2,4] As our experience and expertise grow, the field of indicated conditions will expand, especially considering the development of tailor-made instruments and the surprising recycling of old stalwarts whose size and shape allow them to be passed through the usual thoracoscopy ports and holes.

Thoracoscopy is preferred for patients with reduced cardiopulmonary function. The advantages of thoracoscopy (mostly diminished pain) are especially striking postoperatively in those patients who have reduced or limited lung and heart function for whatever reasons.

If the patient cannot tolerate anesthesia or prolonged collapse of one lung and tissue diagnosis is essential, it is often better to use a combined approach. Expeditious thoracoscopy, including a brief lung collapse, allows the lesion to be localized and projected onto the chest wall by transillumination or probing with a long needle. A small, muscle-sparing incision is made overlying the lesion, and tissue is excised with the lung fully expanded. The staplers are especially helpful to ensure an aerostatic and hemostatic parenchymal closure under these circumstances.

Since modern anesthesia can safely support all essential body functions during an operation, regardless of the size of the incision, the only absolute contraindication to either thoracotomy or thoracoscopy is a contraindication to general anesthesia itself, such as pre-existing debilitating conditions or potentially prohibitive intraoperative obstacles.

Thoracoscopy is preferred for patients with AIDS and hepatitis, because it reduces the exposure of healthcare personnel and the smaller incision heals more easily. Thoracoscopy is also favored for patients with immunosuppression for other reasons and for those with a variety of conditions where bleeding from a traditional incision should be avoided.

Specific Indications

These include almost all the presently known, general, intrathoracic pathological conditions, with the exception of lung cancers that have progressed beyond the T_1 NoMo stage. Here we will limit discussion to diagnostic and therapeutic procedures for which the newly developed endostaplers are useful. These include parenchymal resections and subsegmental resections/incisions with linear everting, overlapping, or intersecting staple lines in the diagnosis/treatment of inflammatory, parenchymal, and interstitial disease; benign, malignant, and metastatic nodules; emphysematous blebs and bullae; and areas of persistent air leak.[2,4] They also include segmental and lobar resections with stapled, anatomical repair of remaining hilar bronchovascular structures and parenchyma and restoration of pulmonary function, in the treatment of peripheral T_1 NoMo cancers.[5]

Perioperative Management

Preoperative anesthetic management and patient preparation are the same as for a planned thoracotomy. The patient is always told that the incision may have to be enlarged and consent for a standard thoracotomy is always obtained.

Intraoperative monitoring equipment consists of an ECG, blood-pressure cuff, arterial line for blood-gas and pressure determinations, pulse oximeter for oxygen saturation (SAO_2), and an end-tidal CO_2 monitor ($ETCO_2$). At least one large-bore intravenous line is placed, preferably into the right internal jugular vein. If a subclavian vein has to be used, it is generally the one on the side of the planned procedure. Swan-Ganz pulmonary catheters and perioperative monitoring of the physiological profile (PaP, PaW, cardiac output, peripheral resistance, and so on) are routinely started preoperatively to guide fine-tuning of the cardiovascular and pulmonary systems pre-, intra-, and postoperatively in all patients at risk from pre-existing conditions.

One-lung ventilation using the double-lumen endobronchial tube (Carlen's type) is essential for thoracoscopy. If the correct placement of the tube can be verified by auscultation, we do not routinely use the fiberoptic bronchoscope to check it. But the bronchoscope is always at the ready, to help with positioning of the double-lumen tube and to examine for possible dislodging after the patient has been turned into the lateral decubitus position. If we cannot obtain satisfactory collapse of the lung to be operated on, we proceed to open thoracotomy; we have not found other means of achieving lung collapse satisfactory.

In order to collapse a rigid or spongy lung, such as in emphysema for instance, we suction air through the endotracheal channel on the side of lung collapse and insufflate CO_2 at 1.5 to 2 L/min (to a maximum pressure of 10 mm Hg) into the corresponding hemithorax. The result is inspected through a thoracoscope introduced first through a small incision into the seventh intercostal space (usually) along the midaxillary line. We do not maintain insufflation throughout the operation but instead use it as indicated. If collapse of the lung is not satisfactory, we convert to open thoracotomy.

At the termination of the procedure, the placement of the chest tubes may present a problem. If one of the existing openings is used, the tubes will be directed transversely across the chest cavity, rather than vertically along the inner chest wall. To reorient the chest tubes we use transmural slings of catgut, placed with straight needles at or near the level of the tip of the chest tube. The tip is guided into the sling, and the sling is tightened by pulling on both ends and tying them outside, on the chest wall. When the time comes to remove the chest tube, the sling knot is cut, and the catgut is pulled out. Finally the chest tube is removed as usual.

Postoperatively, patients do complain of pain in the chest tube sites, often more than anticipated. This problem can be significantly reduced by intercostal or epidural blocks initiated in the operating room while the patient is still asleep and by repeated blocks if the tubes remain in place for a prolonged period of time.

Operative Technique and Instrumentation

It pays to plan the operative approach with the aid of chest radiographs, CT scans, and possibly MRI. Alternative and contingency solutions should be discussed with the surgical team, communicated to the patient, and planned for.

The small intercostal incisions for the placement and introduction of surgigrips, surgiports, and instruments should be accomplished by incising all layers (with careful hemostasis), rather than by puncture after incising the skin, as is customary in laparoscopy. The reason is the pointed trocar may injure the lung. Since CO_2 insufflation is not needed most of the time, and if it is needed, a tight seal around the surgiport, as for a pneumoperitoneum, is not required, the more deliberate incision of the wall, enlarged with progressively larger Hegar dilators, is preferable.

There is nothing more irritating than to have blood trickle into the endoscope from a traumatic puncture wound, obscuring the view. For that reason, although we always maintain hemostasis, we also place a surgigrip and surgiport into the incision reserved for the introduction of the thoracoscope in order to compress the walls of the incision. These technical accessories are moved if the endoscope and camera have to be placed in a different location. The chest incisions for the passage of operative instruments and staplers are selectively splinted with a surgigrip. To obtain optimal placement of the working incisions, we probe with long thin needles under direct vision in the direction of the lesion through appropriate intercostal spaces. The most favorable point of entry is chosen.

The operating-room equipment is the same as for open thoracotomy, which may in fact become necessary. The patient is placed into the appropriate lateral decubitus position and the hemithorax is prepared and draped for a standard posterolateral incision.

Video monitors should be placed on either side of the patient's head for most lung procedures. The surgeon feels most comfortable working from the patient's front except for procedures involving the anterior aspect of the hemithorax, in which case he should position himself at the patient's back. In the case of operations on the esophagus requiring a dissection along the long axis of the body, it is important to place one monitor near the patient's feet so the surgeon can look in the direction of the dissection. The opposite monitor, behind the surgeon at the patient's head, can be rotated so that the surgeon can see it when he turns around to move upward with the dissection. Besides the surgeon, there should be a qualified assistant, a camera holder, a scrub nurse, and one or preferably two circulating nurses in the room.

The videoscopic equipment is essentially the same as that used for laparoscopy. The thoracoscope is a 10-mm 15-in. end-viewing scope. A 5-mm scope is available for smaller patients, but it is rarely used. Occasionally a scope with a 30° (or 45°) field of vision may be used to see behind a structure. A flexible scope can also be used for this purpose, but so far flexible scopes have lower resolution than rigid scopes. The light source, camera, and video monitors are interchangeable with those used in laparoscopy.

Many of the other instruments are also interchangeable. However, most endoinstruments should be shorter and some need to be adapted. Since maintenance of a tight seal around working thoracoports or chest openings is not necessary, some open-surgery instruments may be used. For instance, a soft-bowel clamp can be used to compress lung tissue prior to application of the stapler. In fact we have been able to apply the long arms of the GIA 80 or 90 directly, in the stapling of the apex of the upper lobe, through appropriately placed chest openings no larger than that made by a 15-mm trocar.

Mechanical Sutures and Devices

The Endo Clip disposable clip applier is for occlusion of vascular, tubular, or small-tissue structures and for radiographic markings. The instrument holds 15 to 20 medium

(6 mm), medium/large (9 mm), or large (11 mm) titanium clips. The shaft of the applier rotates 360° for ease of clip placement and the jaw is black, which makes it highly visible, and angled at 15°. The instrument has a safety interlock that prevents closure of the jaws when a clip is absent and prevents loading a second clip behind one that is already in place (Figure 5.1).

The Multifire Endo GIA 30 instrument is for closure and transection of tissue. The instrument places six staggered rows of titanium staples and divides the tissue between the third and fourth rows. The stapler shaft rotates 360° but will remain fixed in position unless the rotation angle is changed. The instrument is available with 3.5 and 2.5 mm (V) staple cartridges to accommodate varying tissue thicknesses. If a longer staple line and transection is desirable, the powered Multifire Endo GIA 60 instrument may be used. This instrument is available with 2.5 (V), 3.5, and 4.8 mm staple cartridges (Figures 5.2B, 5.3B).

For applications requiring a linear staple line without transection, the Multifire Endo TA 30 or powered Multifire Endo TA 60 instruments may be used. These instruments place three staggered staple lines and use the same staple cartridges as the Endo GIA staplers. All Multifire Endo GIA and TA endoscopic stapling instruments rotate 360° and have a safety interlock that prevents the trigger from being squeezed if the instrument is not completely closed or if the cartridge has been fired. They can be reloaded three times (for a total of four applications) and are then discarded (Figures 5.2A, 5.3A).

Mechanical Suture Techniques in Biopsies and Resections of Pulmonary Parenchyma with Everting, Crossing, and Overlapping Staple Lines

Excisional Biopsy of an Apical Lesion (Figure 5.4)

In most cases that involve excision of pulmonary parenchyma, inflammatory lesions, neoplastic nodules, or emphysematous blebs, we use three to four thoracoports,

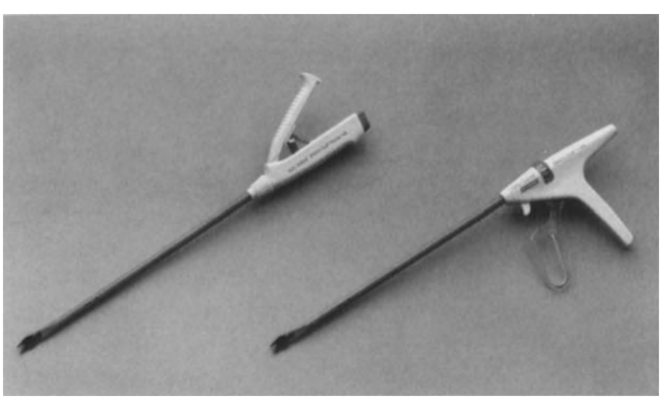
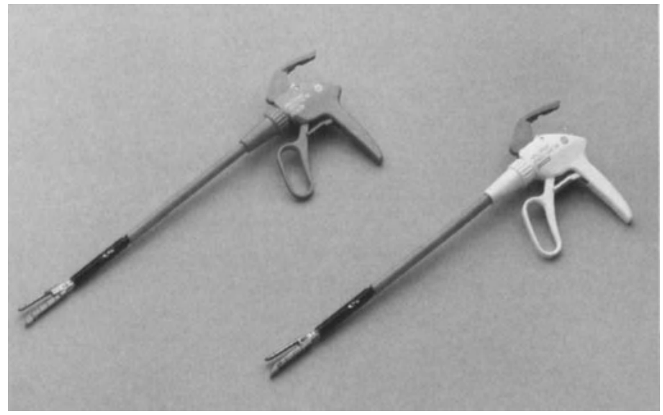
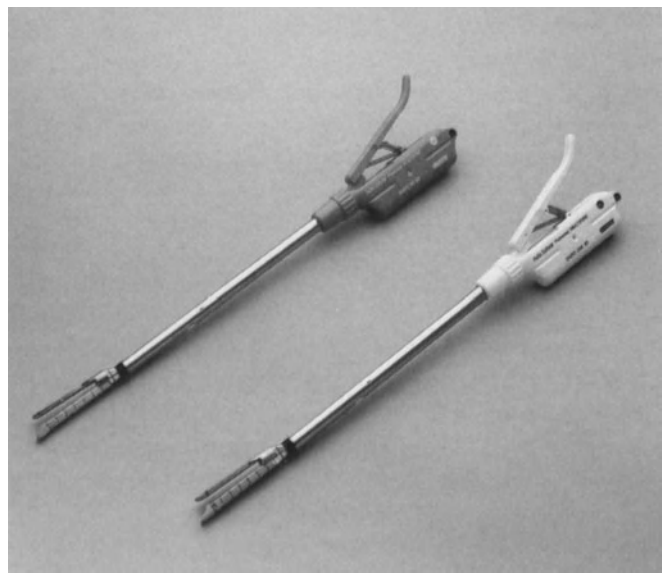


FIGURE 5.1. Endoclip Appliers (US Surgical Corporation Trademark).



FIGURES 5.2 A, B. Multifire Endo TA and GIA 30 instruments (US Surgical Corporation Trademark).



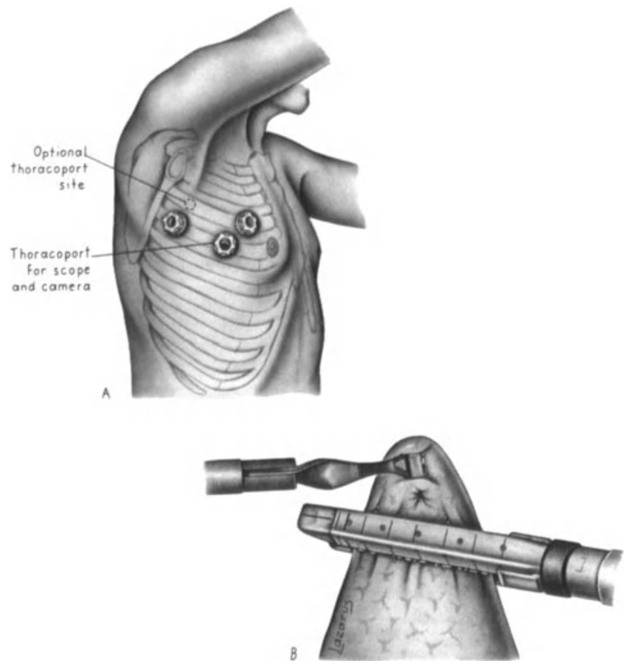
FIGURES 5.3 A, B. Powered Multifire Endo TA 60 and Endo GIA 60 instruments (US Surgical Corporation Trademark).

depending on whether two or three working ports are needed (Figure 5.4A).

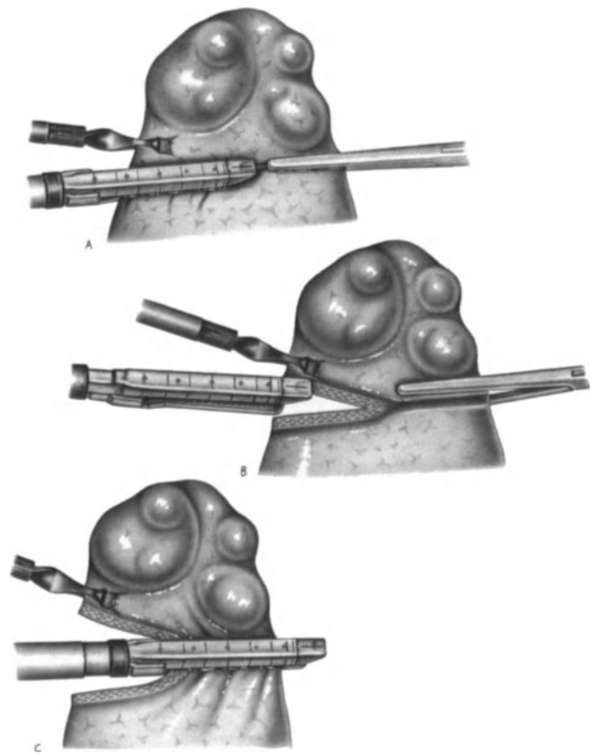
The entry for the telescope is usually placed through the seventh or sixth intercostal space on the midaxillary line. Working ports are placed according to the location of the lesion. Their placement is often decided by probing with a long needle through anterior and posterior intercostal spaces.

Most often an anterior port is placed at the intersection of the fourth or fifth intercostal space and midclavicular line and a posterior port in the fifth or sixth intercostal space, anterior to the lateral border of the scapula. An optional port can be placed one or two spaces above the anterior or posterior sites of entrance as need arises. In operations on the lower half of the hemithorax, the ports may be in lower anterior and posterior sites.

If the ports are so placed in a right-sided thoracoscopy



FIGURES 5.4 A, B. Excisional biopsy of an apical lung lesion.



FIGURES 5.5 A, B, C. Resection of emphysematous bullae and blebs.

and the camera is directed superiorly, the apical structures are seen at the top of the screen, the basal or inferior structures at the bottom, the anterior mediastinal structures on the right, and the posterior paravertebral structures on the left (Figure 5.4B). If the camera is directed downward, the image is inverted, that is, the basal structures are at the top of the screen. If the scope faces in a posterior direction, the paravertebral area is at the top, the apical area is on the right. If the viewing direction is anterior, the mediastinum is at the top of the screen, the apical area is on the left.

In the case illustrated in Figure 5.4 an apical lesion of the right upper lobe is removed peripheral to one application of the Endo GIA 60. The Endo GIA is introduced through the anterior port and the Babcock clamp, which was used to hold and later to extract the specimen, was placed through the posterior port.

Overlapping and Crossing Linear Staple Lines in the Resection of Emphysematous Blebs and Bullae (Figure 5.5)

The disposition of the telescope and working ports is the same as for the apicectomy. A fourth, optional chest-wall port is used in Figure 5.5A for the placement of the specimen-holding Babcock. Since the base of the bleb or bulla is larger than the opening of the Endo GIA, a flat, soft bowel clamp is introduced from an anterior direction to collapse the distended lung tissue. This clamp is withdrawn half closed, and the Endo GIA 60 is moved into the resulting tissue groove from a posterior direction.

Depending on the orientation of the base of the bleb or bulla, it may be necessary to move instruments to different working ports or even to move the telescope and camera.

A soft, flat, atraumatic clamp is also useful in flattening thick lung parenchyma and incomplete fissures prior to Endo GIA application.

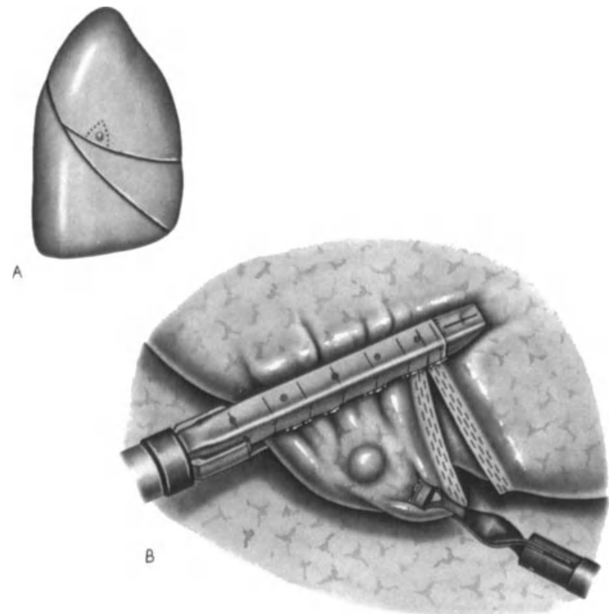
In Figure 5.5B the Endo GIA has been activated, resulting in the separation of the base of the bulla from relatively normal parenchyma and in the creation of an aero- and hemostatic closure of both tissue edges. The compression clamp is removed, leaving a groove for the application of the reloaded instrument. In Figure 5.5C the reloaded instrument is applied a second time to completely separate the diseased from the healthy tissue.

Note: Although only two applications are shown here, it may take many more to remove all the blebs and bullae. Since the chest is closed, and the lung is collapsed, small- and medium-size blebs that have a potential for sudden, massive enlargement when the larger bullae are removed have to be systematically excised as well. During an open thoracotomy the lung is inflated by the anesthesiologist, and blebs enlarging into bullae are detected and dealt with at that time. During a thoracoscopy it is not possible to inflate the lung and inspect it at the same time.

Clinical Experience

A 42-year-old patient had bilateral giant bullae that occupied over half of both hemithoraces, reducing him to a pulmonary cripple. We left two small, benign-appearing blebs in place, after resection of three giant bullae on the left had required 10 Endo GIA 60 applications. Postoperatively the two originally confined blebs expanded into the newly available space faster than the remaining lung. However, it was a simple matter to reoperate through the same thoracoport sites and remove these two new bullae, some four days later.

The right lung was operated on a week later and all giant bullae and blebs were removed with 14 applications of the Endo GIA 60 and Endo GIA 30, depending on maneuvering room within the chest cavity. The patient returned to his employment as a laborer and was able to climb two floors of steps briskly without any shortness of breath.



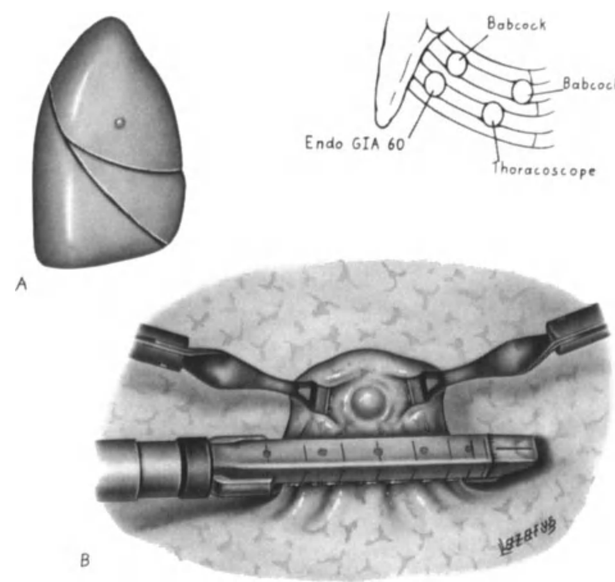
FIGURES 5.6 A, B. Triangular excision for biopsy.

Triangular Wedge-Shaped Excision with Linear Overlapping Staple Lines (Figure 5.6)

The disposition of the telescope and working ports is the same as for the apicectomy. Since the lesion is in mid-hemithorax, it is almost in the line of sight. In the case of peripheral middle- and lower-lobe lesions (with the exception of those in the superior segment of the lower lobe), the telescope and instruments would be directed downwards.

In Figure 5.6A the nodular lesion is situated at the lateral skirt of the right upper lobe. If necessary the parenchyma can be compressed in a pie-shaped wedge, to facilitate the application of the Endo GIA.

In Figure 5.6B the anterior transection and bilateral stapled parenchymal closures have taken place. The triangular excision is completed by advancing the Endo GIA through the posterior chest port and the Babcock through the anterior port; the reverse of what was done for the anterior transection. Care is taken to make sure the staple lines overlap at the angle of the transections. If the GIA blade does not cut clear into the first staple line, it is easy enough to sever a small attachment with scissors.



FIGURES 5.7 A, B. Tangential excision of peripheral lung nodule.

Tangential Excision of a Peripheral Nodule in the Convex Lobar Surface (Figure 5.7)

For this procedure, four thoracic entries are required (Figure 5.7A): two for holding and exposing Babcocks, one for the Endo GIA, and one for the telescope. In this case, preliminary compression of the parenchyma at the base of the nodule, as described in the discussion of blebs and bullae, is especially helpful.

The noninvolved lung tissue at both ends of the nodule is elevated transversely and the Endo GIA 60 is applied from a posterior direction (Figure 5.7B). The remaining stapled lung defect will have a concave, indented shape.

Videoscopically Assisted Lobectomy with Stapled Anatomical Repair of Bronchovascular Structures and Pulmonary Parenchyma (Figure 5.8) (Technique of G. Roviaro)[5]

The lesion is a T_1 NoMo carcinoma in the periphery of the posterior segment of the right lower lobe (Figure 5.8A).

Since the specimen cannot be removed through the thoracoport or average-size chest port, a small submammary utility incision is necessary (Figure 5.8B). It may as well be placed at the beginning of the operation, so that it can also serve as a contingency incision.

In right upper lobectomy where the posterior ascending artery or arteries to the posterior segment are short and it may be difficult to manipulate by purely thoracoscopic techniques, this utility, or contingency, incision may be placed as a short muscle-sparing opening into the midlateral chest wall. The posterior artery is then dealt with under direct vision through the small contingency incision, after the superior division of the pulmonary artery, and the vein from and the bronchus to the right upper lobe have been closed and transected by thoracoscopic techniques.

Placement of the various ports of entry is illustrated in Figures 5.8C and 5.8D. Two ports in the midaxillary line allow greater freedom in placing the telescope. Depending on the size and mobility of the scapula, the posterior ports may be placed anterior or posterior to the tip of the scapula.

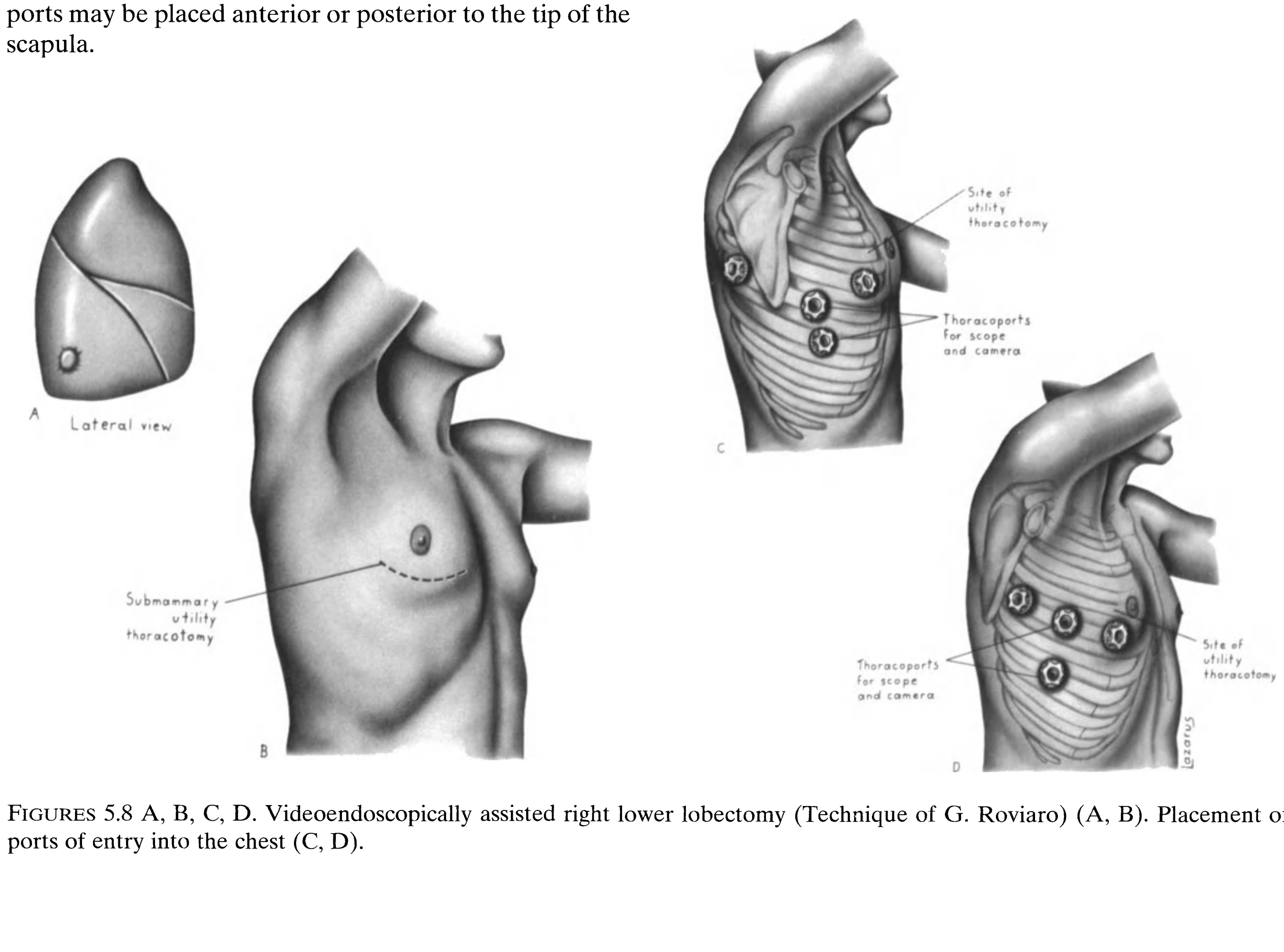
If the fissures are totally obliterated, making mobilization of the various lobes difficult and preventing access to the lower lobe hilus, early transection of the fissures with the Endo GIA 60 towards but not into the hilus is very helpful at the beginning of the operation (Figure 5.8E).

With the thoracoscope directed from below upward and the various instruments introduced and used as shown (Figures 5.8E and 5.8F), the pulmonary artery and its branches to the lower lobe are exposed by incising the hilar pleura and dissecting into the areolar tissue plane directly surrounding the vessels. With the endoscope and resulting view centered along an inferiorly oblique line in the direction of the posterior cul-de-sac, the common stem of the basal arteries is surrounded by a vesseloop and elevated to facilitate placement of the vascular Endo GIA (Figures 5.8G and 5.8H). Activation of this instrument produces simultaneous closures of both arterial stumps and transection between these closures.

The field of view remaining unchanged, the superior segmental artery is occluded and transected between two proximal and one distal clip (Figures 5.8I and 5.8J).

If the artery is large and long, the vascular Endo GIA may be used a second time.

With more of an end-on view and following complete incision and hemostasis of the inferior pulmonary liga-



FIGURES 5.8 A, B, C, D. Videoendoscopically assisted right lower lobectomy (Technique of G. Roviaro) (A, B). Placement of ports of entry into the chest (C, D).

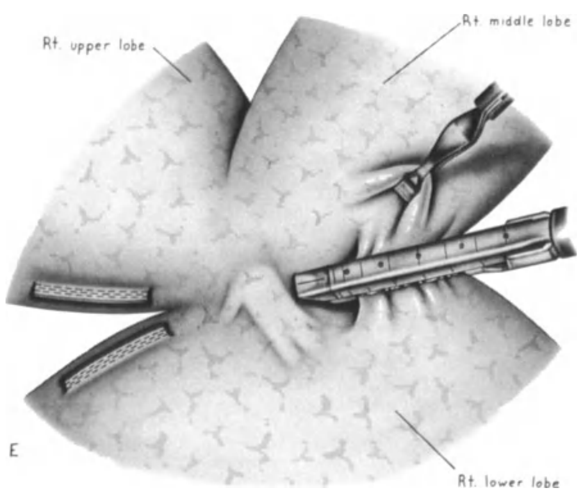
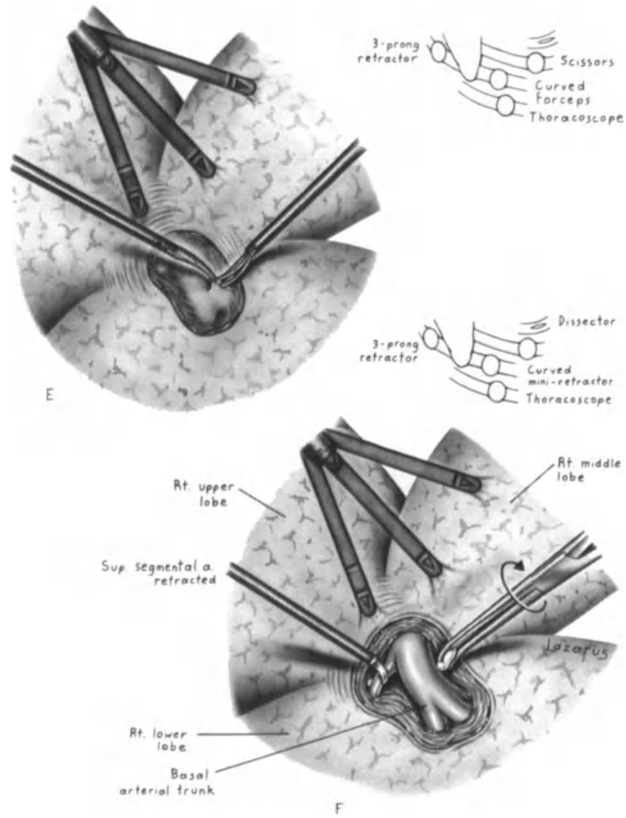
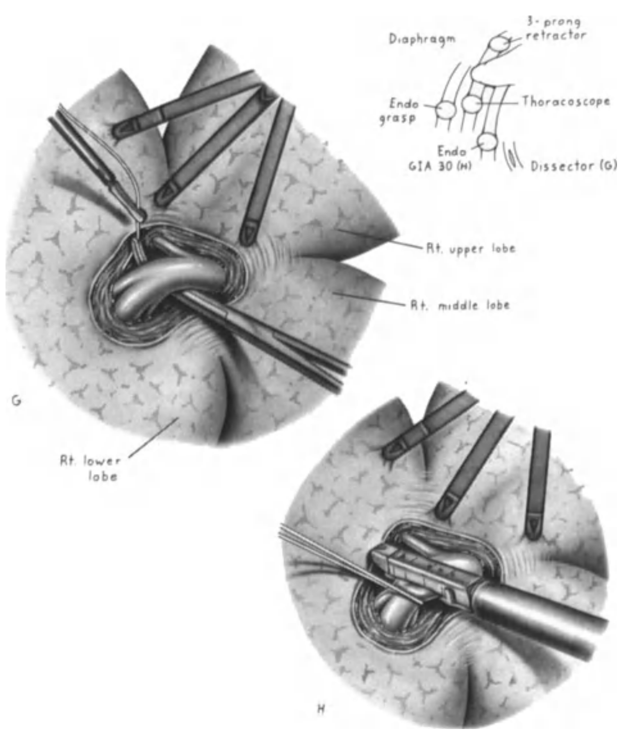
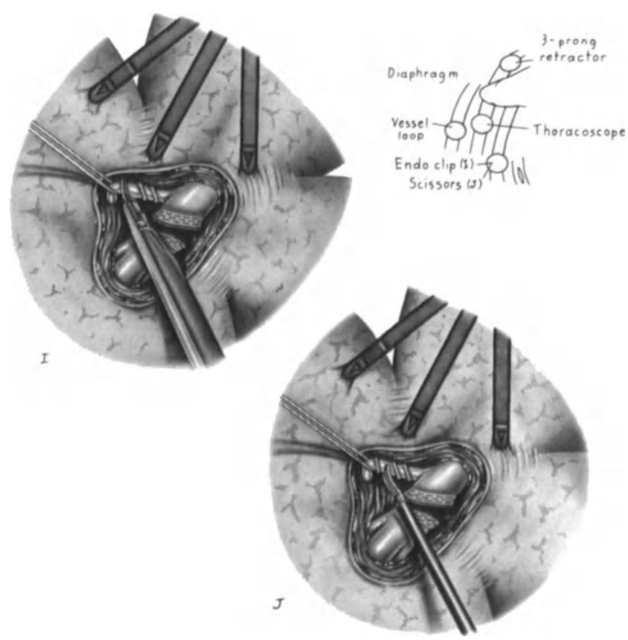


FIGURE 5.8 E. Right lower lobectomy: Early opening of the oblique fissure in preparation for E, F.

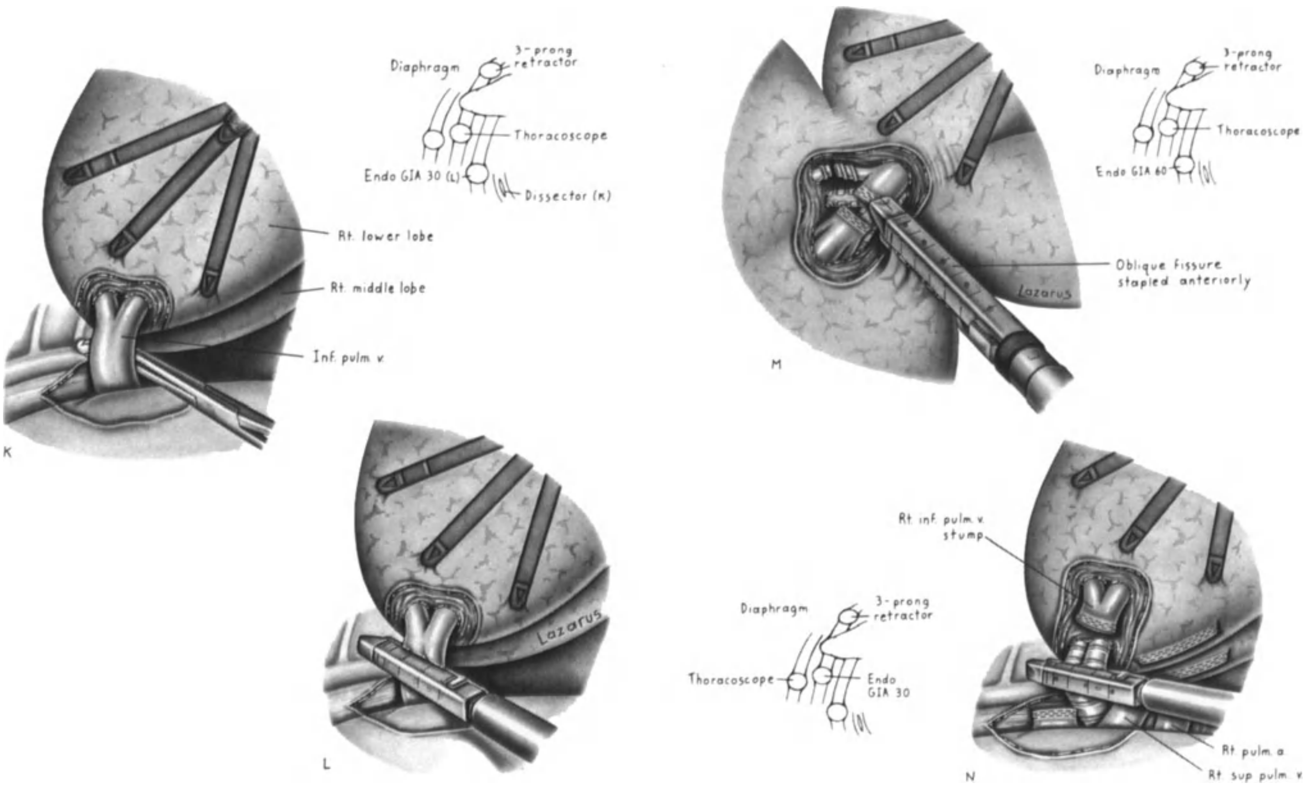


FIGURES 5.8 E, F. Right lower lobectomy: Dissection of the basal and superior segmental arteries.

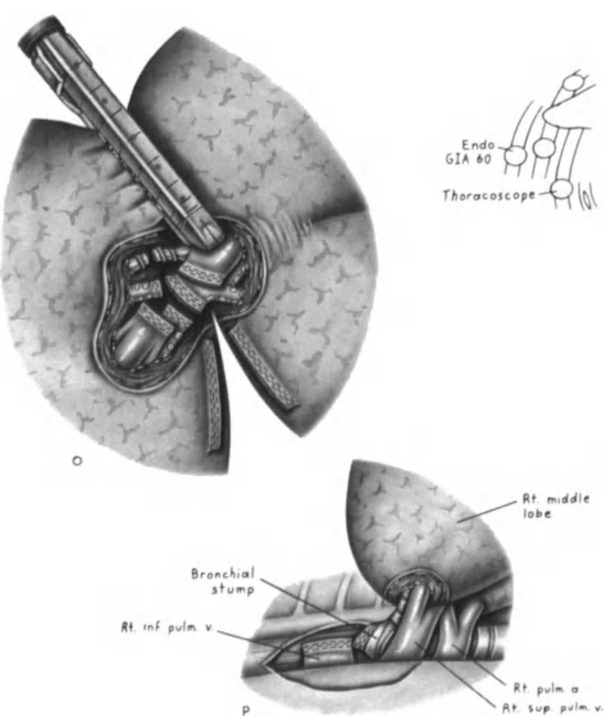




FIGURES 5.8 G, H, I, J. Right lower lobectomy: Control and closure/transection of the basal arteries with the vascular Endo GIA 30 (G, H). Closure of the superior segmental artery with clips and transection (I, J).



FIGURES 5.8 K, L, M, N. Right lower lobectomy: Closure/transection of inferior pulmonary vein (K, L). Complete opening of anterior oblique fissure and closure/transection of lower-lobe bronchus (M, N).



FIGURES 5.8 O, P. Right lower lobectomy: Transection of posterior oblique fissure (late) and removal of specimen.

ment (which can be done earlier in the procedure or now) the lower lobe and the entire lung are elevated superiorly. The inferior pulmonary vein is liberated and transected, and both stumps closed with the vascular Endo GIA (Figures 5.8K and 5.8L).

The same field of view as in Figures 5.8G to 5.8J provides access to the anterior oblique fissure, which may earlier have been partially incised (Figure 5.8E) and is now completely incised, since all vessels are under control (Figure 5.8M).

With the thoracoscope placed in the lower site and with an end-on field of view, the lower lobe is elevated once more and its bronchus is transected and closed distal to the take-off of the right middle-lobe bronchus (Figure 5.8N).

With the thoracoscope placed anteriorly, the Endo GIA is used to transect the posterior oblique fissure (if this had not been done earlier as under Figure 5.8E) and liberate the specimen completely (Figure 5.8O).

In Figure 5.8P the specimen has been removed through the utility incision and the stapled closures of vessels and bronchus provide hemostatic and aerostatic repair of these hilar structures.

Note: The diagrams illustrating this lobectomy were inspired by a videotape graciously lent by Professor Roviaro and Dr. Rebuffat of Milan, Italy.

Left lower lobectomy can be performed by using the mirror image of the technique shown here for right lower lobectomy. Right middle lobectomy is probably the easiest to perform thoracoscopically, if the fissures are complete or can be opened.

We have previously discussed some of the difficulties presented by the dissection of the posterior ascending artery during a right upper lobectomy. Similarly, the bunching and shortness of the anterior and apical-posterior segmental arteries to the left upper lobe would make a thoracoscopic left upper lobectomy very hazardous in my view, although not impossible, particularly as technology becomes more sophisticated.

By definition, pneumonectomy requires a very central dissection and closure of the bronchus and vessels to ensure a radical excision of the primary tumor and surrounding hilar lymph-node metastases included in the "en bloc" resection. Through sheer bulk, these masses present an obstacle to current Endo-stapling instruments. Furthermore, on the left side it would be difficult and perhaps dangerous to have a linear stapler penetrate sufficiently into the aortopulmonary window to safely close the left main pulmonary artery and the left main bronchus without leaving a long stump.

Stapling in Laparoscopically Guided and Assisted Abdominal Operations

Even in open operations surgical stapling has always represented a gentler, less traumatic invasion of tissue. The bowel end is open for a shorter time and the potential for peritoneal soiling is diminished. Discrepancies in intestinal caliber are easily handled either by linear, functional end-to-end anastomosis or (in rectosigmoid or rectocolic anastomoses) by circular triple-stapled anastomosis. The safety record of staples is equal to and often better than that of manual sutures.

Instruments

The Premium CEEA instrument features a curved shaft (Figure 5.9). The regular or low-profile anvil and inner portion of the center rod can be detached to expose a trocar that allows the instrument to be independently inserted into a lumen. A hole at the tip of the anvil's center rod accepts an anchoring suture or thread useful in triple-stapling procedures and in the laparoscopic retrieval of the anvil. A conical trocar accessory can be placed into the hollow center rod of the instrument and then totally retracted into the instrument to protect the tissue as the instrument is advanced. Following intraluminal insertion of the instrument, the trocar is advanced to perforate the wall of a given hollow organ or penetrate through a stapled closure. The instrument is available with titanium staples in 31-, 28-, 25-, and 21-mm cartridges.

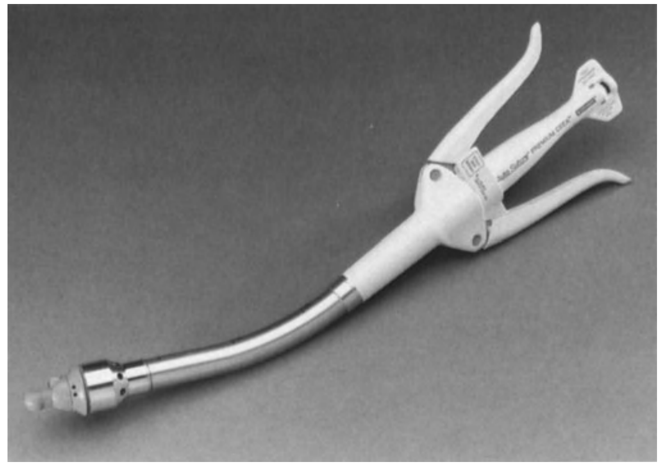


FIGURE 5.9. Premium CEEA instrument (US Surgical Corporation Trademark).

Other "laparoscopy-friendly" instruments for bowel closure and anastomosis will be developed in the near future; conceivably modern versions of Murphy's button for compression anastomosis.

The button may be made of biodegradable material or be fragmented after its task has been accomplished so that it can be eliminated through the intestines.

High-grade biological glues will become available to reinforce circular compression and stapled anastomoses. They may ultimately replace staples or sutures because they could potentially offer total tissue compatibility, absence of microbial and viral contamination, and optimal adhesiveness. Although laser welding of wounds and other techniques of tissue mobilization and bridging are only in the experimental stages, they will probably ultimately be used in conjunction with biological glues.

Techniques and Procedures

In operations on the small and large bowel the following stapling techniques permit total or near total integrity of the laparoscopic approach:

- Lateral, tangential excision and linear bowel closure, as in appendectomy, or Meckel's diverticulectomy;
- Bowel resection and linear functional end-to-end anastomosis, as in right colectomy (also small-bowel transverse and descending-colon resections);
- Resection and circular end-to-end triple-stapled anastomosis through a natural orifice (anus), as in rectosigmoidectomy;
- Resection and circular side-to-end double-stapled anastomosis through a contingency anterior perineotomy, as in low anterior rectal resection.

In general we place the laparoscope and camera through the umbilicus, so that the entire abdominal cavity can be visualized. Usually at least one half and, at times, all of the cavity must be visible for the various manipulations and the dissection. The working ports for handling, liberating, isolating, and reconstructing bowel should be spaced sufficiently apart to permit freedom of movement without intra-abdominal duels and yet close enough to permit convergence of instruments in a given area.

These conditions seem to be satisfied by ports in the right lower quadrant and suprapubic area for appendectomy and in all four quadrants for colectomy, with an optional fifth suprapubic position for sigmoid and rectal resections. Based on visual inspection of the cavity (and possibly intraoperative colonoscopy and delineation of a lesion by transmural illumination, an additional method it is sometimes wise to resort to) the members of the team may decide to concentrate several ports near a given area, to switch viewing and working ports, to have reducing diaphragms available, or to use an angled scope. Good flexible scopes would be of great help.

Additional ports may be necessary, but the total length of port-site incisions should not exceed the length of a reasonably effective traditional incision. The preference of the surgeon, based on previous experience and knowledge of his own operative habits, should also be taken into consideration.

Instruments for bowel retraction and exposure have longer work limbs than those used for cholecystectomy, and more space is required for the various maneuvers necessary to isolate and interrupt the vascular supply when a specimen is taken. For these reasons the instruments used to hold and handle the bowel are best placed through ports in the abdominal wall opposite the target colon segment, that is, on the left side for a right colectomy, on the right side for descending colectomy and sigmoidectomy, and in the lower quadrants for transverse colectomy.

This means the surgeon and the ports that accept the instruments for the dissection and vascular isolation of the specimen as well as for the reconstruction of the bowel will be on the side of the colon segment to be removed. In case of a transverse colectomy the best side depends on whether the surgeon is right- or left-handed. But it is important to realize that these recommendations are not graven in stone and that, as in all other surgical endeavors, there is room for creativity.

It is important that the monitoring equipment be so arranged that what the surgical team sees is the exact image of what their hands are doing and that the endoscopic field of vision follow the course and flow of the dissection. The monitors should therefore be placed in accordance with the projected direction of dissection and area of reconstruction. They should also be at eye level, at a diagonal from the respective viewer. In a right colectomy, the monitor for the surgeon should be placed at the patient's left shoulder and the one for his assistant should be placed at his right shoulder. In a left colectomy or rectosigmoidectomy the surgeon's monitor should be placed at the patient's right thigh and the assistant's at the patient's left thigh.

As for all laparoscopic procedures the patient is prepared for both laparoscopy and laparotomy, told intraoperative conversion is possible, and asked to give informed consent to both procedures. Perioperatively he or she is given three doses of a broad-spectrum antibiotic.

Lateral, Tangential Excision and Linear Bowel Closure (Figure 5.10)

Following the establishment of a satisfactory pneumoperitoneum a 10-mm port is placed at the umbilicus for the laparoscope, a 5-mm working port is placed in the suprapubic area, and a 12-mm port for an Endo GIA is placed in the right upper quadrant (Figure 5.10A).

Meckel's Diverticulectomy

Since most Meckel's diverticula will be discovered during laparoscopy for suspected appendicitis, preparation of the patient and placement of abdominal ports will usually be the same as for appendicitis (Figure 5.10A).

The diverticulum is rotated to expose its posterior wall from the mesentery to the tip of the diverticulum (Figure 5.10B). A window is created between the vessels and the base of the diverticulum to accommodate the vascular Endo GIA. The vessels and the mesentery surrounding them are hemostatically stapled on each side and simul-

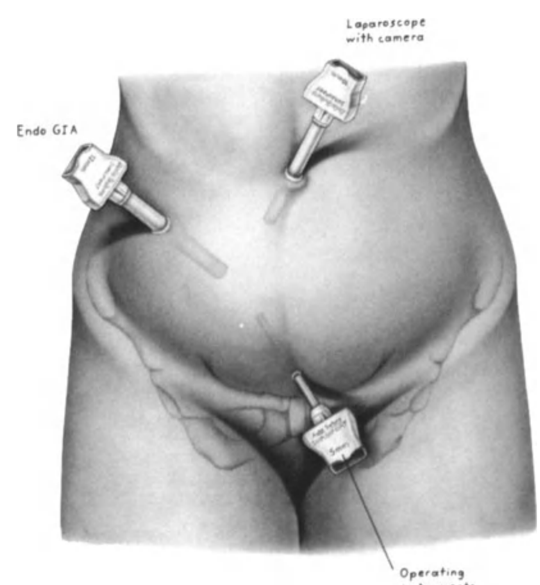
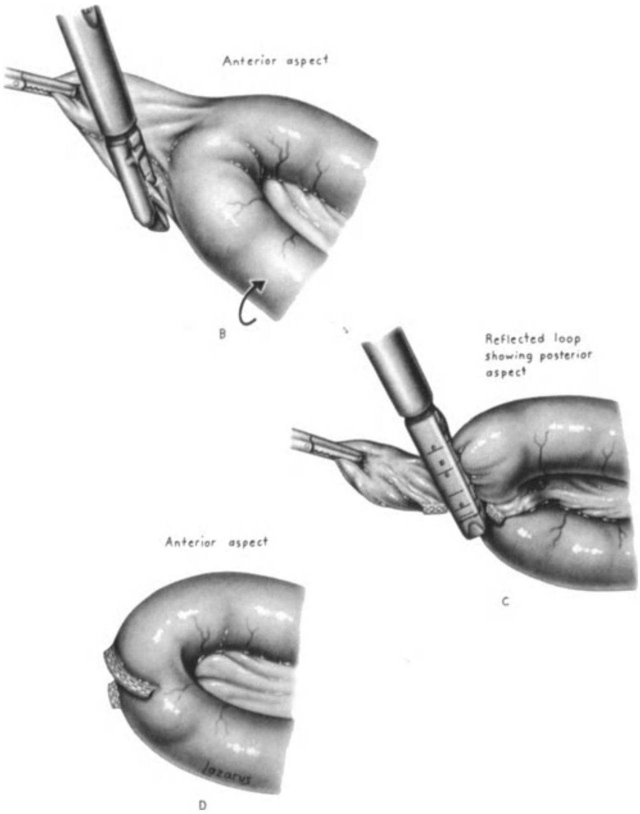
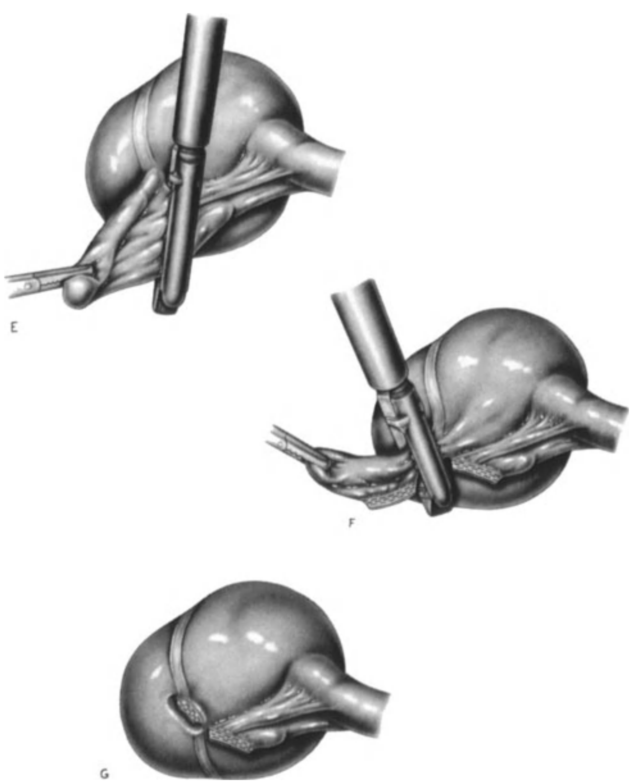


FIGURE 5.10 A. Placement of abdominal ports for Meckel's diverticulectomy and appendectomy.



FIGURES 5.10 B, C, D. Meckel's diverticulectomy.



FIGURES 5.10 E, F, G. Appendectomy.

taneously transected. Often the vascular arcade to the diverticulum is narrow and can be transected between two proximal and one distal clip.

The diverticulum is turned so that the posterior aspect of its base is visible. The visceral Endo GIA is then placed through the 12-mm right-lower-quadrant port and applied to the base of the diverticulum at a right angle to the long axis of the ileum to avoid obstructing or narrowing the lumen. Usually two or three such maneuvers are necessary in the case of a wide-mouthed diverticulum. Use of the Endo GIA 60 may reduce the number of applications. Care should be taken to avoid clamping the vascular staples or clips with the Endo GIA (Figure 5.10C). Following complete closure of the base and site of implantation of the diverticulum, the specimen is removed through a 12- or 15-mm trocar (Figure 5.10D).

Appendectomy

Placement of viewing and working ports should be as shown in Figure 5.10A. Following liberation and exposure of the appendix, held tight with a Babcock clamp, a window is created between the appendix and mesoappendix (Figure 5.10E). The vascular Endo GIA is placed and activated to transect and close the appendiceal vessels.

The base of the appendix is then introduced into the visceral Endo GIA. The instrument slightly encroaches on the cecal wall (Figure 5.10F).

Activation of the Endo GIA transects the appendiceal insertion on the cecum and closes both bowel ends (Figure 5.10G).

The appendix is then evacuated through the 12-mm trocar or, if it is thick and inflamed, with the help of a specimen bag placed through the umbilical port that can be enlarged to retrieve it. The camera is switched to the right lower quadrant. Closure of large port sites follows. Postoperative care is similar to that for standard appendectomy, although the patient is allowed oral fluids and food sooner and is often discharged within 24 hours.

Bowel Resection and Linear, Functional End-to-End Anastomosis, Such as in Right Colectomy

The old-fashioned linear anatomical side-to-side and functional end-to-end bowel anastomosis lends itself to laparoscopic technique. They can be used for reconstruction when the circular end-to-end anastomosing instrument cannot reach the bowel segments from a natural orifice such as the anus, an open vaginal cuff after combined hysterectomy/sigmoidectomy or a manmade anterior contingency perineotomy. By definition the functional end-to-end anastomosis is therefore potentially useful for all bowel resections from the first jejunal loop to the proximal sigmoid colon.

After satisfactory creation of the pneumoperitoneum, five ports are placed: one in the umbilicus for the laparoscope and camera; two on the left side for the holding, handling, and exposing instruments; and two on the right side for the dissecting, isolating, and reconstructing instruments (Figure 5.11A). Additional ports may be needed if special intraoperative conditions develop: a port above the pubis and a 12-mm (for the Endo GIA 30) or 15-mm (for the Endo GIA 60) port in the right upper abdomen, closer to the projected functional end-to-end anastomosis than the original 12-mm port.

Babcock clamps or blunt graspers are used to hold and pull the cecum and ascending colon to the left (Figure 5.11B). The liberation of the specimen is begun by incising the lateral peritoneal reflection through both right-sided ports—from below up and from above down. During this dissection, the right ureter should be clearly identified and carefully preserved. The hepatocolic ligament at the right colon flexure can be transected between two triple staple lines with the vascular Endo GIA. Following complete liberation and elevation of the right colon and corresponding mesocolon, windows are created near the bowel walls at the levels selected for resection (Figure 5.11C). The colon is temporarily replaced in its bed, and the terminal ileum is transected (1) with the Endo GIA 30 introduced through the right upper port. The proximal transverse colon is then transected with several GIA 30 (2) or one GIA 60 application. The instrument is advanced through the right lower port. For each one of these maneuvers the bowel is held and identified with instruments placed from the left, so as to avoid transecting other structures.

The isolation of the specimen is then continued by transecting the mesocolon and the vessels serving the right colon between two proximal and one distal clip, placed with the clip applier advanced through either right-sided port (Figure 5.11D).

Alternatively vascular control and mesocolic transection can be obtained by several applications of the vascular GIA instrument (Figure 5.11E). Following complete liberation of the specimen, it is bagged and temporarily parked in the empty right lower quadrant.

Next the two bowel ends are placed parallel to each other in the right upper quadrant and held in position with Babcocks introduced from the left side. The stapled antimesenteric corners of the bowel ends are excised with instruments advanced from the right side: scissors from above and a holder from below for the colon; the reverse for the ileum (Figure 5.11F).

Carefully holding both bowel ends in position with Babcocks from the left side, the anvil arm of the GIA 30 is introduced into the large bowel through its excised corner (Figure 5.11G). At this point it is often necessary to close the instrument *without firing it,* in order to hold onto the colon, while the ileal end is prepared for placement around the anvil arm of the GIA. While the GIA is held steady and the colon is held in position with the upper left Babcock, the ileal end is grasped at the staple line with a right lower holder and, at a point some 6 to 7 cm upstream, with a left lower Babcock. With both a pulling and pushing motion, the small bowel is brought around the anvil, which is now in the open position. The antimesenteric position of the GIA in both bowel ends is checked, and then the instrument is closed and fired.

If the Endo GIA 30 has been used, a second application is necessary in order to obtain a satisfactory anastomotic cross section. For this purpose the crotch of the reloaded instrument is advanced into the angle of the first linear anastomosis (Figure 5.11H). Care is taken to continue in the same antimesenteric axis as before, by holding the bowel walls together at the tip of the anastomotic prolongation with a left lower Babcock. If the GIA 60 is used, then a second application is not necessary.

Following the side-to-side anastomosis, the now-common bowel opening is closed with the Endo TA instrument and the excess tissue is excised using the stapler as a guide (Figure 5.11I). The specimen, protected by the bag, is then removed through a McBurney incision.

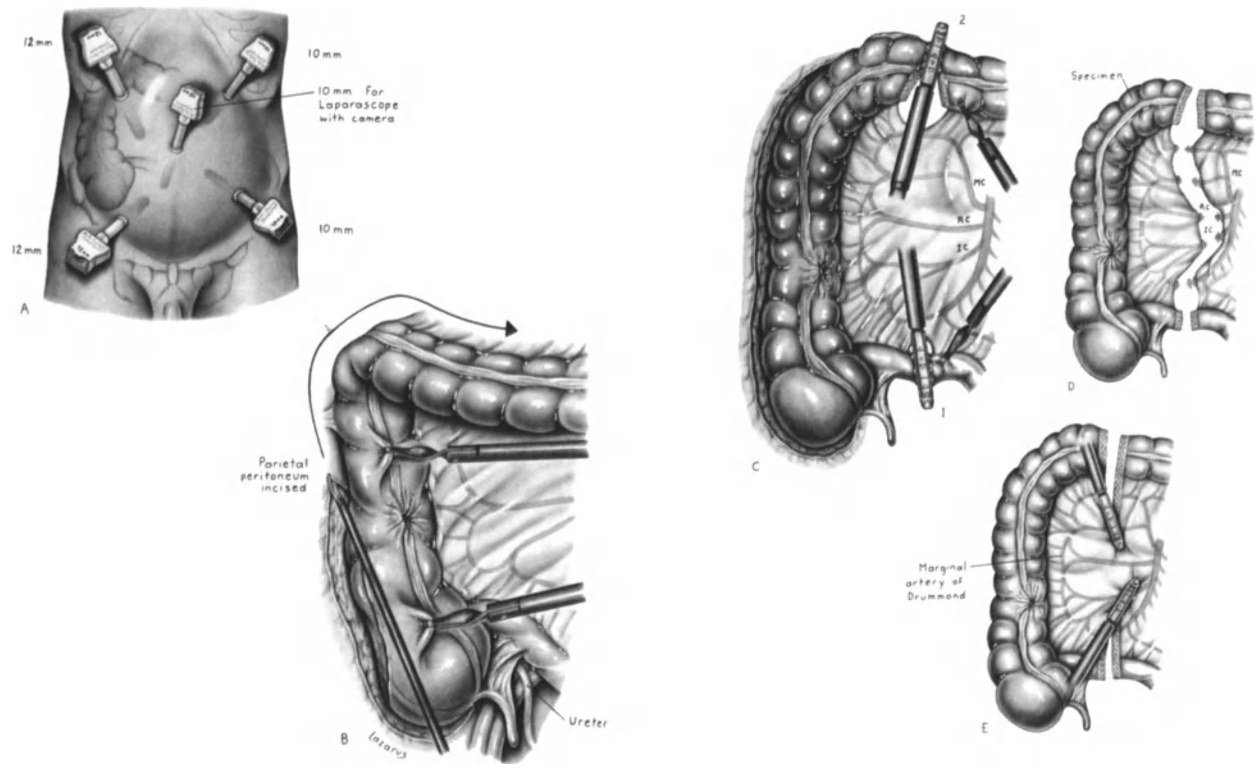
Note: This functional end-to-end anastomosis can also be performed through a small, transverse right-flank utility incision. The videoendoscopically assisted version, illustrated in Figures 5.11G–M is a functional end-to-end anastomosis in which the anastomosis is done first and the resection second.[8]

After the specimen is liberated, mostly by endoscopically guided dissection, it is delivered through the transverse-flank incision and small remaining attachments are severed. While the specimen is attached, it is used for traction, and side-to-side ileo-transverse colostomy is performed (Figure 5.11J), followed by closure of both bowel lumina central to the GIA introduction sites (Figures 5.11K, L). The specimen is excised last, peripheral to the double bowel closure (Figure 5.11M) and includes the GIA introduction sites.

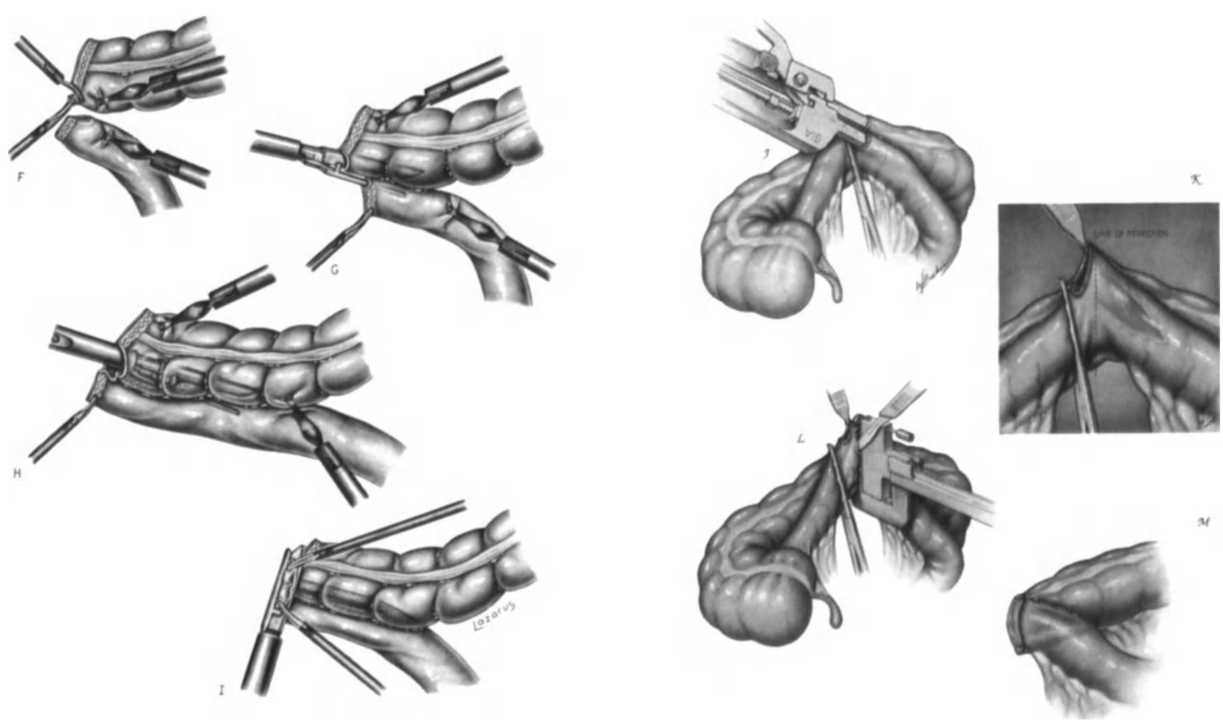
Regardless of the technique used, the final result is always checked by videoendoscopic inspection after closure of the utility incision.

Resection and Circular End-to-End Triple-Stapled Anastomosis Through a Natural Orifice (Technique developed by and from J.S. Azagra)[1]

With the surgeon positioned initially on the patient's left side, the assistant on the right side, and the monitors at the level of the thighs, diagonally across from the surgeon and assistant, five ports are placed as in Figure 5.9A. In addition a sixth, suprapubic port may be necessary to work on the rectum in an anteroposterior direction. However, the lateral ports are used differently in this procedure than they are in the procedure illustrated in Figure 5.9. The two left lateral ports help mostly with the dis-



FIGURES 5.11 A, B, C, D, E. Right colectomy: Abdominal ports and liberation of right colon (A, B). Proximal and distal bowel transection and control of vascular supply (C, D, E).



FIGURES 5.11 F, G, H, I, J, K, L, M. Right colectomy: Functional end-to-end ileocolostomy (F, G, H, I). Functional end-to-end anastomosis in videoendoscopically assisted right colectomy through a right, transverse flank utility incision (J, K, L, M). (By permission of Ravitch MM, Steichen FM: Staplers in GI surgery. In Schwartz and Ellis (eds.) *Maingot's Abdominal Operations*, 8th ed. Norwalk, CT: Appleton & Lange, 1989.)

section and liberation of the specimen, and the right lateral ports are used to introduce holding and handling instruments but also to place the Endo GIA 60 and PTA 60.

Since, for the midline and retrorectal dissection, the surgeon may have to work from the patient's right side, the ports are not dedicated to a single purpose for the entire operation.

With the holding instruments brought in from the right side, the descending and sigmoid colon are elevated and the white line of Toldt is incised through the left-sided ports, from above down and from below up (Figure 5.12B). The vascular supply is interrupted between proximal and distal clips or with the vascular GIA (as shown in Figure 5.11E) at the origin of the sigmoid vessels, and for the marginal artery of Drummond, at the level of proximal bowel transection. The left ureter is identified and preserved.

Following elevation and isolation of the specimen (Figure 5.12C), the bowel is closed proximally (1) and distally (2) with the Endo PTA 60, at a safe distance from the sigmoid tumor. For this maneuver, the holding instruments are placed through the left ports and the PTA 60 instruments through the right ports.

A longitudinal colotomy (Figure 5.12D) is performed proximal to the cephalad colon closure (1) and a transverse rectotomy distal to the caudad rectal closure (2).

The CEEA anvil with a flat head and attached rod is then advanced through the anus and rectotomy into the peritoneal cavity (Figure 5.12E), from which it is transported to the proximal colotomy (2) and inserted into the lumen of the descending colon (intraperitoneal portage).

Following this maneuver, the rectum is closed and transected with the Endo GIA 60 caudad to the distal rectotomy [Figure 5.12F (1)]. The head of the anvil is prevented from proximal drifting by a half-closed Babcock that grasps three-quarters of the large-bowel circumference. The descending colon is closed and transected cephalad to the proximal colotomy (2) with the Endo GIA 60 instrument.

The completely liberated specimen is then bagged and parked into the left lower quadrant (not shown in these drawings).

An alternative for a benign, average-size lesion is to remove it through the anorectal canal. In this case all the steps at the cephalad level remain the same, but the distal anterior rectotomy is completed. In other words, a circumferential transection of the rectum is done (Figure 5.12G).

Just as in the previous steps, holding and transecting instruments are advanced as best suits the task at hand.

The specimen is pulled onto the perineum with a Babcock clamp advanced through the anorectal canal (Figure 5.12H). The rectum is held and pulled cephalad, to prevent invagination and prolapse of the cuff.

The rectal cuff is now closed with the GIA 60 and the excess separated tissue is removed through the left lower port (Figure 5.12I).

Steps to reconstruct bowel continuity are now initiated. The anvil head is maintained in position with a half-closed Babcock, and the center of the proximal-colon staple line is incised by the sharp tip of the anvil shaft (Figure 5.12J).

An empty open PTA 60 is then applied around the colon, proximal to the CEEA anvil, for use as a backstop (Figure 5.12K). Two Babcock clamps, advanced from the lower ports, are used to telescope the colon against the PTA 60 and to slip the anvil shaft through the opening in the staple line.

The anvil shaft is grasped beyond the staple line and pulled through until it is positioned firmly against the staple line inside the proximal colon (Figure 5.12L).

The cartridge of the CEEA is placed through the anus and the trocar, followed by the hollow central rod, is advanced through the rectal staple line. The trocar is evacuated through the right lower quadrant port. Alternatively, as shown here, the trocar is not used, and the hollow central rod is advanced within the rectum until it abuts the linear staple line. The center of this line is then incised over the projecting rod.

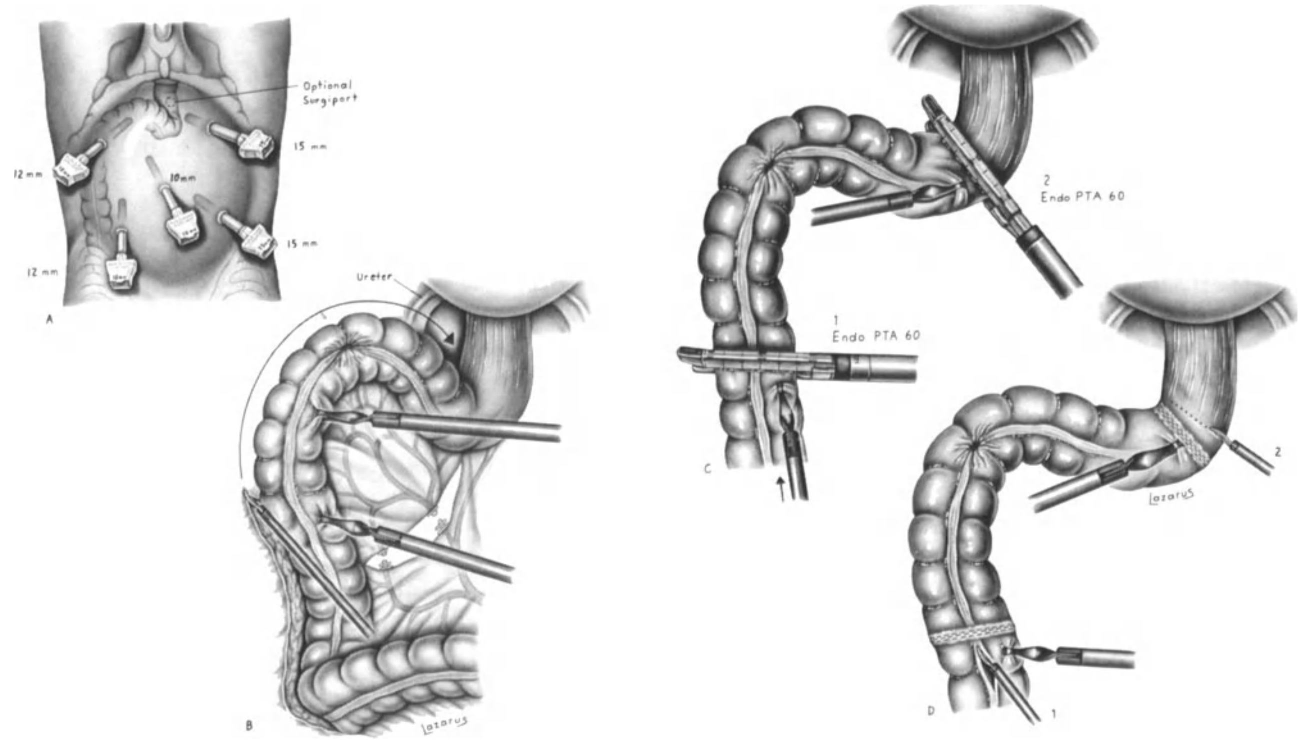
The anvil shaft and central rod are joined and anchored to each other (Figure 5.12M). The CEEA instrument is then closed, joining colon and rectum in an X-shaped configuration.

Following completion of this triple-stapled anastomosis, the specimen is evacuated through a left McBurney incision (Figure 5.12N) unless it had been removed transanally as in Figure 5.12H. The competence of the anastomosis is checked. If a leak is discovered, repair is done by conversion to an open operation.

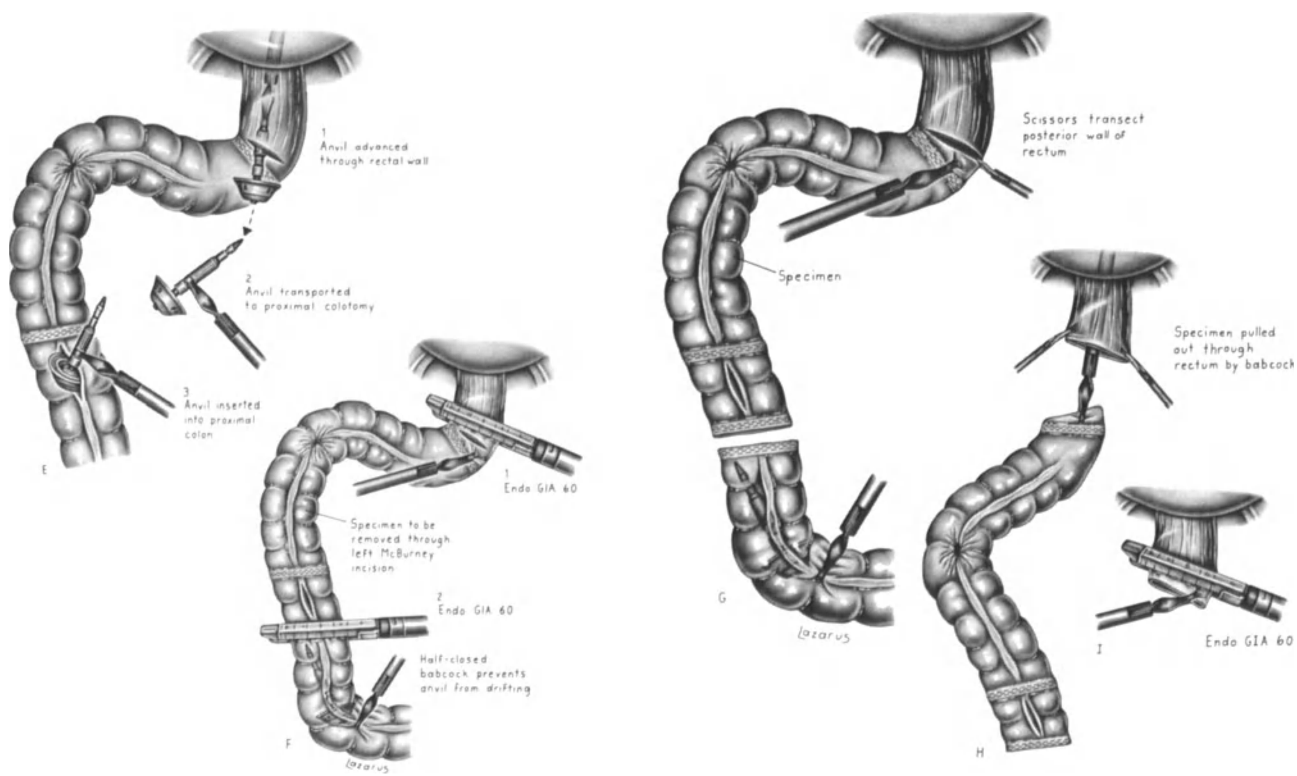
A videoendoscopically assisted version of this procedure is illustrated in Figures 5.12O–Q. Following videoendoscopically guided dissection of the sigmoid colon and proximal rectum, the left McBurney utility incision that is used for specimen evacuation can be used for the bowel reconstruction. In this case, the anvil is advanced into the open, exteriorized descending colon, the bowel is closed, and the anvil shaft is advanced through the staple closure.

The CEEA cartridge is then placed into the rectal stump, the central rod is advanced through the rectal closure, and anvil shaft and central rod are fastened to each other (Figures 5.12R, S). The instrument is closed and circular anastomosis through two linear staple lines (a triple-stapled anastomosis) is performed (Figure 5.12T).

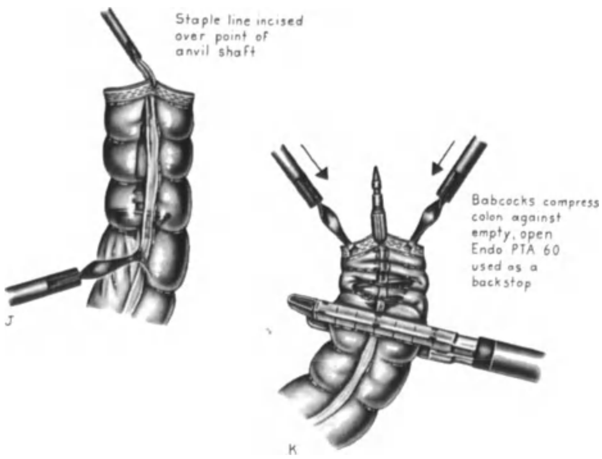
This step may be performed after closure of the utility incision and resumption of pneumoperitoneum and of videoendoscopic guidance. Or it may be accomplished by elevating the lower abdominal wall with a laparolift (Origin Corp. Trademark) placed through the utility incision



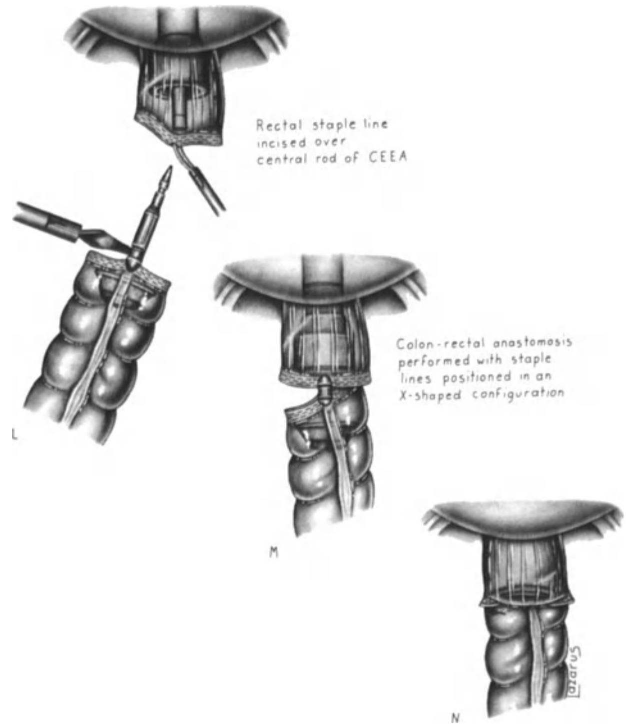
FIGURES 5.12 A, B, C, D. Rectosigmoid resection: Placement of ports and dissection (A, B). Preparation for tumor isolation, introduction, and transportation of anvil (C, D).



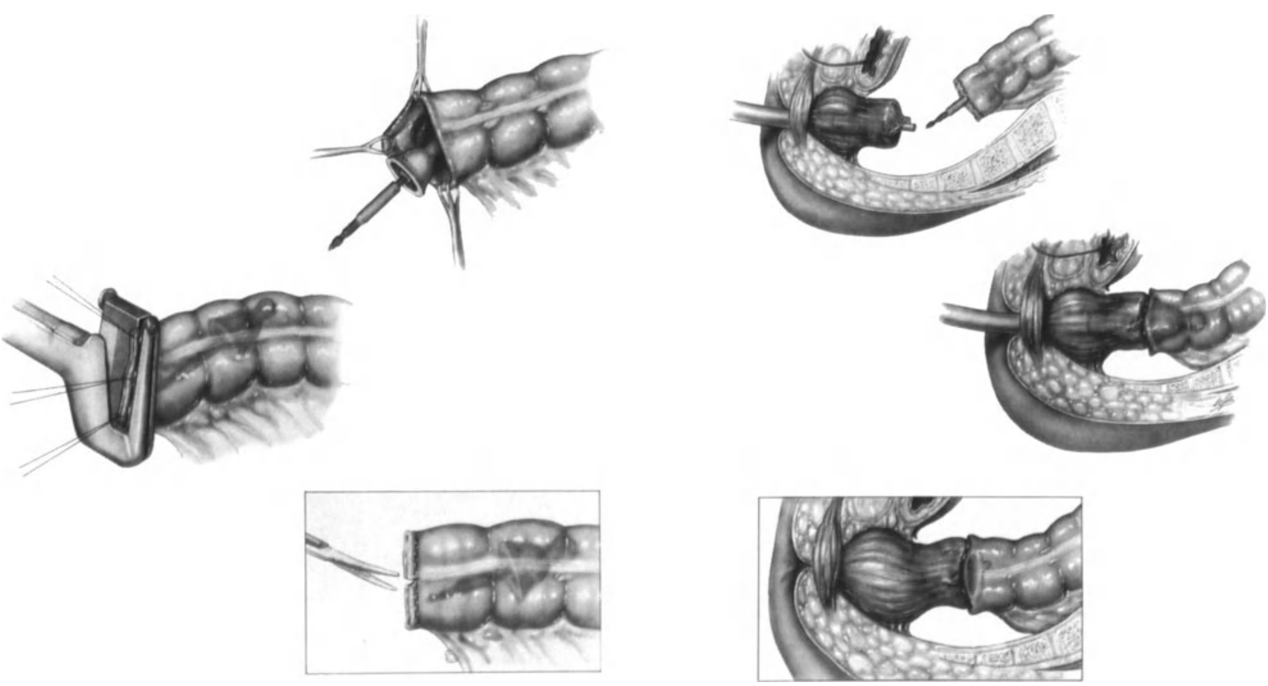
FIGURES 5.12 E, F, G, H, I. Rectosigmoid resection: Intraperitoneal portage and proximal placement of CEEA anvil (E, F). Removal of the specimen through the anorectal canal (alternative approach) (G, H, I).



FIGURES 5.12 J, K. Rectosigmoid resection: Preparation of proximal bowel end and advancement of anvil shaft through linear staple line.



FIGURES 5.12 L, M, N. Rectosigmoid resection: Placement of CEEA cartridge into rectum, advancement of hollow central rod, anchoring of anvil shaft into cartridge rod, instrument closure, and anastomosis.



FIGURES 5.12 O, P, Q, R, S, T. Rectosigmoid resection: Open triple-staple anastomosis. Proximal placement of CEEA anvil through a left utility incision (O, P, Q). Cartridge of CEEA placed through anus and completion of triple-staple anastomosis under laparoscopic assistance (R, S, T).

and visual guidance from the laparoscope left in the umbilical port. Regardless of the technique used, the final result is always surveyed by resuming complete pneumoperitoneum and videoendoscopic inspection and manipulation of the bowel. Persistent bleeding and anastomotic incompetence are causes for conversion to open operation and corrective measures.

Resection and Circular Side-to-End Double-Stapled Anastomosis through a Contingency or Utility Anterior Perineotomy (Technique of Welter-Leahy)[3,9]

The general arrangement of the abdominal ports and the positioning of the operative team and equipment are comparable to those shown in Figure 5.10A (Figure 5.13A). The white line of Toldt is incised along the sigmoid colon (Figure 5.13B).

The peritoneal reflection to the left of the rectum and between bladder or uterus and rectum is incised from the left. The inferior mesenteric artery is divided between two proximal and one distal clip, or preferably, between vascular GIA staple lines as in Figure 5.11E. The left ureter is identified and preserved.

Dissection along the right side of the pelvis would be done from the right side of the patient with holding instruments brought in from the left—a mirror image of the left-sided dissection. The right ureter is identified and preserved.

The mesorectum is identified by blunt dissection into the pelvis. It is transected and doubly stapled with an Endo GIA placed along the hollow of the sacrum.

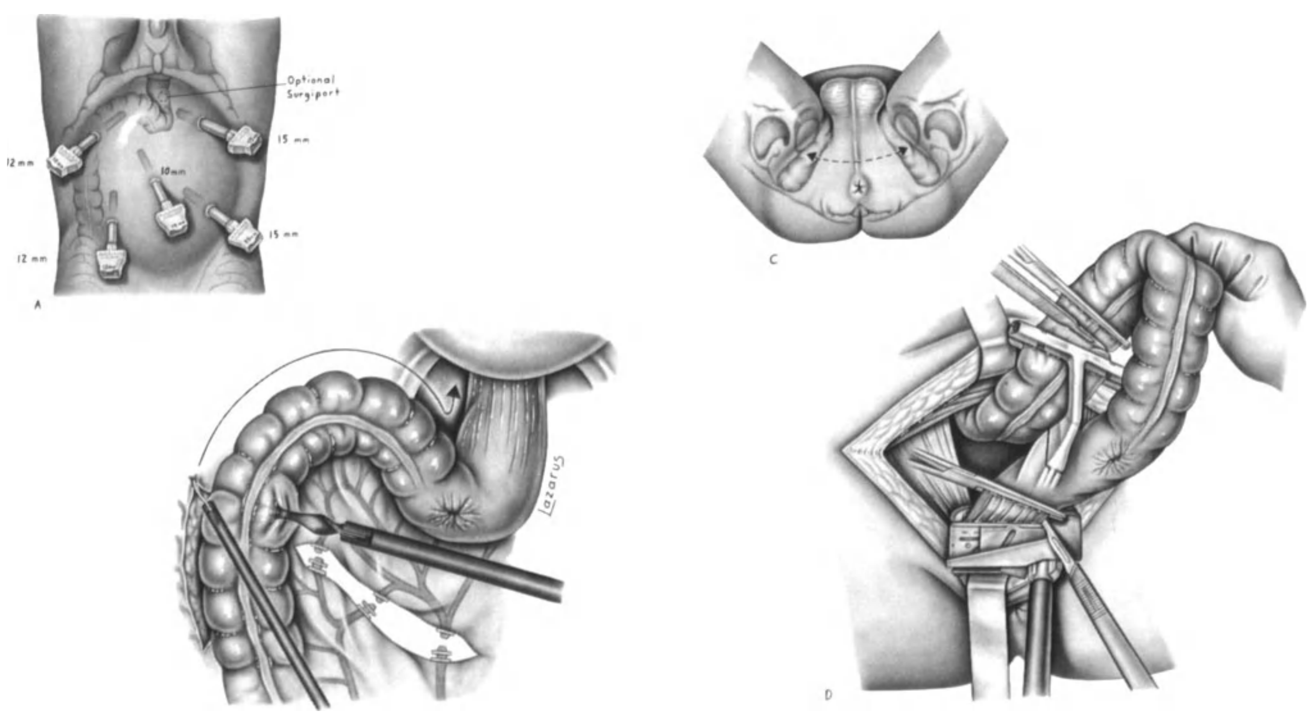
Following satisfactory liberation of the rectosigmoid from above, the surgeon follows the technique of Welter, originally described for anterior perineal coloanal anastomosis (Figure 5.13C) and adapted by Leahy for laparoscopy. The anterior perineal incision serves to complete the dissection from below, to remove the specimen, and to accomplish side-to-end anastomosis. It is the equivalent of an abdominal incision for extracorporeal anastomosis but is associated with lower morbidity.

The patient, previously prepared for the lithotomy position, is now placed into Trendelenburg position, and the legs and thighs are flexed onto the pelvis and hyperabducted. A transverse incision is performed between the genitourinary tract and anus through subcutaneous tissue and the central raphe to the rectum.

The rectum is dissected circumferentially and proximally into the abdomen, if any attachments persisted from the laparoscopic stage of the operation.

The specimen is then pulled through the anterior perineotomy (Figure 5.13D). If the tumor extends lower than was previously appreciated, abdominoperineal resection without oncologic compromise is possible at this stage.

If resection and anastomosis are possible, the specimen is resected between a cephalad purse-string instrument



FIGURES 5.13 A, B, C, D. Anterior rectal resection: Placement of abdominal ports and rectosigmoid dissection (A, B). Anterior rectal resection with anterior transperineal anastomosis: Preparation of the anterior perineal approach (C, D).

and a caudad closure of the anorectal canal just above the sphincter muscles, using the TA 55 roticulator (Figure 5.13D).

The flat CEEA anvil with shaft is inserted into the opening of the proximal colon and the pointed shaft is brought out through the antimesocolic wall some 10 to 15 cm cephalad to the bowel opening (Figure 5.13E).

The CEEA cartridge is placed into the anal canal and the center of the anorectal staple closure is pierced by the trocar followed by the hollow rod. The trocar is removed, the anvil shaft and cartridge rod are joined, and the instrument is closed.

The purse string at the open end of the proximal colon was tied to avoid spillage during this manipulation. The excess colon beyond the side-to-end anastomosis is excised peripheral to a TA 55 closure (Figure 5.13F).

After anastomosis is accomplished, the CEEA is removed and the anastomosis and closure are checked for competence (Figure 5.13G). The incision is then closed in layers.

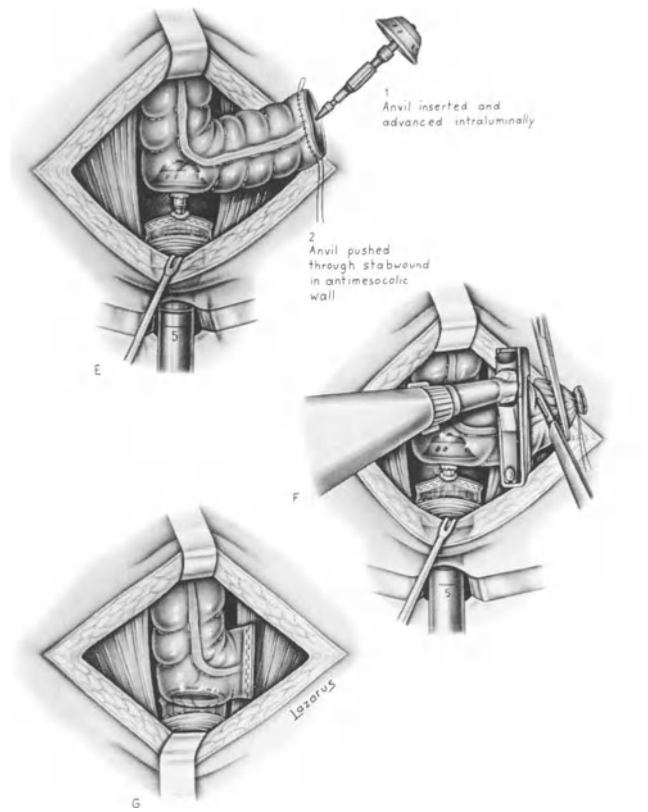
The many reports in this country and abroad of laparoscopic colectomy and anastomosis performed extracorporeally (fish or fowl?) attest to the feasibility of laparoscopic dissection and demonstrate that resection margins are safe, and that removal of malignant mesocolon and lymph nodes is comparable or superior to that obtained by open operations.

Therefore laparoscopic colectomy by experienced surgeons appears justified. The individual and extended teaching of surgeons during preceptorship and residency should be encouraged, rather than through short postgraduate courses and mass demonstrations in a laboratory environment.[7]

However, it would be beneficial if all concerned participated in clinical studies of these procedures. While the headlong rush into laparoscopic cholecystectomy was acceptable because this was largely a change in technique for the removal of benign disease, the surgical treatment of cancer imposes a different set of rules.

It is therefore important to organize study groups similar to those for the analysis of other cancer-treatment regimens at this early stage, while accrual of cases is slow because most surgeons are still learning the technical intricacies of the procedures.[7] For these reasons we have limited laparoscopically guided or assisted operations to benign conditions of the large bowel, to cancers in elderly and debilitated patients who would not tolerate open operation, and to the palliative treatment of obstructing and bleeding cancers in patients with known metastases.

Unlike cholecystectomy, where there are no survival issues, cancer operations are judged by 5- and 10-year survival times. A prospective, randomized double-blind study would convince our patients that the technical and prognostic risks of laparoscopic and open procedures are comparable. Given the present stage of knowledge the



FIGURES 5.13 E, F, G. Anterior rectal resection: Creation of double-stapled colorectal anastomosis. (Reproduced with permission from *Perspectives in Colon and Rectal Surgery,* vol. 6, no. 1, Quality Medical Publishers, 1993. p. 54.)

choice is between more cosmetic buttonhole incisions, less pain, earlier release from the hospital and return to work, but the unknown of a new course; and an abdominal incision, more pain, slower recovery, but the certainty of a time-proven modality.

If laparoscopy is the right way to go, it will be easy to convince the public to accept either procedure as part of such a study! After all the videoendoscopic approach is not a novelty in the theory and practice of surgery, but rather a new way to gain access to the abdominal cavity and the chest. And unlike the early days of cardiac and transplantation surgery, when a rather heavy morbidity was acceptable because there were no other treatment modalities, videoendoscopic techniques resist a high incidence of learning curve related accidents since there is a therapeutic alternative: the time honored and battle proven open operation.

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6
Sterilization and Disinfection of Laparoscopic Equipment

David W. Duppler

Introduction

Traditionally the instruments used in surgical procedures have been sterile. Laparoscopic surgery requires the use of delicate optical and electronic equipment that would be damaged by heat, so other methods of handling this equipment have been devised. This chapter discusses the proper handling of laparoscopic equipment and the rationale behind the existing guidelines for the sterilization and disinfection of this equipment.

Definitions

It is best to start by defining some of the terms used in describing the handling of medical equipment. The term *sterilization,* the complete elimination or destruction of all forms of microbial life, is straightforward.[1,2] Sterilization can be achieved by steam, gas, or liquid chemical sterilants. On the other hand, *disinfection* is a relative term meaning the elimination of many or all organisms except bacterial spores. Disinfection is usually accomplished by the use of liquid chemicals, known generically as *germicides.* Disinfection can be divided into three levels of germicidal action, depending on the numbers and types of microorganisms eliminated. These are referred to as *high-, intermediate-,* and *low-level disinfection.* High-level disinfection eliminates all organisms with the exception of large numbers of bacterial spores. Intermediate-level disinfection destroys all organisms except spores, some viruses, and some fungi. Low-level disinfection destroys most bacteria and some fungi and viruses but does not eliminate spores or tubercle bacilli. The level of disinfection achieved is determined by the type and concentration of germicide, the exposure time, the temperature, and the number and types of microorganisms present. The types of microorganisms eliminated are usually determined by their resistance to disinfection (see Figure 6.1). High-level disinfection is usually achieved by using a germicide capable of producing sterility but exposing the instruments for less time than is needed for sterilization.

Twenty years ago, Spaulding proposed that patient-care items be divided into three categories based on the degree of risk of infection involved in their use.[3] These are referred to as *critical, semicritical,* and *noncritical.* Critical items are those entering sterile tissue or the vascular space, such as laparoscopic equipment. Semicritical items are those that come in contact with skin that is not intact or with mucous membranes, such as gastrointestinal endoscopes and respiratory therapy equipment. Noncritical items, such as blood pressure cuffs and stethoscopes, come in contact only with skin.

Microorganisms	Level of Resistance
Bacterial Spores *Bacillus subtilis* *Clostridium difficile*	**Most Resistant**
Mycobacteria *Mycobacterium tuberculosis* Atypical mycobacteria	
Nonlipid Viruses Poliovirus Rhinovirus	
Fungi *Candida* spp *Cryptococcus* spp	
Vegetative Bacteria *Pseudomonas* spp *Salmonella* spp	
Lipid Viruses Hepatitis B virus Human immunodeficiency virus Herpes simplex virus	**Least Resistant**

FIGURE 6.1. Microorganisms listed in descending order of *in vitro* resistance to germicidal chemicals. From Spach DH, Silverstein FE, Stamm WE. By permission of *Ann Int Med.* 1993; 118:117–128.

Critical patient-care items should undergo a sterilization process before use. However, for various reasons, such as cost, convenience, and turnover time, it may not always be feasible to subject all laparoscopic instruments to a sterilization process. In these instances, instruments can be subjected to high-level disinfection.

Types of Chemical Germicides

Many different types of chemical germicides are available. When using germicides, it is important to remember that the efficacy of the agent is influenced by several factors in addition to its composition.[1,2] These include the organic load on the instrument (that is, whether it is clean or dirty), the type and level of microbial contamination, the concentration of the germicide and the disinfection time, the physical configuration of the instrument (for example, does it have hinges or lumens?), and the temperature and pH of the disinfection process. The potency and useful life of a chemical sterilant are determined by the pattern of use, not by time. Test kits are available to determine if chemical sterilants are still sufficiently potent for high-level disinfection. These chemical concentration monitors should be used routinely to determine the appropriate intervals for germicide exchange or replacement. If all of these factors are controlled and the instrument is adequately cleaned, the end result should be, in theory, a sterile instrument. Each of these factors, however, adds a variable to the disinfection process that may be difficult to control, and the practical result is that absence of bacterial spores cannot always be ensured.

Germicides that can currently be used for sterilization or high-level disinfection of lensed instruments such as laparoscopes include: 2% glutaraldehyde-based formulations, peracetic acid, chlorine dioxide, and 6% stabilized hydrogen peroxide.[2] Chlorine dioxide is not commonly used, in part because of its oxidative effects on metal or plastic surfaces. The use of 6% hydrogen peroxide has also been somewhat limited by its effects on some medical materials, although there are reports verifying its effectiveness in high-level disinfection and sterilization.[4] There is substantial experience in the United States with the use of 2% glutaraldehyde for high-level disinfection.[5,6] Two percent glutaraldehyde produces sterile instruments only after 10 hours of exposure. Since this is not usually practical and exposure for extended periods can cause instrument damage, the agent is used almost exclusively for high-level disinfection. Peracetic acid has been recognized as a strong germicide for years and a new formulation has recently led to a resurgence of interest in this agent.

Glutaraldehyde formulations are the most popular chemical germicides for high-level disinfection of laparoscopic and endoscopic equipment in the United States.[5,6] They are popular because of the advantages of excellent biocidal activity, activity in the presence of organic contamination, noncorrosive action on endoscopes and optical equipment when not used for extended periods, and noncoagulation of proteinaceous material.[2] High-level disinfection is accomplished with solutions having at least 1% glutaraldehyde, which can be re-used. More dilute formulations are ineffective. In the past, the recommended minimum exposure time for high-level disinfection was 10 minutes. More recently, it has become apparent that some strains of atypical mycobacteria are inactivated only by 20 minutes of exposure, and this is the current recommendation. Although the useful life of the 2% glutaraldehyde solution is generally accepted to be about 28 days, it may be shortened by heavy use, contamination, or inadvertent dilution. Glutaraldehyde also has the disadvantage of posing a potential health risk to health-care workers.[7,8] Glutaraldehyde exposure has been linked to dermatitis, rhinitis, asthma, and eye irritation.

A new sterilization process, marketed under the brand name *Steris,* was developed in 1988. The Steris system has the advantage of being a closed system that controls a number of the factors mentioned above that can limit the efficacy of a germicide.[9] In addition, its active agent is peracetic acid, which is generally considered to be a strong germicide that has little harmful effect on optical equipment. The manufacturer claims that the Steris system does not simply provide high-level disinfection but actually sterilizes instruments, a claim backed up by laboratory testing done by the manufacturer.[10] The Steris system has been shown to be effective in eradicating mycobacteria from a bronchoscope that had failed high-level disinfection with 2% glutaraldehyde.[11] To date, there have been no clinical reports on the use of this process in laparoscopy. The Steris system would appear to be a promising option for the reprocessing of laparoscopic equipment, but independently conducted and published studies confirming the manufacturer's claims are lacking at this time.

Laparoscopic Equipment

Most laparoscopic equipment can be safely autoclaved, and this is the preferred method for achieving sterilization. Traditionally, equipment is disassembled for steam sterilization and then reassembled at the time of surgery. This can lead to intraoperative delays and equipment malfunctions, however. Marshburn and colleagues compared this practice with that of reassembling instruments after cleaning and then subjecting them to steam sterilization in the assembled state. They found no difference in the clearance of test organisms and spores between the two methods.[12]

Although steam sterilization can and should be used for most laparoscopic equipment, certain instruments require special treatment. Laparoscopic cameras, laparoscopes, light cables, and flexible endoscopes, such as those used for laparoscopic common bile duct exploration, are damaged by heat. In addition, laparoscopic cameras are also damaged with repeated exposure to chemical germicides. The irregular surface of the camera makes cleaning difficult, which means disinfection may be unpredictable. Therefore, it is preferable to use a barrier for the camera, such as a sterile enclosing plastic sleeve, to avoid contamination of the operative field.

Although some laparoscopes have been developed that will withstand steam sterilization, they are still damaged by repeated exposures to the process and their durability has been a problem. Most laparoscopes now in use can be damaged by steam sterilization, although this is likely to change as more durable laparoscopes are developed. Gas sterilization with ethylene oxide, which is less harmful to the optics, has the disadvantage of requiring a long turnover time (12 to 24 hours). The long turnover time would require institutions to have multiple laparoscopes available if several procedures were to be done each day. This would represent a considerable expense that would eventually be passed on to the patient. The laparoscope can also be inserted into a plastic laparoscopic sleeve, but some optical distortion may result. The only other choice for reprocessing laparoscopes is the use of chemical germicides. Most of the chemical germicides currently available can achieve sterilization only with prolonged exposure.[1,2] At these longer exposure times, many germicides are damaging to optical equipment. Moreover, the turnover time is impractical. Therefore, most chemical germicides are used for shorter periods of time in the hope of obtaining high-level disinfection.

Sterilization Versus High-Level Disinfection

There are no data to suggest that high-level disinfection, when properly performed, leads to higher risk of infection during laparoscopy than sterilization. Despite this, concern has been expressed about the use of instruments that have been subjected to only high-level disinfection. Unfortunately, there is little scientific data to substantiate or allay these concerns. There is a substantial body of literature supporting the use of high-level disinfection for laparoscopes, but it is composed primarily of retrospective reviews and membership surveys.

Loffer conducted a retrospective review of 3,250 patients who underwent laparoscopy.[13] All laparoscopes underwent high-level disinfection with 2% glutaraldehyde prior to use. Only three wound infections were encountered, all minor and treated with local wound care. None of the infections could be traced to contaminated equipment.

The 1975 membership survey of the American Association of Gynecologic Laparoscopists included data on 117,705 patients who underwent diagnostic laparoscopy for laparoscopic tubal sterilization.[5] The majority of surgeons used high-level disinfection for the equipment. The incidence of infectious complications was 0.3%, with seven cases supposedly traced to contaminated instruments. None of these cases could be documented on follow-up, however, and the authors concluded that high-level disinfection with 2% glutaraldehyde was adequate.

One of the few prospective studies addressing this problem was undertaken by Corson and colleagues in 1979.[14] They performed routine cultures of the umbilical skin after preparation with povidone-iodine and alcohol on 100 consecutive patients undergoing laparoscopy. Cultures were also obtained from the pelvic peritoneum, as well as from the laparoscope after soaking in 2% glutaraldehyde for 15 minutes. Surprisingly, 61% of the umbilical cultures and 29% of the peritoneal cultures were positive. The organisms cultured from the skin and peritoneum were similar. Twenty-two percent of the telescope cultures were also positive for microorganisms, but these organisms were different from those cultured from the umbilicus and peritoneum, suggesting that the peritoneum was being contaminated by skin flora and not by the laparoscope. No cross contamination was noted between patients, and there were no clinical infections in any of the patients.

Recommendations for Handling and Reprocessing Laparoscopic Equipment

The guidelines set forth by the Centers for Disease Control (CDC) state: "Laparoscopes, arthroscopes, and other scopes that enter normally sterile tissue should be subjected to a sterilization procedure before each use; if this is not feasible, they should receive at least high level disinfection."[15]

More detailed guidelines for the preparation of laparoscopic instrumentation have been put forth by the *ad hoc* committee on infection control in the handling of endoscopic equipment of the Association for Practitioners in Infection Control (APIC).[16] These guidelines have been endorsed by the Association of Operating Room Nurses (AORN) and are as follows:

1. Meticulous care should be taken in mechanically cleaning all parts of laparoscopic equipment. This is the most important step in the reprocessing of laparoscopic equipment, no matter what type of disinfection or sterilization process is used;

2. Either high-level disinfection or sterilization is an acceptable method of preparing instruments for use. All instruments which can undergo sterilization using a steam autoclave should be handled in this manner. When ethylene oxide is used for sterilization, the recommendations of the manufacturer should be followed for both sterilization and aeration;
3. High-level disinfection, when chosen, should be performed with a chemical germicide capable of killing all microorganisms (gram positive and gram negative bacteria, fungi, mycobacteria, and lipophilic and hydrophilic viruses) except bacterial spores and should be used in accordance with the disinfectant manufacturer's instructions;
4. Aseptic technique should be used in transferring the disinfected or sterilized endoscope and other instruments to the sterile surgical field;
5. When procedures are to be performed on patients who are at increased risk of infection because of a compromised immune system, particular attention must be paid to all aspects of infection control. In these circumstances, sterilization of instruments is recommended.

No additions to the described protocol are necessary to deal with HIV- or hepatitis B-contaminated equipment.[1,15,17] Since laparoscopic equipment is used on patients with both recognized and unrecognized infections, it should be reprocessed in the same manner after each patient. Both hepatitis B virus and HIV are inactivated by many physical and chemical processes much less potent than high-level disinfection.

It is also important to point out that high-level disinfection is effective on laparoscopes because of the smooth surfaces of the instrument. This makes thorough cleaning and exposure to liquid chemical germicides much more simple and reliable. As more complicated laparoscopic instruments are developed, their disinfection and sterilization will become more complicated. There are hundreds of documented cases of the transmission of infections with flexible gastrointestinal endoscopes and bronchoscopes.[18] Most of these represent failures of high-level disinfection. The development of new laparoscopic instruments, such as laparoscopes with irrigating channels, semiflexible laparoscopes with a biopsy channel, flexible small-caliber choledochoscopes, laparoscopes that will provide three-dimensional vision, and even robotic laparoscopes, are likely to challenge the efficacy of high-level disinfection, just as did flexible gastrointestinal endoscopes and bronchoscopes.[19–23] Even traditional sterilization methods may prove ineffective or too toxic for the more complex laparoscopic instruments of the future. For example, gas sterilization with ethylene oxide has been shown to be effective in sterilizing simple instruments such as a rigid laparoscope,[24] but failures have been seen when it was used on more complex instruments, such as flexible endoscopes.[4] A greater risk of laparoscopic-related infections may accompany the use of these physically more-complex instruments unless the practitioner is vigilant regarding their cleaning and disinfection or sterilization. Instrument developers must work with clinicians to develop instruments that will lend themselves to easier and more-thorough cleaning to make the disinfection and sterilization process more reliable.

Historically, laparoscopic procedures have had low infection rates. In part, this has been because the majority of laparoscopies have been diagnostic, generally short procedures that created little devitalized tissue. As laparoscopic surgery is increasingly used for therapeutic purposes, we may see greater contamination of laparoscopic equipment than we have seen in the past. Whether the use of instruments that have undergone disinfection rather than sterilization will lead to an increase in infectious complications in these more complicated procedures remains to be seen. The epidemiology and microbiology of wound infections following open surgery have been well studied (Table 6.1).[25] It is not known whether it will be changed in any way by the laparoscopic revolution.

Summary

Most laparoscopic equipment can be easily and safely steam sterilized. Delicate instruments such as the laparoscope pose unique problems. The debate regarding the merits of sterilization versus those of high-level disinfection of laparoscopic instruments will continue until well-designed scientific studies are completed. Until then, the CDC and APIC guidelines are appropriate. Whenever

TABLE 6.1. Factors increasing the risk of surgical wound infection.*

Host Factors		Surgical Factors	
Age > 60 years	3× increase	Type of wound:	
Malnutrition	3×	contaminated	2×
Active infection	2–3×	dirty	4–6×
Obesity	2×	Preoperative hospitalization:	
Steroid therapy	2×	> 2 weeks	4×
Diabetes	2×	1–2 weeks	2×
		Night-time or emergency operation	2–3×
		Duration of operation > 3 hours	2–3×
		Shaving operative site	2×
		Electrosurgical knife	2×
		Penrose wound drain	2×

From Maki DG [25] by permission of *J Surg Prac.* 1977; November-December:10–23.

*Excerpted from two large multifactorial studies, each encompassing over 15,000 operated patients (*Ann Surg.* 1964; 160(Suppl.):1–192.; *Arch Surg.* 1973, 107:206–211.).

feasible, laparoscopic equipment should be sterilized. When this is not feasible, high-level disinfection is adequate.

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7
Complications of Laparoscopic Surgery

Avram M. Cooperman

Introduction

The preceding chapters in this text confirm how far laparoscopic surgery has progressed in the last four years. The complexity of laparoscopic procedures now being done attests to the dexterity, safety record, and ingenuity of the pioneers in this field. Basic and advanced laparoscopic surgery is safe but not risk-free. The rates of major and minor complications range from 0.5 to 5%. Mortality rates of gynecologic laparoscopic procedures are less than 0.1%.[1–3] These rates may decrease but complications will not be eliminated. Awareness and understanding of the manner in which complications develop may reduce their occurrence. This chapter will summarize the major complications of newer laparoscopic procedures as well as those relating to the index operation, laparoscopic cholecystectomy. Many of the complications cited have been noted, analyzed, and corrected by laparoscopic gynecologists. They spared the general surgeons who later became interested much effort. These specialists have not received the credit they are due.

Laparoscopic Complications

General Anesthesia

Most laparoscopic procedures are done under general anesthesia and utilize carbon dioxide for insufflation. The pneumoperitoneum provides a cushion of safety for underlying viscera. General anesthesia provides relief of pain caused by abdominal distension and allows control of ventilation, which is compromised by the pneumoperitoneum. Although respiratory and cardiovascular problems are the most serious concerns with laparoscopy, there are other problems as well. A report on 101 consecutive patients undergoing laparoscopic cholecystectomy noted the following intraoperative and recovery room events: intraoperative hypotension (12.9%); hypothermia (31.4%); nausea and vomiting (12.9%); and arterial oxygen desaturation (10.9%). Excess pain (4.0%) was the least-common complication.[4]

Respiratory Changes

Intraoperative pulmonary changes during laparoscopy are usually caused by the carbon dioxide gas or the pneumoperitoneum. An increase in peak airway pressures, central venous pressure, arterial carbon dioxide, and alveolar carbon dioxide is due to absorption of carbon dioxide from the pneumoperitoneum.[5] The rate of diffusion of carbon dioxide depends on the pressure of the pneumoperitoneum. Higher insufflation pressures are used during laparoscopy for gynecology (15 to 25 mm Hg) than for general surgery (8 to 15 mm Hg). Thus there is faster carbon dioxide diffusion and gas exchange during gynecologic procedures, although diffusion and changing blood levels of carbon dioxide rarely become a clinical problem. Abnormalities are readily corrected under anesthesia by ventilator adjustments.

Studies comparing pulmonary function before and after laparoscopy have shown a diminution in respiratory function for one to three days after laparoscopy.[5–7] Functional residual capacity (FRC) and forced expiratory volume (FEV) have been shown to decrease between 13 and 23% in several studies.[5,6] These changes are less than half of those seen in patients who undergo open cholecystectomy, where reductions of FEV of 57% and of FRC of 64% are common.[7] Routine postlaparoscopy chest roentgenograms or CAT scans show atelectasis in nearly half of studied patients.[6,8] There are three possible causes of restrictive lung changes after laparoscopy: anesthesia effects; postoperative pain; and diaphragmatic dysfunction. General anesthesia is an unlikely cause because patients who undergo nonabdominal operations of equal length have normal pulmonary functions.[9] Postoperative incisional pain could limit inspiration, but most respiratory studies after laparoscopic cholecystectomy were done when patients were not experiencing discomfort. Accumulating evidence incriminates diaphragmatic dysfunction as the major cause of respiratory dysfunction after laparoscopy.[10,11] Stretching of the diaphragmatic muscle by the pneumoperitoneum causes reflex inhibition of diaphragmatic excursions.[10] Attempted compensation by intercostal muscles is insufficient to correct the deficit. It is the visceral afferent reflexes that inhibit respiratory efforts and cause the restrictive pulmonary changes.[10] Studies of breathing patterns after open and laparoscopic cholecystectomy confirm that diaphragmatic dysfunction is the major cause of pulmonary changes after either type of procedure.

Pneumothorax

Dissection of the pleural space by carbon dioxide can cause unilateral or, less frequently, bilateral pneumothorax.[12–14] The pneumothorax may occur alone or in combination with pneumomediastinum, subcutaneous emphysema, and pneumopericardium.[12] Since carbon dioxide, the gas most frequently used in laparoscopy, is very soluble and diffusible, many cases of pneumothorax, including tension pneumothorax, will resolve spontaneously, particularly if gas flow is discontinued.[14] Pneumothorax secondary to communication between the abdomen and pleural space has been noted since the 1940s, when pneumoperitoneum was used in the treatment of tuberculosis.[15] Pneumothorax should be kept in mind when ventilation becomes difficult during or shortly after laparoscopy.

Cardiovascular Complications

Cardiovascular changes during laparoscopic surgery are usually not due to intrinsic cardiac disease. The pneumoperitoneum or patient positioning during surgery are more commonly responsible for cardiovascular changes. Cardiac output, pulse, and blood pressure are normal when intraperitoneal insufflation pressures are less than 20 mm Hg.[16–18] Trendelenburg or reverse Trendelenburg position, as utilized in gallbladder surgery, will decrease cardiac output by as much as 25%.[19,20] These changes are reversible and well-tolerated as long as the intravascular volume is maintained. This is done by volume loading 10 to 20 mL/kg prior to positional change. High abdominal pressures (greater than 40 mm Hg) cause caval compression or collapse and diminution in cardiac return.[21] These pressures should not be used in clinical situations.

Even with the low insufflation pressures used during laparoscopic cholecystectomy, the reverse Trendelenburg position is associated with significant venous stasis in the dependent legs and an increase in femoral-vein pressure. Despite this stasis, the leg veins remain free of thrombi. Venous flow returns to normal after the pneumoperitoneum is released.[5] These effects are significant, however, and the literature emphasizes the need to use mechanical compressive stockings intraoperatively, particularly when the patient is placed in the reverse Trendelenburg position.[11] Fortunately, thrombophlebitis or pulmonary emboli are rare.[22] In large collective series of laparoscopic surgeries, the mortality from pulmonary emboli is very low (0.016%).[22] Nonfatal pulmonary emboli and clinical thrombophlebitis are uncommon after laparoscopy (2%). Perhaps the negative effects of decreased venous flow are overcome by early ambulation and hospital discharge. Mechanical compressive intraoperative stockings and hydration should diminish the risk of these complications in cases where the patient is placed in reverse Trendelenburg position.[11]

Gas Embolism

Absorption of small amounts of carbon dioxide into the bloodstream from the peritoneal surface or by inadvertent intravenous injection is usually not a problem because carbon dioxide is readily diffusible. When larger amounts of carbon dioxide gain access to the bloodstream through a Veress needle or by transected veins during laparoscopic surgery, it can be fatal. Two of four fatalities in 50,247 gynecologic laparoscopies were due to gas emboli. The incidence is fortunately rare: between 1 and 4 per 65,000 laparoscopies.[2,23] Nor is gas embolism always fatal. Many diagnoses of suspected cases of gas embolus are presumptive and cardiovascular collapse is actually due to other causes (pneumothorax, vasovagal reaction, or myocardial infarction). Since gas embolus leaps to mind when sudden intraoperative deterioration occurs, it is understandable that it is overdiagnosed. A sudden unexplained fall in blood pressure, a change in cardiac rhythm, the appearance of a new heart murmur, and an increase in end-tidal CO_2 suggest gas embolus from carbon dioxide. These changes cause hypoxia and right ventricular failure, particularly if gas accumulates in the right ventricle. Therapeutic measures should be undertaken immediately and include: release of the pneumoperitoneum, turning the patient onto the left side with the head lower than the right ventricle (Durant position), aspirating gas from the right ventricle through a central line, and ventilating with 100% oxygen. The complication usually resolves within minutes if cardiovascular support is maintained. Hyperbaric oxygen has been used to treat a few patients with gas embolism.

Hypertension and Hypotension

Rose and associates noted that 12.8% of laparoscopic cholecystectomy patients were hypotensive during the procedure (their blood pressures were less than 80 mm Hg for five or more consecutive minutes).[4] Postulated mechanisms included decreased venous return from the splanchnic and lower extremities due to caval compression and the head-up position used to facilitate gallbladder exposure. Preoperative volume loading, mechanical compressive stockings to increase venous flow through the femoral veins, or avoidance of the head-up position may serve to limit venous stasis. Goodale and colleagues noted a small but significant increase in systolic blood pressure, which ranged from 110 to 124 mm Hg.[5] The pulse rate and diastolic pressures did not change. They did not discuss the correlation of these pressure changes with position during surgery. This type of hypertension may represent a sympathetic response, particularly if it is transient.

Arrhythmias

Changes in cardiac rhythm are common during surgical procedures for many reasons. With laparoscopy, particularly with carbon dioxide pneumoperitoneum, arrhythmias occur in up to 20% of patients.[24,25] The risk is three times greater when carbon dioxide is used than when nitrous oxide is used. Most cardiac rhythm changes are transient and do not cause clinical instability. Controlled ventilation with continuous pulse oximetry and end-tidal CO_2 monitoring allows the ventilation disorders that are often the cause of arrhythmias to be corrected.

Cardiac arrest is rare during induction of anesthesia. The incidence, according to the gynecologic laparoscopic literature, is 1 in 2,500.[27] Postulated mechanisms for cardiac arrest include hypercapnia, anoxia, and increased abdominal pressure as a result of the Trendelenburg position, pneumoperitoneum, and decreased cardiac output. Careful study of these factors indicates that absorption of CO_2 from the pneumoperitoneum does not cause significant hypercapnia during laparoscopy, even under local anesthesia.[28] Intracardiac stretch receptors in the ventricular and atrial walls are activated when there is decreased venous return to the heart, but these reflexes are activated at pressures higher than those used during clinical laparoscopy.[29] Vagal reflexes secondary to peritoneal distension are another possible cause of asystole and hypotension. Pneumoperitoneum combined with traction on pelvic structures can initiate this vagal response. A report of asystole when vecuronium was used as a neuromuscular blocker during insufflation has led to the suggestion that anticholinergic agents be included in neuromuscular blocks to avoid asystole.[30]

Subcutaneous Emphysema

In a series of 27 asymptomatic, consecutive patients who underwent CT scans within 24 hours of laparoscopic cholecystectomy. Subcutaneous emphysema was seen in 56% of patients, pneumoperitoneum in 70%, atelectasis in 44%, and pleural effusions in 33%.[8] Twenty-two percent of patients had fluid in the abdomen, and 48% had ileus. No clinical significance could be attributed to these findings. Isolated cases of significant subcutaneous emphysema have been due to malfunction of insufflators (higher intra-abdominal pressures than the instrument recorded) and the mispositioning of needles and trocars during insufflation. Such cases usually resolve by spontaneous absorption.[31]

Nausea and Vomiting

Nausea and vomiting occur in up to 42% of patients after laparoscopy.[32] Traditionally, surgeons have attributed this to anesthesia, and anesthesiologists, ever gracious, have laid the blame on surgical traction and dissection. The incidence is higher after upper abdominal procedures than after pelvic surgery. In women, it may be related to the menstrual cycle.[32,33] The mechanism is unclear but is probably multifactorial. Anecdotal remedies include routine use of intraoperative antiemetics, substitution of regional anesthesia for general anesthesia, use of nonsteroidal anti-inflammatory agents rather than narcotics, and use of nasogastric tubes. A study of the use of nitrous oxide in gynecologic laparoscopy concluded it is not the cause of postoperative emesis.[34] Identification of the cause of nausea and vomiting would be welcomed by patients, surgeons, and anesthesiologists.

Hypothermia

In laparoscopic procedures lasting more than two hours, nearly one-third of patients are hypothermic.[4] Cool inhalation agents, room-temperature insufflation gas, and room-temperature irrigating fluid contribute to hypothermia. The use of intraoperative warming units should be routine when the procedures are anticipated to last two or more hours, but they are used in fewer than half the cases.[4]

Pain

Laparoscopic surgery is not painless, publicity notwithstanding. At least 13% of patients have significant pain after laparoscopy.[4] Ibuprofen, an antiprostaglandin mediator (in a dose of 800 mg given one hour preoperatively) resulted in better pain relief immediately after surgery and after hospital dismissal than fentanyl.[35] Other studies have confirmed that nonsteroidal anti-inflammatory agents are effective analgesics with pain relief equivalent to 8 to 10 mg of morphine. Maximum gastrointestinal absorption takes three hours, and the agents remain at therapeutic levels for more than four hours. By inhibiting cyclooxygenase enzymes that metabolize arachidonic acid, these agents limit the production of thromboxanes, prostacyclins, and prostaglandin, all mediators of the inflammatory response.[36] Intraoperative irrigation with dilute local anesthetics and injection of local anesthetics into laparoscopy incisions may also relieve pain.[37]

Complications Specific to Laparoscopy

The immediate and obvious risk to patients undergoing laparoscopy is an entry injury from a Veress needle or trocar. The incidence is between 1 in 500 and 1 in 1,000, but since most studies are retrospective, the true incidence is underreported. A Canadian survey indicated that at least one-fourth of the gynecologists who did laparoscopy noted Veress-needle injuries.[38] Since needle injuries are small-diameter wounds to the bowel or blood vessels, they are often unrecognized; the injury seals spontaneously and requires no treatment. Recent advertising campaigns extolling the merits of disposable safety-shielded trocars, both for their ease-of-entry and as a means of avoiding vascular of visceral injuries, should be regarded skeptically. They have not been subjected to randomized prospective trials. The safety shield is less important than the external forces applied by the surgeon at the other end! A study of complication rates in the Federal Republic of Germany published in 1986 indicated vascular and bowel injuries occurred in 1.9% of 250,000 laparoscopic procedures.[39] All procedures were done with nondisposable, nonshielded trocars. An early report from the American Society of Gastrointestinal Endoscopy of 27,000 laparoscopic procedures in the United States indicated injury rates were no lower when safety-shielded trocars were used.[40] Blind intraperitoneal entry through the umbilicus with a needle or trocar is surprisingly safe. The incidence of unsuspected bowel injury was 4 in 4,532 consecutive outpatient laparoscopies.[41] In only one case was a bowel adhesion present at the insertion site. Perforation injuries during insufflation are uncommon (0.3%), and the incidence is low in prospective as well as retrospective studies.

The common assumption that open laparoscopy and direct insertion of a nontrocar sheath is the safest method of entry has not been formally studied or questioned. Experience with open laparoscopy is spotty because of the low incidence of closed insertion injuries.[42] A randomized study of 200 patients that compared three methods of cannula insertion—Veress needle, direct puncture with a 10-mm nonshielded trocar, and direct puncture with a safety-shielded trocar—indicated there were no major complications with any method, although more minor complications occurred when the Veress needle was used.[43]

A review of vascular injuries during insertion indicated that the Veress needle causes more injuries than the trocar, but fatal injuries are more often caused by misdirected trocars.[44] A theoretical advantage of the safety-shielded trocar compared to nondisposable trocars sharpened after every 16 uses is that less force is needed to establish pneumoperitoneum.[45] My clinical experience does not bear this out, particularly in the case of the newer nonshielded trocars. Temerity and fear make many inexperienced laparoscopists circumspect about direct trocar insertion, these small studies notwithstanding.

The incidence of vascular or bowel injuries should be low if: a midline entry at the umbilicus is used; the trocar or Veress needle is directed towards the bladder in the midline; minimal force is used; and the skin incision allows the sheath of the 10-mm trocar easy entry into the subcutaneous space above the fascia. The assumption that if entry is forceful the trocar will pass through the gas layer and enter the bowel is incorrect. The small bowel is so mobile that it will be pushed out of the way more often than it will be penetrated.

Vascular injuries of the vena cava, iliac arteries, or the aorta are rare but occasionally fatal. The use of short trocars, the exertion of minimal force, and directing trocars toward the midline of the pelvis should avoid this. If the trocar entry is near the midline and below the aortic bifurcation, major vascular injuries should be uncommon.

Thermal and Cautery Injuries

Experience with electrosurgical units in laparoscopic surgery has been favorable for the most part. Electrosurgical units facilitate cauterization of small vessels and avoids the need for clips, sutures, and ties. Monopolar electrosurgery is safe, economical, efficacious, and has been a mainstay in surgery, but newly recognized problems with its use are particularly evident in laparoscopic applications.

The first use of electrosurgical techniques in laparoscopy was for tubal fulguration in gynecologic surgery. Many of the early complications, particularly thermal injuries to the bowel, were fatal because they were not recognized until peritonitis was evident. Analysis of many "thermal" injuries, however, revealed that they were mechanical and not thermal.[46]

Voyles and Tucker have done much to elucidate the potential problems of laparoscopic monopolar surgery.[47] Unrecognized tissue injury may be due to: insulation breaks in the sheaths that cover instruments; capacitive coupling, that is, the passage of current through the intact insulation of the active electrode to other cannulas or instruments; and direct coupling, or unintended contact between the active electrode and other metal instruments within the abdomen. Problems are more frequent during laparoscopy than open surgery because the abdominal wall transmits current between trocars.

Insulation defects were more common with early instruments. The defects, which were not apparent on visual inspection, led to the patient being burned. The insulation failure was sometimes signaled by tingling of the surgeon's hands and interference with video monitors. Insulation failure has been minimized by better-designed instruments and the use of devices that monitor for insulation failure and deactivate the electrosurgical generator when a break develops. Direct coupling is frequently not recognized because the point of contact between the electrode and the metal laparoscope may be outside the field of view of the laparoscope. This injury is potentiated when the laparoscope is passed through a plastic cannula because electrical energy cannot dissipate through the cannula. An unusual thermal injury is a late bile-duct stricture caused by direct thermal contact or one of the above mechanisms.[48]

Infections

Significant infections after laparoscopy are very uncommon. Minor wound infections or the formation of sinuses from sutures in the umbilical or epigastric fascia occur in less than 1% of cases. There may be prolonged seropurulent drainage but this does not usually prolong hospitalization or increase the amount of time missed from work. Deeper infections are related to the specific disease treated and are discussed in the appropriate chapters.

Specific Complications

Tumor Seeding

Implantation of tumor cells in wounds or drain-tract sites has been noted after conventional surgery.[49] Removal of gallbladders with unsuspected carcinoma through a minilaparotomy incision has rarely resulted in secondary implantation.[50] Implantation of tumor cells in laparoscopy wounds in general is infrequent. Recent reports of two cases question whether biopsy should be done in cases of resectable tumors that are potentially curable.[51] Tumor cells may be spread by the systemic circulation rather than by direct implantation. This is an unresolved issue, but caution should be used in removing malignant lesions through small incisions during laparoscopy.

Bile-Duct Injuries

The most-feared nonfatal complication of conventional or closed cholecystectomy is bile-duct injury. Opinion differs whether duct injuries in conventional surgery are more common with straightforward or complicated cholecystectomies. Most surgeons feel that with careful dissection and adjunctive use of intraoperative sonography or cholangiography common bile duct injuries can be avoided. Nevertheless, the problem has not disappeared.

With the surgeons "eye" (the laparoscope) at the umbilicus, the view of the common duct is tangential and along its axis, not perpendicular to its axis, as is the view from the right upper quadrant. Thus, the lower to middle third of the common duct is visualized. The upper duct (that portion above the cystic duct) is difficult to examine because the surgeon has poor depth perception and because tenting of the cystic duct from infundibular traction exaggerates the view of the lower common duct and causes the upper duct to "fall away." If there is excessive traction on the cystic duct, the surgeon may see what appears to be a single cystic-duct/common duct structure exiting from the gallbladder, particularly if the view is head-on.[51]

Identification of the junction between the ducts and of the segments of the common duct above and below the cystic duct is important in eliminating common duct injuries during both laparoscopic and conventional surgery. This was not appreciated early in the history of laparoscopic cholecystectomy, and a number of injuries and fistulas may have been traced to unrecognized upper-duct anomalies or abnormal displacement of the upper common duct. Each surgeon will devise intraoperative maneuvers for identifying the common duct. Possible maneuvers include passing a spatula or clamp around the cystic duct until the junction is reached, dissecting the lower third of the gallbladder from the liver bed to facilitate exposure of the common duct, and retrograde dissection to free the gallbladder completely from the liver bed. All these maneuvers identify the duct exit from the gallbladder. The use of intraoperative sonography or cholangiography to identify the common duct is sometimes of benefit. None of these procedures are panaceas, however. Common ducts have been injured after negative intraoperative cholangiograms.

Treatment of common duct injuries depends on the level of injury and the quality of duct. When a partial injury is recognized, a T-tube may be placed laparoscopically or by conventional surgery. Since the blood supply to the common duct is circumferential, partial-duct injuries tend to heal well. For complete transections, biliary enteric anastomoses have a greater chance of healing without stricturing than end-to-end anastomoses. For complete high transections, an interposed jejunal limb or Roux-en-Y limb offers the best solution.

The incidence of common duct injury, which was once thought to be 10 times more common with laparoscopic surgery than with open surgery is much lower today. Surgeons are now experienced enough that laparoscopic cholecystectomy, for the most part, is as safe as conventional cholecystectomy.

Bile Leaks

Leakage of bile through secure clips on the cystic duct, the liver bed, or a large duct beneath the liver surface in the gallbladder fossa is rarely manifest at surgery.[52] It becomes a concern when bile comes through a drain or trocar site or a patient develops ascites after an operation. Small quantities of bile drainage require no treatment.[53] These leaks are most likely due to aberrant small ducts in the liver bed that are transected during removal of the gallbladder.

The site of a bile leak can be pinpointed by radionucleotide scan, injection of a percutaneous drain after one week, or endoscopic retrograde cholangiography. Endoscopic study allows removal or correction of any distal obstruction or passage of a stent beyond the fistula to facilitate closure. As with any opening in the bile duct, when pressure/flow relationships cause bile to flow preferentially into the duodenum rather than through the fistula, the leak will close spontaneously.

Gallstone-Induced Abscess

These abscesses are due to infected spilled stones that have been left in the peritoneal cavity, usually around the liver. Percutaneous drainage and dilatation of the tract may allow passage of an endoscope and retrieval of stones, avoiding surgery.[53] Most often, stones in the peritoneal cavity cause no harm.

Bleeding

Bleeding after laparoscopic cholecystectomy may be from the operative bed, the cystic artery, or a trocar site (usually the epigastric artery, which was punctured during placement of a trocar through the rectus muscle). The latter is particularly important if the operation has gone well and hemostasis appeared satisfactory. One should consider repeat laparoscopy and inspecting the abdominal wall for a bleeding vessel. This can be controlled by suturing the bleeding trocar site.

Miscellaneous Complications

Traction or pressure injury to the femoral or sciatic nerve cause by lithotomy positions or leg straps is avoidable by padding, foot boards, and awareness of this possibility.[54] Hernias through the trocar sites are uncommon. They can be avoided by being certain all intraperitoneal contents are in the abdominal cavity before fascia closure.[54]

Conclusion

Laparoscopic general and gynecological surgery has come of age in the past few years. Interest and enthusiasm remain high and new applications are constantly being described. Sometimes, basic research is omitted in the hurry to place techniques in practice.

The complication rate of laparoscopy, mortality included, is very low. Constant diligence, awareness of anatomical variations, and acquisition of bimanual surgical skills needed to suture and tie will make laparoscopic surgery even safer. Awareness of the time required to perform procedures will keep new operations within reasonable bounds. The development of manual skills will decrease reliance on mechanical staplers and clips, providing surgeons with the needed tools to deal with intraoperative complications with confidence. Experience and thought will prevent many complications from developing in the first place.

The future in laparoscopy is bright, particularly since risks of complication continue to decline.

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8
Anesthesia

8.1 Anesthetic Implications of Laparoscopy, Thoracoscopy, and Hysteroscopy

Martin B. Wehlage

The recent explosion of surgical procedures performed with endoscopic devices has led to a new array of potential surgical complications and to new concerns for the anesthesiologist. Administration of a safe anesthetic entails understanding the surgical approach, specific instrumentation used for tissue resection, physiologic sequelae of optimal positioning, and effects of the visualization medium. This review will examine specific anesthetic considerations of laparoscopy, thoracoscopy, and hysteroscopy, and focus on preoperative evaluation, patient preparation, optimal monitoring, type of anesthesia, and postoperative concerns.

Laparoscopy

The bulk of literature regarding the physiologic effects of laparoscopy comes from gynecology, where laparoscopy has been performed for years for a variety of diagnostic and therapeutic indications. The complications of laparoscopy can be divided into three general categories: trocar insertion, CO_2 insufflation, and positioning. The trocar is inserted blindly and may lead to inadvertent perforation of gastric, intestinal, or vascular structures. This is a period of heightened anesthetic vigilance, especially regarding the potentially catastrophic disruption of vascular structures. Other trocar-related complications include abdominal wall vessel bleeding, omental injury, adhesion disruption, and hepatic or splenic injuries. Carbon dioxide insufflation is utilized to create a pneumoperitoneum. Complications include pneumothorax or tension pneumothorax, pneumomediastinum, subcutaneous emphysema, hypoxemia, hypercarbia, hypotension, carbon dioxide embolism, dysrhythmias, or cardiovascular collapse. The cardiovascular changes associated with a pneumoperitoneum depend on the intra-abdominal pressure, the volume of CO_2 absorbed, the mode of ventilation, the anesthetic agents, and the patient's intravascular volume status. Most studies examining the cardiovascular effects of a pneumoperitoneum have included young, relatively healthy female patients undergoing short gynecologic procedures. They have shown only minor effects when intra-abdominal pressure did not exceed 25 cm H_2O.[1] The data, however, are lacking concerning these effects in patients with pre-existing cardiopulmonary disease.

As the intra-abdominal pressure is gradually increased to 25 cm H_2O, one sees increases in intrathoracic and femoral venous pressures, with associated hypertension, tachycardia, and increased cardiac output.[2] When intra-abdominal pressure is further increased to 40 cm H_2O, tachycardia, hypotension, decreased central venous pressure, and decreased cardiac output are noted.[3] The increased cardiac output resulting from a moderate intra-abdominal pressure has several causes: increased filling pressures secondary to inferior vena cava blood being forced centrally, sympathetic-mediated constriction of capacitance vessels, and increased cardiac sympathetic activity secondary to hypercarbia. At higher intra-abdominal pressures the cardiac output drops due to significantly impeded inferior vena cava blood flow. The effects of hypovolemia and volatile anesthetic agents, which have inherently negative inotropic effects, have been shown to further exacerbate the decreased cardiac output seen with high intra-abdominal pressures.[4]

The respiratory effects of a pneumoperitoneum are significant, especially in patients with pre-existing cardiopulmonary disease. Healthy patients reveal a mild increase in end-tidal CO_2 ($ETCO_2$) and arterial CO_2, a decrease in arterial pH, but no significant changes in peak airway pressure or minute volume. Patients with cardiopulmonary disease, to the contrary, exhibit significantly increased $ETCO_2$ and arterial CO_2, decreased arterial pH, and significantly higher peak airway pressure and minute ventilation.[5] Increased ventilating volume and pressure may worsen the risk of barotrauma in these patients.

General anesthesia is associated with a decreased functional residual capacity (FRC), and this effect is compounded by both the pneumoperitoneum and the cephalad shift of the diaphragm in the supine or Trendelenburg position. If FRC decreases below the closing volume, atelectasis and intrapulmonary shunting may occur, resulting in hypoxemia.

The carbon dioxide used for insufflation has effects of its own. Both nitrous oxide and room air have been used for laparoscopic visualization, but their flammability has limited their usefulness when electrocautery is used. In addition, gas embolism of nitrous oxide, and especially air, are more likely to cause significant cardiac decompensation. Carbon dioxide, on the other hand, does not support combustion, is readily available, and is relatively inexpensive. Despite the increased peritoneal irritation that carbon dioxide causes (as compared to nitrous oxide), its increased solubility minimizes potential complications associated with vascular injury and gas embolism.[6] Carbon dioxide is highly diffusible and is absorbed at the peritoneal surface to be returned to the systemic circulation.

The resulting increased arterial CO_2 can be hazardous in a spontaneously ventilating patient, potentially leading to dysrhythmias. Dysrhythmias frequently noted include sinus tachycardia, premature ventricular contractions, or even asystole.[7,8] The spontaneously ventilating patient is absorbing carbon dioxide from the peritoneal surface at the same time his respiratory centers are depressed by anesthetics. In addition, pulmonary mechanics are limited by the Trendelenburg position and the pneumoperitoneum. Thus, controlled ventilation is generally recommended. Other causes of dysrhythmias may include hypoxemia, vagal stimulation, light anesthesia, or tracheal stimulation.

Hypercarbia resulting from inadequate ventilation leads to sympathetic activation; hypercarbic patients exhibit increased plasma catecholamine concentrations, blood pressure, heart rate, and cardiac output.[9] In addition, there are reports of hypotension, hypoxemia, and cardiovascular collapse during laparoscopy.[10,11] Suggested etiologies include hemorrhage, venous gas embolism, vagal response to peritoneal stretching, IVC compression, or hypercarbia-induced dysrhythmias. Of particular interest is the observation that arterial CO_2 is highest immediately following release of the pneumoperitoneum, necessitating added vigilance for dysrhythmias as the procedure nears completion.

Laparoscopy demands multiple patient position changes, depending on the location of the surgery. The hemodynamic effects of the Trendelenburg position have been extensively studied, again, generally related to gynecologic procedures.[12] The head down position improves venous return and augments cardiac output. This may be affected by many variables, including the patient's volume status, pre-existing cardiovascular disease, positive pressure ventilation, degree of Trendelenburg, and anesthetic choice. While healthy patients in the Trendelenburg position have shown an increased cardiac index and normal hemodynamic parameters, patients with pre-existing coronary artery disease revealed increased central venous and pulmonary capillary wedge pressures, and a decreased cardiac index in this position.[13]

The respiratory effects of the head down position depend on the ventilatory technique, the patient's age and weight, the presence of pre-existing pulmonary disease, and the degree of head down tilt. This position decreases vital capacity due to cephalad displacement of the diaphragm, and this decrease is further exacerbated by morbid obesity, advanced age, or excessive surgical retraction. Endobronchial intubation leading to hypoxemia has been reported in the head down position because the carina is shifted cephalad while the secured endotracheal tube remains in a fixed position.[14]

The reverse Trendelenburg position is employed for laparoscopic cholecystectomy and other upper abdominal laparoscopic procedures. This position improves the respiratory function by caudal displacement of the diaphragm and abdominal contents. The head up position would be expected to decrease venous return and cardiac output, but studies on healthy patients suggest these changes are clinically insignificant. Interestingly, there are no studies to date that focus on the effects of the reverse Trendelenburg position in elderly patients or in those with pre-existing cardiopulmonary disease.

Laparoscopic procedures also frequently require tilting the patient either right or left to improve surgical exposure. Strict attention to immobilization of the patient's arms, legs, and torso is essential to avoid significant nerve compression. Lateral tilt may alter the distribution of ventilation and pulmonary perfusion. However, these changes are clinically insignificant with the degree of tilt utilized.

Anesthetic Techniques

Preoperative evaluation of the patient for laparoscopic surgery should focus on coexisting diseases and the extent of the operative procedure. Any attitude of "it's just a scope" ignores the multitude of potential complications and hemodynamic perturbations. Patients should have, at the minimum, a preoperative hematocrit, and type and screen because of the risk of major vascular injury. Good intravenous access is also imperative for the same reason. Further evaluation (which may include EKG; chest x-ray; pulmonary function testing; electrolytes or other blood studies; or cardiac, pulmonary, or medical consultations) should be based on the patient's pre-existing diseases.

The primary goal of premedication is to reduce patient anxiety. Additional goals may include the reduction of nausea and vomiting, production of amnesia or analgesia for line placement, or to reduce intraoperative anesthetic requirements. The most important technique for allaying anxiety is a preoperative consultation with the anesthesiologist. At this time the anesthesiologist can address patient concerns regarding the surgical procedure and the anesthetic choice. Surgical patients have several common fears: intraoperative awareness, failure to awaken, nerve injuries, uncontrollable postoperative pain, and intractable nausea and vomiting. Patients also frequently worry about being left unattended during the procedure. By specifically addressing these fears in the preoperative visit, the anesthesiologist can significantly reduce patient anxiety.

Intramuscular or intravenous benzodiazepines have become the cornerstone of preoperative anxiolytic therapy. Midazolam has a relatively short duration of action and is an excellent anxiolytic and amnestic drug. An additional advantage of midazolam is its anticonvulsant effect, which may raise the seizure threshold of concurrently administered local anesthetic agents. In addition, the recent introduction of the benzodiazepine antagonist flumazenil has made midazolam a reversible component. If analgesia is sought in the premedicant, then a narcotic must be added, as the benzodiazepines lack analgesic effect. Frequently used narcotics include morphine, meperidine, fentanyl, sufentanil, and alfentanil administered intramuscularly or intravenously.

Other preoperative medications administered may include a variety of antiemetics, such as metoclopramide, droperidol, prochlorperazine, or hydroxyzine. Premedication may also take into consideration the potential increased risk of acid aspiration in patients undergoing outpatient procedures. Pregnant patients, obese patients, or those with a documented hiatal hernia are at further risk of acid aspiration. Prophylactic premedication with metoclopramide, ranitidine, or cimetidine, and a nonparticulant antacid such as sodium citrate may help decrease the potential for pulmonary compromise with acid aspiration.

General anesthesia is commonly utilized due to discomfort of the pneumoperitoneum and multiple position changes. Cuffed endotracheal tube placement helps to minimize the risk of acid aspiration. The risk of passive gastric regurgitation during laparoscopy may be significant due to the elevated intra-abdominal pressures and the steep Trendelenburg position.[15] Furthermore, controlled ventilation is suggested to help avoid the deleterious effects of hypercarbia. General endotracheal anesthesia and controlled ventilation are ideal when a motionless operative field is important, for example, laser laparoscopy. It is the appropriate choice in patients requiring lengthy or extensive procedures, those suspected of having dense adhesions, the morbidly obese, or those with significant pre-existing pulmonary disease. It is a logical choice for patients with excessive fear, anxiety, or inability to cooperate or communicate. Often, the surgeon's preference may influence the choice of a general anesthetic as many surgeons are more comfortable with an asleep patient. General anesthesia may also be the optimal choice for inexperienced laparoscopists or in training institutions. Complications of general anesthesia may include excessive gastric dilation, hoarseness, sore throat, myalgias, lethargy, delayed postoperative recovery or discharge, nausea and vomiting, or dental trauma. Major complications, including myocardial infarction, stroke, or death, are fortunately much less common.

The induction of general anesthesia is frequently accomplished with the use of a rapid-acting barbiturate, such as thiopental or methohexital. Other drugs used include etomidate, ketamine, and propofol. Propofol has gained wide popularity, especially for outpatient procedures, because of its rapid recovery profile and low incidence of nausea and vomiting.[16,17] Care must be taken when administering propofol to those with cardiac disease because of its cardiac depressant effect and blood pressure lowering characteristics.

As previously discussed, a cuffed endotracheal tube is frequently placed to protect the airway. The placement of this tube is generally facilitated by use of a muscle relaxant. Succinylcholine is a depolarizing muscle relaxant commonly used for endotracheal intubation. It provides rapid onset, short duration of action, and excellent intubating conditions. Frequent side effects include postoperative myalgias, dysrhythmias with administration, and fasciculations, which may increase the risk of aspiration by transiently increasing intra-abdominal pressure. Less common effects include bradycardia, life-threatening hyperkalemia, myoglobinemia, malignant hyperthermia, or prolonged apnea in patients with atypical plasma cholinesterase. These untoward characteristics, however, are overwhelmed by its ability to ensure the most rapid intubating conditions of any relaxant currently available.

Several nondepolarizing muscle relaxants are available. These include the short-acting drug mivacurium; the intermediate-acting drugs rocuronium, atracurium, or vecuronium; and the long-acting drugs pancuronium, pipecuronium, or doxacurium. Adequate intubating conditions are generally provided within two to four minutes. The use of muscle relaxants, although not a substitute for adequate anesthesia, may allow the anesthesiologist to maintain a lighter depth of anesthesia, thus speeding recovery. Muscle relaxants may be necessary to provide adequate abdominal wall relaxation for establishment of a satisfactory pneumoperitoneum. The effects of the nondepolarizing muscle relaxants can be rapidly reversed at the completion of the procedure using an anticholinesterase drug such as neostigmine or edrophonium. Adequate reversal of the muscle relaxant should be documented using a nerve stimulator.

A bladder catheter and naso- or orogastric tube are inserted to decompress the bladder and the stomach prior to the establishment of the pneumoperitoneum. Anesthesia can then be maintained with either inhalational agents or intravenous agents. The volatile anesthetic agents halothane, enflurane, isoflurane, sevoflurane, and desflurane have all been used in laparoscopic procedures. Halothane may predispose the patient to dysrhythmias, particularly when hypercarbia ensues or epinephrine-containing local anesthetics are used. Propofol as a continuous intravenous infusion is also frequently utilized for laparoscopic procedures for the reasons previously mentioned.

The use of nitrous oxide during laparoscopy remains controversial. Because nitrous oxide is 34 times more soluble than nitrogen, it will rapidly expand closed air-containing spaces, potentially leading to bowel distention and postoperative nausea. Several studies have shown significant bowel distention and a higher incidence of postoperative vomiting when nitrous oxide is used for laparoscopy.[18,19] Other studies, including a large randomized blinded study, have found no correlation between the use of nitrous oxide and postoperative nausea and vomiting.[20,21] Furthermore, the nitrous oxide use had no significant effect on operating conditions or bowel distention. We feel nitrous oxide may still be a useful adjunct during general anesthesia for laparoscopy. A balanced anesthetic technique using nitrous oxide and either fentanyl, alfentanil, or sufentanil has been commonly used for laparoscopic procedures. These drugs provide excellent analgesia, rapid elimination, and cardiovascular stability. Specific concerns about these narcotics in outpatient surgery include postoperative respiratory depression or narcotic-induced nausea and vomiting.[22]

There has also been some concern regarding the use of narcotics for laparoscopy due to their potential for causing spasm of the sphincter of Oddi.[23] This spasm may confuse cholangiographic findings by mimicking those seen with an impacted common bile duct stone. This could lead to unnecessary exploration of the common bile duct. However, in a prospective study, choledochoduodenal sphincter spasm was assessed in patients receiving fentanyl.[24] The contrast failed to enter the duodenum in only 3% of cases and was reversed by 2 mg of glucagon in all patients. Our conclusion is that narcotics may be safely administered for laparoscopic procedures. The new parenteral nonsteroidal anti-inflammatory drug ketorolac may decrease or eliminate the need for perioperative narcotic administration, thus minimizing their undesirable side effects and speeding recovery. The theoretic concern of postoperative bleeding in patients receiving ketorolac, especially on an ambulatory basis, must be considered as well.

Regional anesthesia is an alternative in some patients. Regional anesthesia allows an awake patient who can inform the anesthesiologist of potential complications (pneumothorax, embolism, dysrhythmias, ventilatory difficulties) leading to prompt treatment. Regional anesthesia allows for good muscle relaxation and excellent surgical exposure. Another significant advantage may be the ability to provide postoperative pain relief that decreases the need for narcotics. Disadvantages of regional anesthesia include hypotension, failed or inadequate block, and local anesthetic toxicity. High blood levels of local anesthetics may result in seizures, apnea, dysrhythmias, or cardiovascular collapse. The level of the block must be high enough to eliminate peritoneal discomfort and this frequently requires a sympathetic level above T4. In patients with pre-existing pulmonary disease or morbid obesity, this sympathetic level may decrease ventilatory function, eliminating their ability to cough or remove secretions and increasing the risk of atelectasis and hypoxemia. Other complications, especially postdural-puncture headache or urinary retention, may delay discharge from an outpatient facility.

Epidural and spinal anesthesia result in the loss of sympathetic tone and produce peripheral vasodilatation. The administration of approximately 1 L of crystalloid solution prior to the initiation of the block helps to avoid hypotension. Regional anesthesia is relatively contraindicated in the previously volume-depleted patient when time does not allow for adequate intravascular volume replacement. Other contraindications include pre-existing neurologic disease, coagulopathies, infection in the area of needle insertion, known allergic reactions to local anesthetics, or patient refusal. Spinal anesthesia is usually provided with hyperbaric lidocaine, bupivacaine, or tetracaine. Lidocaine, with the most rapid onset and shortest duration, is appropriate for procedures lasting less than 45 minutes. Bupivacaine and tetracaine have a duration of approximately two to three hours. The incidence of spinal headache is decreased in the elderly and when small gauge spinal needles are used. Epidural anesthesia is introduced either through a needle or catheter placed in the epidural space. The onset of the epidural block is dependent upon the local anesthetic agent used. The catheter technique allows for intermittent reinjection to provide anesthesia for lengthy procedures. Frequently used drugs for this include 1.5 to 2% lidocaine and 0.25 to 0.5% bupivacaine. Epinephrine in a 1:200,000 concentration is frequently added to reduce the systemic vascular uptake and potential toxicity of the local anesthetic, as well as to prolong the anesthetic block. Regional anesthesia has yet to gain widespread application for laparoscopic procedures. This is attributable to the high sympathetic level required, the frequent position changes (which may affect patient comfort as well as anesthetic level), and the circulatory and ventilatory effects imposed by the pneumoperitoneum.

Local anesthesia in combination with intravenous analgesics/amnestics is gaining popularity for some laparoscopic procedures.[25] Advocates cite its safety, rapid recovery, and minimal physiologic disturbances. Patient selection is of utmost importance when considering performing laparoscopy under local anesthesia. The patient must be cooperative, well informed, and highly motivated. The patient will require thorough preoperative instruction in what to expect intraoperatively, as well as continual reassurance by the anesthesiologist during the procedure. This technique requires a surgeon adept in the gentle, precise manipulation of the laparoscope under local anesthesia. It also involves skin and subcutaneous tissue infiltration with local anesthetic at the trocar insertion sites and along the axes of suspected movement. Intravenous sedation may be provided with a combination of a benzodiazepine, usually midazolam, a short-acting narcotic such as fentanyl, alfentanil, or sufentanil, and intermittent or continuous administration of propofol, especially at the time of local infiltration. The anesthesiologist's goal is a somnolent but responsive patient who can maintain his own satisfactory respiratory status.

A significant degree of intra-abdominal anesthesia can be provided by the intraperitoneal lavage of local anesthetics.[26] This is especially useful as an adjunct to local or regional anesthesia when the peritoneum and its contents are not completely anesthetized. It may also be utilized with a general anesthetic, allowing the anesthesiologist to maintain a lighter depth of anesthesia in order to speed postoperative recovery. Toxic reactions are rare, as long as the maximum recommended doses are not exceeded. The usual volume instilled is 200 cc and the onset of action is approximately 3 to 8 minutes, depending on the agent used. Local anesthetic choices include 1% procaine, which provides a 30-minute duration; 0.5% lidocaine, which provides a 45-minute duration; and 0.1% tetracaine, which provides a 1-hour duration. Limitations to the use of local anesthesia for laparoscopy include those discussed for regional anesthesia, as well as the risks of excessive intravenous sedation and local anesthetic toxicity.

Monitoring for laparoscopy must take into consideration the patient's cardiopulmonary status and the planned surgical procedure. Routine intraoperative monitors, especially pulse oximetry and capnography, are essential since hypoxemia, hypercarbia, and dysrhythmias are of primary concern. Controversy exists regarding indications for radial artery cannulation in order to continuously monitor blood pressure and obtain frequent blood gas determinations. The commonly used $ETCO_2$ monitor has been shown to accurately reflect changes in the arterial CO_2 in healthy patients. A study of patients with cardiopulmonary disease, however, revealed significantly increased arterial CO_2 and decreased arterial pH, despite the absence of significant alterations in the $ETCO_2$. This is most likely explained by significant V/Q mismatching in this patient population. Therefore, radial artery cannulation may be indicated in these patients or when intraoperative difficulties of hypoxemia, elevated peak airway pressures, or high $ETCO_2$ values occur.

All patients, regardless of the anesthetic technique employed, are observed in a recovery unit. The incidence of postoperative nausea and vomiting is significant following laparoscopic procedures and may be as high as 40%. Metoclopramide, droperidol, and other antiemetics have been shown to effectively decrease this incidence.[27,28] Residual intraperitoneal gas may cause diaphragmatic irritation and referred pain to the shoulders and chest. These complaints are frequently noted in the recovery room and can be difficult to distinguish from symptoms of cardiac origin. A high index of suspicion must be maintained in those with significant cardiac risk factors or pre-existing coronary artery disease. Finally, all outpatients must be discharged with a responsible adult who will accompany the patient home. This adult, as well as the patient, are informed of postoperative instructions and potential delayed complications. They are also instructed whom to notify should problems arise following discharge.

Thoracoscopy

The technique of thoracoscopy differs from laparoscopy in several respects. There is no gas insufflation; the visual field and operative exposure are created by unilateral lung deflation with a double lumen endotracheal tube and selective one lung ventilation. There is no exogenous source of carbon dioxide with its attendant problems. The major physiologic changes noted during thoracoscopy are a result of the lateral decubitus position and one lung ventilation. The primary advantage of thoracoscopy is its lessened impact on postoperative ventilation. It has been shown to produce less postoperative pain, less pulmonary dysfunction, and provide a shorter postoperative hospitalization than open thoracotomy.[29]

Lateral decubitus positioning must be performed carefully to protect lines and tubes and to avoid patient injury. Strict attention to safe positioning practices to avoid neurologic complications is imperative. The lateral decubitus position allows gravitational forces to distribute more blood flow to the dependent lung and less to the nondependent lung. The dependent lung receives, on average, 60% of the total pulmonary blood flow. This increased blood volume may decrease the compliance of the dependent lung, and with controlled ventilation of both lungs, relatively more ventilation may be diverted to the nondependent lung. This can lead to significant V/Q mismatching.[30]

For thoracoscopy, however, the nondependent lung is collapsed by selectively ventilating only the dependent lung. This leads to an obligatory intrapulmonary shunt through the collapsed lung. Passive mechanisms, like gravity or surgical manipulation, may aid in reducing blood flow to the collapsed lung. However, the most important factor in reducing blood flow to the nondependent lung is hypoxic pulmonary vasoconstriction, an active vasoconstrictor mechanism. The pulmonary vasculature responds to atelectasis and hypoxemia by increasing pulmonary vascular resistance and diverting blood flow to ventilated lung units. There is a limit to this mechanism, so some shunting is always present.

Although animal studies reveal that inhalational anesthetics inhibit hypoxic pulmonary vasoconstriction,[31,32] a recent study reports no significant decrease in arterial oxygenation with inhalational anesthetics compared to intravenous anesthetics in patients undergoing one lung ventilation.[33] Furthermore, these agents are rapidly eliminated, allow for the use of a higher FiO_2, are excellent bronchodilators, and at one MAC (minimum alveolar concentration) have minimal cardiovascular side effects. This makes them very valuable anesthetics for thoracoscopic procedures.

The double lumen tube is technically more difficult to place than the standard endotracheal tube. It is usually inserted into the trachea following institution of general anesthesia and skeletal muscle paralysis. The tube is then properly positioned, either blindly or with the aid of a fiberoptic bronchoscope. Correct position is confirmed with the bronchoscope and chest auscultation.

Management of one lung ventilation is characterized by varying degrees of hypoxemia. The dependent lung has decreased volume secondary to compression from the abdominal contents, the mediastinum, and positioning effects. Fluid may transudate into the dependent lung and secretions may also accumulate. This V/Q mismatching in the ventilated lung, combined with the obligatory shunt of the nonventilated lung, can make hypoxemia severe. The initial treatment of this hypoxemia is utilization of an FiO_2 of 100%. The benefits of 100% oxygen far outweigh the risks of resorption atelectasis. Oxygen toxicity will not occur in the span of an operative procedure. Tidal volume is set at approximately 10 mL/kg and the rate is adjusted to maintain an arterial CO_2 of approximately 40 mm Hg. Hyperventilation is deleterious because the increased airway pressure may increase pulmonary vascular resistance in the dependent lung, worsening the intrapulmonary shunt. Hypocapnia may also inhibit hypoxic pulmonary vasoconstriction.

If hypoxemia persists despite these maneuvers, selective dependent lung positive end-expiratory pressure (PEEP) may improve arterial oxygenation by increasing the dependent lung volume. If the level of PEEP increases pulmonary vascular resistance, however, it may actually worsen arterial oxygenation as described above. Nonventilated lung continuous positive airway pressure (CPAP) has been shown to significantly increase arterial oxygenation by slightly but constantly distending the upper lung with oxygen. This allows some gas exchange in the nonventilated lung and simultaneously diverts more blood flow to the dependent ventilated lung. One may combine the above two techniques, called differential lung PEEP/CPAP, to provide the best arterial oxygenation and operative conditions possible.[34] A less desirable alternative is to interrupt the procedure and intermittently ventilate the nondependent lung to maintain arterial oxygenation. Finally, when hypoxemia is refractory to all these maneuvers, the unilateral clamping of the nonventilated lung pulmonary artery may be required. This maneuver may be particularly difficult to perform with thoracoscopy and may necessitate the conversion to open thoracotomy.

Monitoring during thoracoscopy involves routine intraoperative monitors and radial artery cannulation for continuous blood pressure recording and frequent arterial blood gas determinations. Intravenous access must consider the possibility of major vascular injury and/or the need for conversion to open thoracotomy. Central venous or pulmonary artery catheter placement is determined by the patient's pre-existing cardiopulmonary disease and the extent of the planned intervention. Similarly, decisions regarding postoperative mechanical ventilation must consider the patient's preoperative pulmonary function tests, cardiac status, acid/base status, O_2 carrying capacity, and the extent of the surgical resection. These decisions must be made on an individual case-by-case basis. Specific anesthetic drugs useful in thoracoscopy are similar to those discussed previously for laparoscopy.

Hysteroscopy

Visualization during hysteroscopy is frequently facilitated by gas insufflation. Carbon dioxide insufflation is commonly used for short office procedures and requires the use of a special insufflator. The risk of carbon dioxide embolism is a potential concern. For more extensive hysteroscopic procedures, the visual field is maintained by an irrigating solution. Many solutions have been utilized to provide optimal visualization and uterine distension while minimizing potential complications. Hyskon, a solution of Dextran 70 in dextrose, is the most commonly used medium for diagnostic hysteroscopy. The most significant complication of its use is fluid overload and pulmonary edema. The fluid not only leaks into the peritoneal cavity where it is slowly absorbed, but may be rapidly absorbed into the systemic circulation through open venous channels in the uterus. The risk of volume overload is increased in procedures lasting more than 45 minutes, when greater than 500 cc of Hyskon is infused, or when large areas of the endometrium are traumatized.

Other adverse reactions are rare but include fatal anaphylactic reactions, hypotension, itching or flushing, rash, chest tightness, dyspnea, cyanosis, coughing, wheezing, nausea and vomiting, oliguria, seizures, and coagulation abnormalities. Recommendations to minimize the risk of hypervolemia include instilling the Hyskon at low pressures and using the smallest volume that adequately distends the uterus.[35] The use of gravity-fed systems without extrinsic pumping devices may also be associated with less fluid absorption. Input and output should be strictly monitored and when a significant amount is unaccounted for, the procedure must be promptly completed. Hyskon is generally unsuitable for operative hysteroscopy because of the carmelization of the medium with electrocoagulation and temperature changes. For these procedures, glycine or sorbitol is usually used. These media can also lead to fluid overload and hyponatremia. As above, strict input and output measurements, a short duration procedure, and low infusing pressures can all help minimize these complications. Other complications of hysteroscopy include bleeding, infection, or uterine perforation.

Anesthesia for short diagnostic procedures is frequently provided with local anesthesia with or without intravenous sedatives. More lengthy or complicated procedures may require regional or general anesthesia for patient tolerance. The specific drugs and techniques have been discussed previously. One particular advantage of regional or local anesthesia is the ability to assess the patient's mental status for changes related to hypervolemia and hyponatremia, for example, confusion, restlessness, headache, nausea, twitching, and seizures. Awareness of the potential complications of this relatively noninvasive procedure is imperative regardless of the anesthetic choice.[36]

Summary

The extensive number of surgical procedures performed with endoscopic devices requires the anesthesiologist's understanding, recognition, and treatment of a new set of potential complications. The advantages and disadvantages of the various forms of anesthesia may differ depending on the patient's pre-existing cardiopulmonary status and the specific procedure planned. As always, open communication between surgeon and anesthesiologist is essential for the conduction of both a safe anesthetic and a safe surgical procedure.

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8.2 Local Anesthesia in Laparoscopy

Barry A. Salky

With the advent of laparoscopic cholecystectomy, the general surgeon was rapidly exposed to using laparoscopy in a therapeutic manner. General surgeons have been trained to assume that most procedures involving the abdominal cavity require general anesthesia. Therefore, it was natural to connect laparoscopic surgery to general anesthesia. After all, the gynecologists have been performing laparoscopic procedures for more than two decades using general anesthesia almost exclusively. However, laparoscopic surgery involves diagnosis as well as therapeutics. Most diagnostic procedures can be performed safely, adequately, and comfortably under local anesthesia. There are some therapeutic maneuvers that also can be performed with local anesthesia. It is the hope of the author that the reader will consider laparoscopic surgery as a diagnostic specialty as well as a therapeutic one.

Historical Review

Laparoscopy originated in 1901 when Kelling inspected the abdomen of a dog with a standard cystoscope.[1] However, its first use in the human was described by Kelling in 1910. Two years later, Jacobaeus published his classic monograph on laparoscopy and thoracoscopy.[2] Through the mid-1930s, only scattered reports appeared in the medical literature about this "exciting" new technique. In 1934, Ruddock published one of the first complete reports on laparoscopy in the United States.[3] It was this publication that was primarily responsible for the interest in laparoscopy in the United States. It described the technique (use of local anesthesia) and new instrumentation. During the 1950s and 1960s, significant advances were made by Beck,[4] Wittman,[5] and Vilardell.[6] Almost all of the progress was made in the diagnostic arena with development of better fiberoptics and ancillary instrumentation. This was especially true in the field of gynecology in which Semm had a major role.[7] As the field of gastroenterology became more well defined in the 1970s, Boyce and Palmer were leading proponents of this accurate diagnostic modality.[8] Dagnani and others made significant contributions in Europe at the same time.[9] However, the real breakthrough in therapeutic laparoscopic surgery occurred in March 1987 when Philippe Mouret performed the first laparoscopic cholecystectomy in a human.[10] That event has rapidly revolutionized the surgeon's approach to many diseases of the abdominal cavity.

Laparoscopic Technique

The most important part of using local anesthesia is proper communication with the patient beforehand. The patient must understand what will take place in the operating room or endoscopic suite so that he or she will be relaxed and cooperative. An uncooperative patient is an absolute contraindication to the use of local anesthesia in diagnostic or therapeutic laparoscopy. The use of verbal communication is far more helpful than all the hypnotics and sedatives that can be administered. Even the simple mechanics of what the holding area looks like, the nurses who will be present at the procedure, and the various operating room equipment stationed there, will decrease the patient's anxiety, and therefore, make the use of local anesthesia easier.

The patient also must be instructed how to push out the abdomen and, at the same time, keep the spine flat on the table (Figure 8.2.1). This relatively simple maneuver can be extremely difficult for some patients to perform. If the spine is arched forward while the abdomen is pushed forward, the potential for visceral or vascular injury increases. Excessive preoperative medication will make the patient less able to cooperate and perform this maneuver. Overmedication with intravenous diazepam-like drugs is not encouraged. This will be more evident in the older patient. Another way of thinking of it is to have the patient push out the abdomen while performing

FIGURE 8.2.1A. Cross table view of abdomen. The head is to the right.

FIGURE 8.2.1B. Cross table view of patient pushing out the abdomen. The head is to the right. The patient's back is kept flat on the table.

a Valsalva maneuver. These maneuvers are intended to tense the abdominal musculature in order to allow easy penetration of the abdominal wall by the Veress needle and the trocar.

Selection of the entry site is somewhat different under local anesthesia. Figure 8.2.2 depicts the most commonly used entry points. As many of the diagnostic procedures involve liver disease and portal hypertension, avoidance of the umbilical area and its potential collaterals is highly recommended. The epigastric vessels run approximately 3 cm off the midline. All transrectus incisions are measured 2.5 cm from the midline to avoid the vessels. If there is a significant amount of ascitic fluid present, the abdomen will be ptotic. Therefore, the incision should be placed higher than normal. If not, the laparoscope will not reach the liver for visualization. The use of the transrectus approach will also result in less postoperative herniation through the trocar site. In fact, the author does

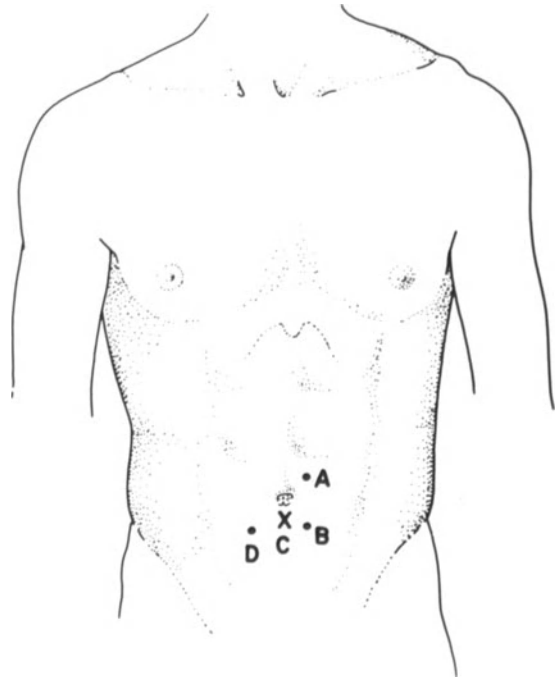

FIGURE 8.2.2. Potential puncture sites.

not routinely suture transrectus incisions unless ascites is present. The only transrectus postoperative hernia the author experienced was in a patient with cirrhosis and ascites. All midline fascial incisions should be sutured, as postoperative herniation with incarceration can occur.

Most diagnostic laparoscopic examinations take less than 60 minutes; therefore, any local anesthetic can be employed. The author does not recommend adrenaline with the local, as some patients get very anxious as a reaction. This makes the conduct of the procedure very difficult. The author routinely uses 0.25% bupivacaine.

As most of the somatic afferent pain fibers are in the epidermis, a generous wheal of local anesthesia is placed here (Figure 8.2.3). The length of infiltration will be dependent on whether 5- or 10-mm trocars are being used. With the skin as the apex and the parietal peritoneum as the base of a cone, the area is infiltrated with anesthesia (Figure 8.2.4). The author uses a 25-gauge hypodermic needle for the superficial infiltration and a 25-gauge spinal needle for the muscle, fascia, and peritoneum. With practice, each layer of the abdominal wall can be easily felt. The incision is made directly over the infiltrated skin. The subcutaneous tissue is bluntly separated with a hemostat down to fascia. The Veress needle is positioned perpendicular to the fascia, and the patient is asked to push out the abdomen (Figure 8.2.5). A distinct "pop" is heard as the needle traverses the parietal peritoneum. The patient should be told to relax the abdomen at this point. If the muscles remain tense, a falsely high pressure reading will occur. The standard saline drop test is per-

FIGURE 8.2.3. Close-up view of a generous skin wheal of local anesthesia. The head is to the left. The umbilicus is at the bottom right.

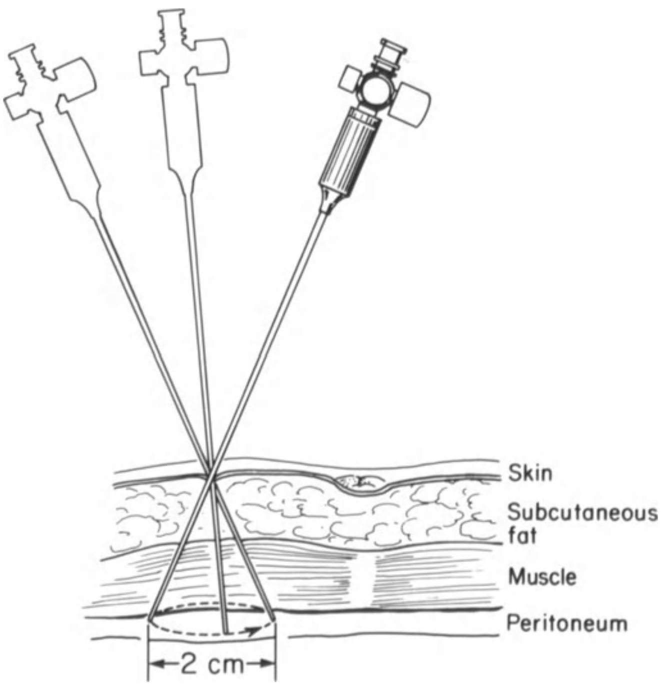

FIGURE 8.2.4. Cone.

formed to ensure the proper position inside the abdominal cavity. The abdomen is inflated with nitrous oxide. Nitrous oxide is the insufflation gas of choice when using local anesthesia. Carbon dioxide combines with the fluid in the abdomen to form carbonic acid, which is irritating to the parietal peritoneum and painful to the patient. Insufflation should be slow at 1L/min. Rapid insufflation is also very painful to the patient and should be avoided. The volume of insufflation should be kept to below 2.5 L. In the author's experience, it is very uncommon to need more than 2 L of N_2O. This usually translates to an

FIGURE 8.2.5. With abdomen pushed out (see Figure 8.2.1B), the Veress needle is inserted into the abdomen at right angles to the abdominal wall. The head is to the left.

intra-abdominal pressure of approximately 10 to 12 mm Hg. It is important to not over-insufflate the abdomen as is done with therapeutic procedures. The patient will develop a reflex bradycardia, which can be very dramatic. The Veress is removed, and the trocar and sleeve are positioned down to fascia. The patient is once again asked to push out the abdominal muscles. The back of the surgeon's left hand is placed on the abdominal wall, while grasping the sleeve and trocar (Figure 8.2.6). In this way the muscles can be not only seen to be tense, but also felt to be tense. With firm, steady pressure applied with the right hand, the trocar and sleeve are passed through all layers of the abdominal wall into the abdominal cavity. A circular, rotating motion will greatly facilitate its passage through the fascia.

The placement of second punctures are made under direct visualization. Figure 8.2.7 demonstrates the appropriate size parietal "wheal" to ensure a painless insertion. 10-, 5-, or 3-mm trocars can be placed depending on instrumentation needed. If the operator is careful not to touch the parietal peritoneum in areas unanesthesized, a complete laparoscopic examination can be performed. Biopsy of solid organs does require other anesthesia. If biopsies of other parietal surfaces are needed, direct local infiltration must be performed.

Electrocautery can be used in the presence of nitrous oxide, as long as there has not been an inadvertent injury to the intestine. Nitrous oxide is not a combustible agent. However, it will support combustion.

FIGURE 8.2.6. The back of the surgeon's left hand rests on the abdominal wall. The thumb and index finger help hold the trocar and sleeve, which is inserted at right angles to the abdominal wall.

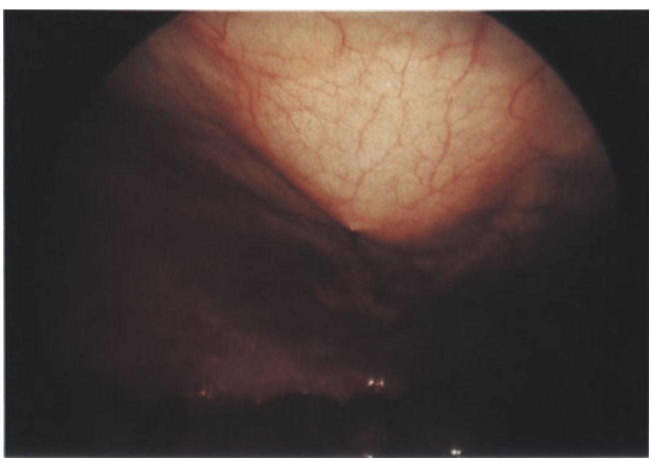

FIGURE 8.2.7. Wheal of local anesthesia is placed in the parietal peritoneum. The point of the 25-gauge needle is clearly seen.

Results

Local anesthesia is appropriate for most diagnostic laparoscopic procedures. Table 8.2.1 lists the most common indications. Laparoscopy was successfully completed under local anesthesia in 93% of the patients. There was one episode of reflex bradycardia that occurred early in the series. This was appropriately treated with intravenous atropine with prompt resolution and without sequela. If the patient is very uncomfortable and does not respond to the usual intravenous sedation, conversion to general anesthesia would then be indicated. Unless there are extenuating medical reasons, this procedure is performed on an ambulatory basis.

TABLE 8.2.1. Common indications for diagnostic laparoscopy.

Indications	No. of Patients
Abdominal pain	276
Focal liver disease	255
Abdominal mass	101
Ascites of unknown etiology	78
Prelaparotomy or second look	69
Trauma	1

The literature is replete with articles documenting the effectiveness of local anesthesia in diagnostic laparoscopy.[8,11] The advantages to the patient are many. The risks of general anesthesia are negated completely, the recovery is more rapid than general anesthesia, and in high-risk patients, it appears to be safer than general anesthesia. It does take practice to become efficient, and there is definitely a learning curve. In the author's experience, it took about 25 procedures to learn how to place an effective block. Conversion to general will be more common in the early trials of the surgeon.

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9
The Team: Nursing's Perspective

Nissa Partain De Lisle, Karen Denise Jackson, Vangie Paschall, and Kevin Wagner

A commonplace item, one found in almost every household, was partially responsible for the explosion of endoscopy in 1980. The item? A VCR. The significant impact, and the rapid changes that were forthcoming, affected everyone working in the operating room. Several surgeons in various parts of the world were expanding the use of scopes with surgery, but it took substantial proof to make us believers. Interestingly enough, we are now backing away from using the VCR due to legal issues. More and more options for pictorial operative reports are available and will become as standard as the written operative report before too long.

Unlike open procedures, operative endoscopy requires the surgeon to rely more on the team, in a different way. The surgeon's "eyes" are in someone else's hands—a new, and somewhat uncomfortable feeling. The surgeon must also depend on the team to set up, operate, and troubleshoot a new array of instrumentation and equipment. This chapter is written from the operating room nurse's perspective. It is intended to assist the entire team in making endoscopic procedures run more smoothly. Such an approach to surgery requires a committed, competent, and organized team. This chapter covers the endoscopic team and their roles. Education of the team is also addressed, an area that has been overlooked in the past as surgeons were offered numerous courses, but few existed for the other team members. Room setup, instrumentation, equipment and complications, how to prepare for procedures and potential complications, how to react if complications occur, and how to keep the patient safe are covered from a nursing perspective. Teams must change in order to succeed with endoscopy. Resistance to change may have inhibited progress the past few years.

The Team

Preparation for a Procedure

With the advent of endoscopic surgery came the term *endoscopic team.* Although staffing situations and team member titles will vary from one institution to another, a few roles are universal. Each operating room suite should have an endoscopy coordinator or team leader. In a large institution where a high volume of endoscopy is performed, this may be a full-time position, while in a smaller institution, several people may share the responsibility of making sure that things are well coordinated. Someone should be specifically responsible for ensuring that all equipment and instruments are in working order at all times. Staff training needs to be systematic and consistent.

When an endoscopic procedure is posted, the availability of staff, video equipment, and instrumentation must be considered. Some of the following questions should be asked. First of all, where does this case fall on the surgery schedule? Is there more than one endoscopy procedure posted for that day, and, if so, is it in the same room? If they are not in the same room, will they possibly overlap? Is there more than one complete set of instruments and video equipment available in case they do need to be going on simultaneously? This is not usually a problem in a large institution but could be in one that is not accustomed to higher volumes of scope cases. If possible, it is best to arrange the schedule to avoid possible conflicts. Endoscopic surgery can be very unpredictable, especially early in the surgeon's experience. A planned two-hour procedure can easily turn into a four-hour procedure if complications arise. This may affect surgical cases slated to follow. The endoscopic coordinator should be aware of this and plan accordingly.

Circulating Nurse

Ideally, two circulating nurses should be assigned to every advanced endoscopic procedure: one to take care of direct patient care circulating duties, and the other to assist the scrubbed personnel with video equipment, set-up, and supplies. The circulator must be familiar with how to set up and troubleshoot equipment such as video systems, irrigators, and energy sources. Knowledge of the different types of endoscopic instruments, their general use, and location is essential. Surgical endoscopy should be considered a specialty in itself and, just as the cardiovascular service has a specialized team of circulators for open heart procedures, the same staffing philosophy should be adopted for endoscopic surgery when possible. Because it is difficult to really learn a surgeon's routine with sporadic exposure, rotating nurses in and out of endoscopy procedures can create frustration, not only for the nurses, but also for the surgeon working with different staff from day to day.

Scrub Nurse

The scrub nurse/technician role may be filled by an individual employed by the hospital or may be someone employed by a physician or group of physicians. Many surgeons find it beneficial to hire a private scrub because having someone who knows his routine and set-up for every procedure can make things go more smoothly. The same benefit to the surgeon can be obtained by assigning the same personnel to scrub on all scope cases. The scrub nurse should have a thorough knowledge of all instruments and their uses. It is important to know the difference between a grasper and a dissector and what instruments are traumatic versus atraumatic. All instruments should be checked for intact insulation, sharpness of reusables, and ease of opening/closing instrument handles. Of course, the scrub nurse should ensure that all potentially necessary equipment and supplies are readily available. It is also important to be familiar with the different methods of obtaining hemostasis, such as use of monopolar and bipolar cautery, other energy sources, endoloops, endoknots, intracorporeal and extracorporeal suturing techniques, and use of endoscopic stapling devices (including the proper trocar sizes used with different sized staplers). If trocar sizes need to be changed, transfer rods must be available. The possibility of converting to an open procedure is always present in endoscopy. It may occur in an emergency situation, and the scrub nurse should know how to quickly set up and pass instruments for the open technique.

Camera Operator

The camera operator is another member unique to the endoscopic team. This role is crucial to the successful and safe completion of an endoscopic procedure. Since the camera operator serves as the eyes for the surgeon and assistant, absolute familiarity with the planned procedure is vital. This individual should be skilled at scrubbing the same procedure. This ensures familiarity with the sequence of events and with what the surgeon feels is important to visualize at different stages of the procedure. It is worth mentioning that the camera operator must have good visual acuity at the distance at which monitors are placed. What is considered a clear image by the camera operator must also be clear to the rest of the team.

The camera operator should be familiar with techniques for obtaining and maintaining a clear image throughout the procedure. Proper white balancing of the camera is essential and must be done correctly each time the camera is turned on. It is important to make sure the scope lenses are free from scratches or smudges, and that the eyepiece and camera are completely dry before connecting them. Rinsing scopes in warm water and using an antifog solution will help decrease fogging when entering the abdominal cavity. When the scope becomes dirty, the best way to clean it is to take it out and wipe it with a wet sponge. When it is not feasible to remove the scope, a quick touch with a side swipe on the liver or uterus will often clear the lens nicely. Do not leave the scope in contact with any tissue for a prolonged period of time, as this could result in a burn. It is best not to touch the bowel at all with the scope. Irrigating the lens from within using the suction/irrigator is also a good way to clear the scope when removal from the abdomen is not an option.

The camera operator should always keep the surgeon's instruments in the middle of the screen. This helps the surgeon maneuver instruments safely by keeping them and their immediate surroundings in view. The position of the surgeon's instruments is constantly changing and the camera should follow these changes. The assistant is also maneuvering instruments and should not be forgotten by the camera operator, especially when the surgeon is changing instruments. This is often a good time for the assistant to reposition graspers and it is important that the camera operator facilitate this. The camera operator's eyes should not leave the abdominal/chest cavity as long as an instrument is still in. The temptation to assist the scrub nurse or look at something else in the room must be avoided. When the surgeon re-enters the abdominal cavity after changing instruments, the camera operator should always make sure the surgeon can see where the instrument is entering.

The camera operator should white balance the camera properly, as this is the basis for a good image with true color. Improper white balancing can adversely affect the image on the monitor. Care should be taken not to get the scope too close to the operative site, as the surgeon requires a clear view of the surrounding area. When zooming in or panning out with the scope, the focus may change and should be adjusted as necessary. The camera operator should be able to focus smoothly without moving the scope. It is helpful to keep one hand on the camera head and two fingers of the other hand on the focus ring so slight adjustments can be made smoothly. As the camera operator gains proficiency, the need to be prompted to adjust the focus decreases, facilitating a smooth procedure.

Patient Educator

Another team member, often overlooked, is the patient educator. This role is often filled by several different people, such as the office nurse, the admitting nurse at the hospital, the floor nurse, the holding area nurse, or by an RN first assistant. Education should begin with an assessment of the patient's understanding of their disease process and of their upcoming surgical procedure. Allowing the patient to ask questions first will give the nurse an idea of what areas are of particular interest/concern for the patient.

Patients should be instructed to bathe the evening prior to surgery with special attention given to cleansing the umbilicus. They should be instructed not to eat or drink anything after midnight. Explain that they can, however, rinse their mouths and brush their teeth the morning of surgery. If a bowel prep is ordered, an explanation of its importance may help the patient's tolerance and compliance with the process. Explain the use of a Foley catheter to keep the bladder drained during long procedures, and that the patient may wake up with one still in place. The patient should know that an intravenous line will be started in the holding area and that possibly a prophylactic antibiotic will be administered at this time. A sequential compression hose will also be put on in the holding area if ordered by the physician.

The patient educator should give patients a general overview of the sequence of events they can expect upon arrival to the hospital the morning of surgery. Include family members by letting them know where to wait, the approximate length of the procedure, and how long after surgery they can expect to wait before getting to see the patient. Discharge planning can begin in the preoperative stage and should cover postoperative pain management, activity, diet, and wound care. The patient should be instructed to call the surgeon if abdominal pain of increasing intensity develops as this could be an early sign of bowel perforation and should be evaluated as soon as possible.

First Assistant

Traditionally, the role of the first assistant has been filled by another surgeon. This is changing rapidly and many first assistant positions are being filled by RN first assistants or surgical technicians trained to assist at surgery. One of the many benefits of using a non-physician first assistant is his or her availability, since another surgeon may be called upon to tend to his/her own practice. Having an assistant trained by the surgeon who knows the surgeon's routine and preferences can often make a procedure go better. Many RN first assistants make preoperative and postoperative visits, and serve as a liaison between the surgeon and the rest of the endoscopy team, as well as between the surgeon and the patient. Non-physician assistants can be hospital based, privately employed by the physician, or independent contractors.

Intraoperatively, the first assistant's primary function is to provide visualization and exposure of the operative site. This is accomplished by manipulation of tissue with endoscopic instruments, possibly holding the camera, or both. Many assistants also put trocars in under direct visualization. Depending on their skill level, the first assistant may also close skin incisions. A first assistant in endoscopic procedures should thoroughly understand insufflation techniques, including proper pressure and flow rates. It is also important to know the steps of the planned procedure, the details of the anatomy involved, and what to do should a complication occur. Skill using all hemostatic devices should be acquired, including techniques for intracorporeal and extracorporeal suturing and knot tying.

Team Education and Planning

When preparing for an endoscopy procedure, the team should begin with in-depth education about the procedure itself, including the disease process for which the surgery is indicated, basic anatomy of the involved system, and the steps of the operation. The surgeon is an excellent resource person. If the surgeon is willing to share video tapes, journal articles, and course materials with the team, this will facilitate better preparation for his/her endoscopy procedures.

An open line of communication between the surgeon and at least one member of the endoscopic team is essential in planning. The day before a new endoscopic procedure, the coordinating team member should feel free to call the surgeon and discuss specifics about the planned procedure. Information to be obtained from the surgeon should include special equipment/supply needs (stapling devices, energy sources, special sutures, etc.). It is also important to know required patient position when setting up the operating room.

The best way to prepare for an endoscopic procedure is to do a practice run from beginning to end. Arranging equipment, positioning a team member, and practicing with a pelvic trainer or a cardboard box will give the team hands on experience and will be invaluable during the actual procedure. The camera operator can practice running the camera while the first assistant practices intracorporeal/extracorporeal suturing and knot tying. A piece of raw chicken works well for practicing tissue manipulation with endoscopic instruments. If using endoscopic stapling devices for the first time, the scrub nurse should practice loading cartridges, firing the instrument, and reloading it. A practice run also gives the circulator a chance to practice setting up the room and hooking up equipment. This is also a good time to practice troubleshooting techniques.

Even though many specialties are now performing advanced endoscopic procedures, there are some basic equipment and instrument requirements common to almost all specialties. A generic endoscopic preference card would look something like the one that follows:

Generic Endoscopic Preference Card

EQUIPMENT
High-resolution camera
Scopes (5-mm, 10-mm-straight and angled)
Xenon light source with fiber optic cord
High-flow insufflator
High-resolution television monitors (× 2)
VCR and other recording equipment
Energy source
Irrigator/aspirating device

ENDOSCOPIC INSTRUMENTS
Graspers-traumatic/atraumatic
Dissectors
Scissors
Trocars (varies with procedure)
Blunt probe
Transfer rod
Fine needle for injecting
Larger bore needle for aspirating
Cautery cord
Cautery handpieces
Irrigating handpieces
Needle holders
Suture passers
Veress needle or Hasson trocar

SUTURE
Fascia
Skin
Endoloops (available)
Endoknots (available)

NONENDOSCOPIC SUPPLIES
Knife
Sponges
Saline-filled syringes (one for drop test, one for foley)
Towel clips × 2
Small retractors
Tissue forceps with teeth
Needle holders
Suture scissors
Suction tubing with tip
Foley catheter and drainage bag
Cautery pencil
Rinse basins (if applicable)

GASTRIC
Patient position: Lithotomy (surgeon between legs)
10/11-mm trocars (× 3 or 4)
Esophageal dilators (for anesthesia)
Flexible esophagoscope and related equipment
48 in. long 2–0 Prolene suture (for Nissen/Toupet)
Needle holders
Knot pusher
Endoscopic stapler
Endoscopic clip applier
Endoscopic linear cutters
Double lumen endotracheal tube for anesthesia
Pediatric flexible bronchoscope and light source

COLON/RECTAL
Patient position: Supine or low modified lithotomy. Table position will change frequently—use electric table
Laparotomy instruments
Endoscopic clip appliers
Endoscopic linear cutters
18-mm trocar with transfer rod
10/12-mm trocars (× 3 or 4)
33-mm trocar with transfer rod
Intraluminal circular stapler
Suture for sewing pursestring around anvil
Traditional linear cutters
Traditional linear staplers
10-mm endoscopic bowel instruments (Babcock, DeBakey)
Colonoscope with related supplies

Each specialty has some equipment unique to the type of procedures done in that particular area.

THORACIC
Patient position: Posterior lateral on bean bag
Open chest instruments
Chest tube and air evacuation system
Thoracic trocars
Endoscopic thoracic instruments

GYNECOLOGY
Patient position: Low modified lithotomy; Trendelenburg
Right angle retractor
Assorted weighted speculums
Single double toothed tenaculums
Uterine dilators
Uterine sound
Sponge stick
Uterine manipulator
Clamps for uterine pedicles (LAVH)
Bipolar forceps
Endoscopic linear cutters (LAVH)
Dilute Pitressin solution
7/8-mm trocar for CO_2 laser handpiece
10/12- or 18-mm trocar for removing ovaries or other masses
Morcellator for large specimens
Flip top reducers
Endoloops and endoloop passer

Energy Modalities

There are several choices of energy modalities that can be used in laparoscopic surgical applications. The surgeon chooses the appropriate energy and delivery device depending on the need. The most commonly used energies are electrosurgery, laser, harmonic scalpel, and argon beam coagulator. Each has specific characteristics, safety, and delivery system considerations.

Electrosurgery

Electrosurgery is the most commonly used, and least understood. While physicians attend a course in laser physics and safety prior to performing laser surgery, this is not a requirement in electrosurgery. Electrosurgery can be used very effectively within set safety parameters. The basic concept of electrical energy is that, because of their electrolyte composition, tissue cells act as electrical conductors. The fundamental rule of electricity is the path of least resistance, and this becomes a function of the water content of the cell. As the fluid reaches a temperature of 100°C, vaporization dries up the cell. The different rates, blinds, and delivery tips determine the effect on the tissue.

It is important that the endoscopic team understand wattage and voltage. Voltage is the electrical force through tissue, and can be altered on the electrosurgical unit (ESU) by setting the unit on a pure cut or blends. These wave forms change the amount of voltage delivered; for example, a Blend I on most units has an 80% on and 20% off. The longer off time, such as with Blend IV of spray fulguration, the higher the peak voltage, resulting in an increased percentage of spark jump. This is significant in laparoscopy because of the close proximity of other instruments and structures. Wattage is energy converted to heat. The combination of different wattage and wave forms will determine the tissue effect needed by the surgeon. Power density (the amount of wattage delivered over a centimeter squared of tissue) also determines tissue effects; for example, a needle tip probe will have a higher power density than a ball tip probe because of the smaller surface area. This increases the resistance and electrical concentration.

When delivering electrosurgical energy, there are three effects to tissue. Desiccation is low coagulation without sparking. This produces a soft brown eschar and optimally the best effect to control bleeding. Resting tissue of the cell is 32°C and irreversible damage occurs at 44°C. Creating a hard, black eschar will not provide the coagulation required for hemostasis. Instead, pulling the eschar off the vessel wall once it sticks to the instrument causes further bleeding. Eschar also conducts heat, and if left on tissue causes additional thermal damage. Fulguration is sparking without cutting to coagulate and a cutting mode is sparking to produce cutting. The desired tissue effect determines the selection.

There are unique issues when electrical energy is delivered through a scope: increased moisture, limited visibility, and limited access. Sparking to a secondary location may occur with a well-insulated instrument. The tissue is desiccated and the electrical energy takes the path of least resistance to a nearby site. Tissue resistance at the distal site occurred in earlier monopolar deliveries when the gynecologist performed laparoscopic tubal ligation. As the tissue was coagulated, the electrical energy would flow back through healthy tissue because of the decreased resistance. Examples were ovarian death and bowel burns. It is also important for the scrub nurse to consistently inspect the insulation of monopolar delivery systems. The smallest amount of metal exposure can cause an electrical flow from that defective area.

As the laparoscopic team began to do more advanced procedures and a variety of instrumentation was introduced, another issue resulted, capacitive coupling. Capacitive coupling of electrical current occurs when a portion of the current is allowed to couple with an insulated probe to a secondary metal surface. The electrical current enters the body in an alternate site, setting up the possibility of a burn. This can happen even with a well-insulated instrument. Capacitive coupling is not an arcing of current, but an electrical charge of one metal surface to another. It happens when the electricity cannot return out and discharge through the abdominal wall to the ground plate because of a poor conductor, such as a plastic stability thread or a plastic trocar sheath. Examples of capacitance are a metal trocar with a plastic sleeve with monopolar delivery, or an operative scope with monopolar delivery with a plastic sleeve or trocar. The way to safely deal with this situation is to eliminate the secondary metal surfaces by which the electrical current could couple, or by providing a means to allow the current to effectively and safely discharge to the abdominal wall.

There are specific safety considerations when using electrosurgery laparoscopically, but there are other safety parameters that should be enforced during the intraoperative phase. The ESU is a high-risk piece of equipment and requires a validated skill, as per Association of Operating Room Nurses (AORN) recommended practices. A Return Electrode Monitoring (REM) system should be a consideration when purchasing the system. This feature will not allow the energy to discharge when the grounding plate detaches. Inservice to all personnel involving a return demonstration of the groundplate and the appropriate attachment sites should be given. Emergency Care Research Institute (ECRI) statistics state that 70% of the burns occur at the plate site. Last, but not least, continuous staff development can make a potentially dangerous device a useful and cost effective way to deliver energy in surgery.

Laser

Laser is another means of delivering energy through a laparoscope. Lasers have become wavelength specific and specialty specific in their uses in surgery. Due to the advancement of electrosurgery technology, lasers play a small role in laparoscopic applications. The more common wavelengths used laparoscopically are the CO_2, NdYag, and the 532/KP. The CO_2, NdYag, and KTP lasers are used in gynecological applications and have limited use in general surgical laparoscopic procedures.

For precisional delivery, nothing matches the capability of the CO_2 laser, the most precise energy modality currently in the operating room, but be aware, it is only as good as the user. It is not a substitute for good technique or good judgement. The disadvantages are the rigid articulating arm delivery system and the high cost, ranging from $30,000 to $100,000. Delivery devices have improved with the introduction of a fiber guided system, but the rigid arm still attaches to the device. Until facilities can recognize the laser as another tool in the operating room, it will be difficult for the surgeon to choose the best tool for the application without stopping to consider the cost.

The NdYag laser with a contact probe is very precise and has the ability to coagulate vessels in a contact mode of 1 mm in diameter. The fiberoptic delivery device makes the access to tissue easy for the surgeon, allowing tactile feedback. Because there is no real justification for precise delivery with laparoscopic cholecystectomies, and because surgeons were already familiar with electrosurgery tissue response, the NdYag took a back seat with this application. It serves an advantage in procedures where precision is needed, such as laparoscopic ectopic pregnancies where the surgeon intends to save the tube.

The KTP 532NM laser was introduced to the general surgeon with the advent of laparoscopic cholecystectomies. It also has a fiberoptic delivery that allows good tactile feedback for the surgeon. The tissue characteristics of the KTP laser are peripheral coagulation with a high absorption in oxyhemoglobin. It is a near contact laser that allows a defocus mode to be used and can provide coagulation of blood vessels up to 2 mm in diameter. Cost and the learning curve of the KTP 532NM was replaced by the electrosurgery unit.

Harmonic Scalpel

The harmonic scalpel is a fairly new laparoscopic tool and has proven quite useful because of its coagulation and precision. Other characteristics that make it a safe tool are the absence of smoke, no muscle or nerve stimulation, and no currents or sparks. The harmonic scalpel is composed of a generator and a 5- and 10-mm handpiece. The generator sends an electric signal through a shielded coaxial cable. This in turn is delivered to a transducer in the scalpel handpiece. The transducer converts electrical energy to a mechanical motion resulting in vibrations of 55,000 cycles per second at the blade tip. The blade motion couples with tissue protein, the energy disrupts and denatures the protein, and then it is heated and coagulated. Even though smoke is not produced, an aerosolization of cellular particular matter is created. The scalpel comes in a variety of tip configurations and is a disposable device in the 5-mm probe at this time.

Argon Beam Coagulator

The argon beam coagulator (ABC) was initially introduced in open laparotomy. Dr. James F. Daniell completed the clinical trials on the ABC 5- and 10-mm probes for laparoscopy. Argon gas is an inert, noncombustible gas that is easily ionized and is heavier than air. The mechanism of action is radio frequency energy that ionizes argon gas. This creates a bridge between the electrode and tissue, displacing nitrogen and oxygen. The characteristics are cutting and coagulation with a depth of 2 to 3 mm into tissue. Features of the ABC include decreased tissue adhesion to the electrode and decreased smoke production in a noncontact mode. A disadvantage to the ABC is the flow of argon gas at 4 L/min, which requires constant venting of the intraperitoneal gas pressure to prevent overinsufflation. Just as with the conventional electrosurgery unit, the patient must be grounded. The cost of the ABC is approximately $15,000 and a disposable charge for the 5- and 10-mm probes. Because the laparoscopic surgeon is comfortable with the use of electrosurgery, adaptation to the ABC is minimal.

Possible Hazards

There are many safety issues that need to be considered as new technology is introduced into surgery. One of the most controversial topics is the hazards of surgical smoke. Not only is there a hazard to the operating room personnel, but to the patient. For years the American National Standards Institute has recommended practices on providing high filtration smoke evacuation systems for smoke generated from laser procedures. Only recently has it been proven that all smoke and aerosolization of particulate matter is a result of all energy modalities. There is no such thing as safe smoke. Resources for hazard reduction are the American Standards Institute (ANSI), the Centers for Disease Control (CDC), the National Institute of Occupational Safety and Health (NIOSH), and the Association of Operating Room Nurses (AORN), which recently released the recommended practices for smoke evacuation.

When any energy impacts tissue, two things can occur, vaporization or aerosolization of tissue. Vaporization occurs when the cell membrane reaches temperatures greater than 100°C. Each modality has a different rate of work that results in different concentrations of smoke and viable particular matter. Nelson Laboratories in Sioux Falls, SD has a study that indicates 1 g of tissue vaporized by a laser is equivalent to three unfiltered cigarettes, and 1 g of tissue vaporized by a cautery is equivalent to six unfiltered cigarettes. Dr. Michael Baggish published a study showing the viability of HIV DNA and Dr. J. Garden followed, publishing a study showing the transmission of HPV.[1,2] In essence, the operating room team is smoking human parts without proper smoke evacuation.

Toxic gases are also a concern to the staff and patient. Gases such as benzene, formaldehyde, hydrogen cyanide, and many others are byproducts of smoke. These gases can exceed OSHA's maximum permissible limits if not properly removed. This is also what creates the odor in the room. Symptomatology exerted by the patient are that of carbon monoxide elevations. The symptoms are abdominal pain, headaches, nausea, and dizziness.

Proper protection of staff and patient is prompt removal of smoke through high filtration systems with proper inservicing and 0.3 filtration masks tied properly. The misconception that smoke from surgery is sterile, or not a health hazard, has been proven wrong. There is no such thing as safe smoke. Protect yourself, the staff, and the patient.

Advanced Surgical Equipment

An integral part of the success of a laparoscopic program is the proper selection and troubleshooting of advanced equipment. The cart should provide ease of access to the monitors and other accessory equipment during surgery. It is not realistic to think that once they are set up problems will not occur. There are many extraneous factors that influence the delivery of the energy and signals. Color coding connections with diagrams provides quick access to correct any problems. Video education regarding the mechanics of the signals should be provided to all team members involved. The monitor should receive the signal from the camera control unit to provide the optimal picture for surgery, and the last signal sent should go to the recording devices. Advanced video set up, such as video mixers, allow the team to see a picture within a picture, and to decrease possible complications because they can focus on the entire procedure.

Some of the problems associated with the monitors are: grainy pictures, interference, out of focus pictures, and terminating signals. Grainy pictures can occur with decreased light delivery, whether it is at the coupled portion of the camera to the scope or at the scope tip. Always begin at the scope end. If the camera has the ability to change focal lengths, keep in mind with the increased focal length you have increased light with decreased resolutions, and with a lower focal length the resolutions are increased and the light is decreased. Other factors are the optics of the scope, the diameter of the light cord, and inspection of all fiberoptics prior to the procedure. White balance if indicated should be on the scope with the light on high, on a pure white background.

Interference of the signal can occur when electrical cords and audio-visual cords intersect. Alignment of the different cords along the cart, and not placing the electrosurgery cords over the camera cables decreases interference. Medical grade monitors should be used and routinely inspected by biomedical support personnel. A defocused picture is usually a problem at the scope tip. Applying antifog solutions, warming the scope, or irrigating the scope tip clears the picture. If the electrosurgery tip gets too close to the scope tip the antifog solutions can cook onto the scope optics making the picture foggy and difficult to clear. Prefocus the camera to the scope prior to introduction into the abdomen instead of trying to focus intra-abdominally on one individual structure. If there is older equipment in the operating room suite, preassess the monitors for self-termination. If the monitor must be manually terminated by the staff, leaving the video cord attached to the slave monitor instead of the primary monitor eliminates an extra step when troubleshooting. If the primary monitor has not be terminated and the video cord remains attached, the signal continues to be transmitted through the cable, depleting the transmission of the signal to the primary picture. The need to terminate a video signal is characteristic of each individual video brand.

The insufflator used for advanced laparoscopic procedures should have several features: high flow replacement of CO_2 gas, gauges to monitor increased pressure and delivery of gas, alarm status for troubleshooting, and ease of use. Troubleshooting insufflation of the patient is not always a result of the equipment. As with the scope, begin at the delivery system first. Preassessment of the machine eliminates troubleshooting steps during the procedures. Check for CO_2 levels in the tanks, proper attachment, setting of dials, insufflation tubing, and filter size, and that it is turned on! Preassessment of the Veress needles or open laparoscopic trocars should be inspected before surgery. Reusable Veress needles are not interchangeable; a slight burr or bend and bioburden blockage will indicate high pressures on initial placement. Of course, surgeon technique is also a consideration with needle placement. Intra-abdominal flow setting should begin at 2.5 to 3.5 L/min and not be increased until after the patient has adjusted to the introduction of the gas. Keep in mind, with open laparoscopic technique, the larger diameter will not initially indicate CO_2 flow and will read at zero. The pressure must be present at 2.5 to 3.5 L/min to eliminate a rapid flow that can result in complications. Other factors such as fluid in the CO_2 line or tissue obstruction will also create elevated pressures. After pneumoperitoneum has been achieved, set pressures of the insufflator between 10 and 16 mm Hg. Each patient is different and the desired pressure is determined in each individual case. To help keep maximum flow during surgery, connect the CO_2 line to the most patent port. For example, use an alternate puncture site where the instrument diameter allows free flow of gas through the trocar port.

There are many types of irrigation systems available.

The irrigation pump keeps the surgical field clear, allows for introduction of medication, and removes excess fluid and energy carbon. Ringer's lactate is the desired solution and temperature should be at 37°C. Other devices can be delivered through the probe to eliminate an extra puncture site.

Reusable Versus Disposable Instruments

One of the most controversial issues in operating room suites today is whether to use reusable or disposable instruments. When the rapid evolution of laparoscopic instrumentation occurred, attempts were made to adapt to changes in technique as well as new procedures. Hospitals would order the instruments only to find they were back ordered for six months or a year. Upon arrival, the design was already obsolete, and the physician had been using disposables. Instrument integrity and quality is always a concern with both reusables and disposables. Monopolar delivery became the energy modality predominately used, and the insulation of the reusable instrument as well as safety issues were questioned. The number of uses was not monitored, and there was no guarantee as to the stability of the instrument during the procedure. An example is the sharpness of a pair of scissors or the ability of a grasper to hold tissue. Complications can increase because of defective instrumentation and increased operating time.

Sterility was addressed because of the difficulty in accessing ports and the configuration of the tool. Is there such a thing as sterile dirt? A patient can be allergic to the residual bioburden. Disinfection versus sterility was another concern. Would the health-care provider be able to guarantee the same standard of care to each patient? Other issues were the exposure of the personnel during the precleaning process, as well as following OSHA's guidelines for exposure. Each facility must address these issues when deciding to purchase reusable or disposable instruments. Reusable instruments can be mixed with disposables. The disposable instruments can supplement those instruments that are difficult to clean and maintain. The choices depend on hospital needs.

Cost is probably the biggest concern. Companies that make disposable instruments have now come up with cost saving kits and companies that make reusables have come up with reposables (with a cap on use to guarantee integrity). There are many hidden costs to reusables that should be considered such as the sterilization process, wrapping, and maintenance. These can push costs close to those of disposables. Supplementing reusables with disposables can help achieve the best of both worlds and still be cost effective. Each hospital must look at all issues when deciding whether to purchase reusable or disposable instruments. The goal is to meet the needs of the surgeon for the procedures as cost effectively as possible, and without compromise to the patient. In the words of Benjamin Franklin, "The best investment is the tools of one's own trade."

Complications

Recognition of potential complications by the endoscopic team is vital to the future success of laparoscopic surgery. Although complications of laparoscopic surgery are relatively rare, if recognized early, most are usually preventable or treatable. Laparoscopic complications, whether major or minor, may be categorized as *early* or *delayed*. Early complications are those that occur during the surgical procedure, and are recognized and corrected by the endoscopic team. Delayed complications may be subdivided into those that occur shortly after the surgical procedure (up to 48 hours immediately postprocedure), and those that occur at a subsequent date (up to two weeks postprocedure). Major complications include hemorrhage, gas embolism, perforation of viscera, and peritonitis. These have been reported to occur at an incidence of 0.6 to 2.49%. Minor complications like abdominal wall hematoma and subcutaneous emphysema occur with a much higher frequency ranging from 1.07 to 5.1%.

Bleeding/Vascular Injuries

Bleeding may be minimal, usually resulting from injury to a majority of small vessels, and it can be controlled by direct pressure. However, hemorrhage due to injury to a major vessel can be a life-threatening event requiring immediate alternative steps including but not limited to, cauterization, clips, suture ligatures, and vasopressive agents. Conversion to an immediate laparotomy due to vascular injury during laparoscopy should include direct pressure with the endoscopic instrumentation and maintenance of the pneumoperitoneum, both of which will have a tamponade effect on the vascular injury. Otherwise, during the few minutes while the team is converting to a laparotomy, an uncontrolled bleed may contribute to a greater amount of blood in the retroperitoneum, therefore causing delay in identification of the problem. The majority of vascular injuries have been reported in the literature as a result of Veress needle or principal trocar insertion. Review of needle and trocar designs and identifying factors that may contribute to injuries will greatly minimize risks of potential vascular injuries.

Infection

Infection, in the absence of bowel injury, is most unusual following laparoscopy. Cystitis may be more common due to cauterization or wound infection at the skin site of trocar insertion if skin is not properly disinfected. Prevention of infection in relation to care, handling, disinfection, and sterilization of endoscopic instrumentation must be carefully reviewed, and a standard of practice established. The value of prophylactic antibiotics is not yet well established.

Neurologic Complications

Potential for nerve damage, not new to perioperative nurses, is generally due to improper positioning of the patient prior to a procedure. Injury to the brachial plexus, sciatic nerve, or the "shoulder-hand" syndrome may occur. Proper positioning and adequate padding of the surgical patient on the operating table should be a shared responsibility by the team and will help avoid neurologic complications.

Gas Complications

Subcutaneous emphysema during laparoscopy is reported to occur at a rate of 0.43 to 2%. It is primarily caused by improper positioning of the Veress needle or trocar through which CO_2 gas is introduced to establish the pneumoperitoneum. This improper position allows infusion of CO_2 gas preperitoneally or subcutaneously that may move along the anterior chest wall to the neck and face. This phenomenon may also occur during laparoscopic lymph node dissection or laparoscopic hernia repair. The CO_2 will readily diffuse along the confluent tissue planes of the pelvis, therefore resulting in genital emphysema. Subcutaneous emphysema most often will absorb without any consequences, although it must be brought to the attention of the surgeon and anesthesiologist, as the affected area may be covered by the drapes. A written, as well as verbal, report must document the incident.

Insufflation of carbon dioxide during laparoscopic surgery is generally safe when proper practices of insufflation are followed. Although gas embolism during laparoscopy is rare, the potentially fatal complication must be understood. When a venous carbon dioxide embolus enters the central circulation, complete cardiovascular collapse can occur without any advance warning. This is due to an air-lock in the right side of the heart obstructing the pulmonary outflow tract, and if of sufficient volume, also causing obstruction of venous return to the heart. The above-described air-lock or embolus manifests clinically with an immediate drop in arterial pressure and blood pressure, elevations in central venous pressure, cardiac arrhythmias and EKG changes, onset of a continuous cardiac murmur described as a "mill wheel" murmur, caused by the sound of large amounts of intracardiac gas mixing with blood, which is detected by an esophageal stethoscope. Additionally, continuous monitoring of end-tidal CO_2 can warn of air embolus, since there is an immediate decrease in the level of end-expired carbon dioxide caused by progressive reduction in lung perfusion relative to ventilation, thus increasing the physiologic dead space. Additionally, CO_2 embolus may elevate airway pressures during mechanical ventilation owing to bronchoconstruction and reduced pulmonary compliance.

Emergency treatment of carbon dioxide embolus during laparoscopic surgery requires immediate action by the entire team. The first and most important: discontinuation of the infusion of CO_2 and evacuation of CO_2 by releasing the existing pneumoperitoneum. Strong positive pressure ventilation as well as discontinuing the use of nitrous oxide and increasing inspired oxygen to 100% is recommended. Optimal patient positioning is the left lateral decubitus position. Manual aspiration through a central line may also be recommended but not applicable in all cases. Due to the rapid absorption of CO_2 when it does enter the central circulation, early recognition of the problem can result in successful emergency resuscitation, provided the embolus is limited to a small size and is treated promptly.

Organ Injuries

Injuries to the bladder and bowel most commonly occur in patients who have had previous surgery with adherence to the peritoneum. Emptying the bladder prior to the procedure may decrease the risk of injury. Discontinuing the use of nitrous oxide, which may distend the bowel, prior to the procedure may also decrease the risk of bowel injury. Bowel, bladder, and ureteral injuries may occur by either blunt or sharp dissection or by the improper use of electrical energies. The classic feature of unrecognized organ injury is lower abdominal or back pain occurring two to three days postoperatively, associated with nausea, fever, elevated white blood count, elevated creatinine and BUN, and decreased urine output. Bowel injuries associated with peritonitis need to be explored, exploration being a wiser choice than procrastination. Bladder or ureteral injuries may require urologic consultation, cystoscopy, ureteral catheterization, and close follow-up.

There are multiple possible complications directly related to laparoscopic surgery. However, keep in mind some important factors in prevention of complications: meticulous technique, appropriate patient selection, appropriate preparation (entire endoscopic team, instrumentation, equipment and supplies, patient preparation). Operator experience is an important factor, as most complications occur during the learning phase. Continuous staff development, education, and training of perioperative nurses in laparoscopic procedures will prove to be key in future success.

Conclusion

Hearing comments like, "endoscopy has impacted surgery as much as general anesthesia," helps us realize the importance of the changes endoscopy has brought. "Seeing structures we never saw via the open technique," is another comment that gives us insight to why endoscopy is here to stay. Technology will certainly play a huge role in the future. It will allow miniaturization of equipment so that space problems may be solved. We hear promise of visualization from three dimensional cameras returning to include a 360° view. Robotics may someday replace the camera operator, and then the team will need to adjust and change again. Education must become a priority for endoscopy to succeed. In order to increase patient benefits, contain costs, and decrease complications and operating time, there must be a commitment to staff education. Knowledge and experience enable us to feel comfortable with our performance with endoscopy.

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10 Teaching, Credentialling, and Privileging

Theodore R. Schrock and Thomas L. Dent

Laparoscopic surgery has presented a unique challenge to established mechanisms for educating and credentialling surgeons in new techniques.[1–3] Over a period of less than three years, it became necessary to teach a large proportion of practicing general surgeons to perform cholecystectomy in a radically different way. The development of flexible gastrointestinal endoscopy created a similar situation 20 years earlier, but the teaching of endoscopy to established surgeons, although more difficult in some respects, never stimulated anything like the enormity or the intensity of the effort to train surgeons in laparoscopic cholecystectomy.[2] General surgeons and other surgical specialists who work in the abdomen or chest continue to require a steady supply of training opportunities in the more advanced techniques that have followed cholecystectomy. The associated problems of credentialling and privileging have grown accordingly.[4] There has been great concern over the quality of the training programs and the criteria for credentialling and privileging.[2,3,5] These issues are discussed in this chapter.

Definitions

Certification and *credentials* both refer to the documentation of successful completion of a period of education or training, such as a medical degree, specialty board certificate, certificate of attendance at a postgraduate course, or a statement by a preceptor certifying competence.[1,4] *Competence* is defined as a safe and acceptable level of skill and can refer either to a physician's general ability within a specialty to care for patients or the ability to perform a technical procedure or group of similar procedures. Importantly, certificates and credentials documents may or may not contain statements of competence, and even when they do, certification does not guarantee competence in procedures that are not taught during the training period.[4] *Clinical privileges* are those functions and procedures that a physician is permitted to perform in the course of caring for patients in a given hospital.[4]

Initial Privileging

According to the Joint Commission on Accreditation of Health Care Organizations (JCAHO), the hospital governing board has ultimate responsibility for granting clinical privileges to practitioners who work in that institution.[6] The hospital, therefore, is charged with assuring the competence of each member of the medical staff. Each hospital must develop its own mechanism for granting clinical privileges, typically through a credentials committee, although this responsibility can be delegated to a clinical service chief. Usually, national criteria developed by specialty boards or specialty societies are adopted.[4]

A request by a physician for clinical privileges is evaluated by reviewing the applicant's credentials, general and specific training and experience in the privileges requested, and certification of competence by instructors or peers. In some hospitals, the clinical service chief makes an initial evaluation and adds his or her recommendation before forwarding the application to the credentials committee. If all items in the application meet the standards set by the reviewing body, a favorable recommendation to the hospital's governing board is followed by the granting of clinical privileges.

Some hospitals initially grant privileges provisionally, typically for six months, and assign a proctor to monitor the physician's work during the probationary period. Although the terms preceptor and proctor often are used interchangeably, there is a distinction: a *preceptor* is a teacher and a *proctor* is a monitor.[7] Thus, the preceptor is an active participant in the learning process, and the proctor remains an impartial observer. This definition places a great burden on a proctor who participates in a procedure and sees that the surgeon who is being proctored is about to make an error that may lead to a complication or even a disaster. According to the strict definition, a proctor should not intervene in such an instance. The ethical and legal issues raised by this narrow view are complex, and every surgeon who is asked to serve as a proctor should be familiar with them before the proctoring episode begins.[7] Upon receipt of a satisfactory report from the proctor, full privileges are granted. Clinical privileges must be renewed every two years, and in some hospitals, privileges must be renewed more often by some practitioners, for example, those over a specified age.

Privilege Lists

Each physician's clinical privileges are specified by the hospital. Privileges may be granted categorically, that is, privileges are granted in all procedures common to the specialty and defined by the specialty's accrediting board.[5] There are two disadvantages to the categorical approach, especially as it applies to surgeons. First, not every surgeon receives adequate training and experience during residency in every procedure that is claimed by that specialty. Second, new procedures may be developed after the applicant has completed training. An alternative is to grant privileges in a detailed list of procedures. An exhaustively complete and constantly updated list of this sort might contain hundreds of procedures, and it would be difficult to develop and maintain. If a surgeon performed any procedure that was not on the list, the surgeon would automatically have exceeded the limits of his or her clinical privileges, and a nightmare of administrative and legal problems would result.[5]

The best formula is a combination of the categorical approach and the detailed list.[4] Privileges are granted in categories of similar surgical procedures, such as "gastric operations" or "peripheral vascular operations." Additional listings or procedures may be required as discussed in the next section. Newly developed procedures are added during periodic review, and at the same time, procedures may be moved from the additional list to the standard privilege category after they have been incorporated into the residency curriculum for that specialty.[5]

A nagging problem that defies resolution for most surgical specialties is posed by the observable differences among surgeons in rates of postoperative complications, postoperative deaths, and eventual outcome of standard operations.[8] At present, privileges to perform most operations are granted to any surgeon who meets the requirements of training as discussed above. In some highly visible specialties, such as cardiac surgery and liver transplantation, tighter control of privileges to perform certain operations is beginning to appear, or is already in place, by mechanisms that include certification of centers and restriction of reimbursement. In a recent study documenting the differences in results of resection of colorectal cancer, the authors suggested—not for the first time—that such surgery should be concentrated in the hands of those with a special interest in this disease.[8] Greater supervision of health care by regional or national governing bodies is likely to bring more scrutiny of results and perhaps greater restrictions on who is permitted to perform certain operations.

Additional Privileges

Additional privileges are required for some new procedures.[1] The hospital must determine whether a new procedure is safe and effective, and then applications for privileges to perform the procedure can be considered. If a new procedure is not substantially different from an older one, it usually is regarded as covered under the umbrella of the initial privileges, and no further privileging is required. Attendance at seminars and postgraduate courses and reading of the literature are sources of cognitive information about new procedures, and learning of this sort may be sufficient for a surgeon to be able to incorporate minor variations of established techniques into clinical practice. But if a procedure is significantly different from those learned during residency, the credentialling process requires documentation of additional training and experience, and often proctoring in the additional procedure is necessary to establish competence before unrestricted privileges may be enjoyed. It is a basic principle that the physician should have expertise in the clinical area in which the new privilege is requested; that is, the physician should not attempt to enter a new specialty by the mechanism of additional privileging.

The credentials committee in each hospital must establish criteria for the granting of additional privileges in new procedures. The type of certification and credentials required, the method of assessing competence, and whether or not proctoring will be required should be included in the criteria. Guidelines for the granting of clinical privileges in new procedures are available from national specialty societies.[9] These guidelines are useful despite the potential for bias and protectionism.[5]

Judging which procedures need additional privileges and which do not is not always easy, but one useful test is to determine if the new procedure requires additional formal training in an animal laboratory.[5] If so, additional privileging is advisable. Additional privileges also should be required for procedures that are controversial, risky, associated with high visibility to accrediting agencies or the public, and those that will be performed by more than one medical or surgical specialty.[4]

Laparoscopic Surgery

Gastrointestinal endoscopy and laparoscopy are two types of procedures that require specific training before clinical privileges can be granted.[3,9–13] In the past, adequate hands-on training in new procedures was difficult for established physicians or surgeons to obtain. That certainly was true of efforts to learn gastrointestinal endoscopy outside a residency or fellowship program. Both the American Society for Gastrointestinal Endoscopy (ASGE) and the Society of American Gastrointestinal Endoscopic Surgeons (SAGES) have addressed this problem, and programs have been developed to provide opportunities for members to learn new endoscopic skills or enhance existing ones.[14]

Laparoscopic surgery, for the most part, began in the community; surgical training institutions were slow to respond to the remarkable changes that were underway.[2] Industry stepped into this void by creating courses that offered didactic material and hands-on training in animal laboratories to every surgeon with the interest and the means to participate. In the opinion of some thoughtful and concerned surgical educators, this development was unfortunate indeed because it avoided the quality assurance aspects of surgical training and it allowed the surgeon to be presented with a biased demonstration of untested techniques with the implication that these procedures could be applied to patients after a few attempts in animals.[2] Industry should not be blamed for doing what it is expected to do, namely design, manufacture, and market their products, but it is time now for the surgical community to regain control of the laparoscopic training of our young colleagues and eventual successors.[2] This change in surgical education is already well underway, and happily, industry has shown a willingness to underwrite this shift by support of endoscopic and technologic skills laboratories in academic centers.

The elements of a good training course include a comprehensive curriculum, an experienced faculty, and an extensive animal laboratory experience.[3,15,16] Not all courses qualify. Moreover, even at their best, courses to teach endoscopic procedures cannot match the training that a surgeon receives during residency.[17] Before long, the wave of established surgeons seeking to learn basic laparoscopic techniques should subside, and laparoscopic surgical courses will be devoted to teaching new and advanced procedures to surgeons who already have substantial skills and experience.[2,17] A skills laboratory will be a fundamental element of surgical residency programs in the future if it is not already.[2]

Guidelines for Privileges in Laparoscopic Surgery

SAGES has published guidelines for granting of privileges in laparoscopic general surgery.[11] Some hospitals have modified the guidelines to fit their own concepts and their own circumstances.[5] The requirements for privileging in laparoscopic general surgery as outlined in the SAGES document are as follows:

1. Completion of a residency or fellowship which incorporates structured experience in laparoscopic surgery. Competence should be documented by the laparoscopic training instructor.
2. Alternatively, demonstration of proficiency and clinical judgement equivalent to that obtained in a residency or fellowship program. Documentation and demonstration of competence with verification in writing from experienced colleagues are required.
3. For the surgeon who did not learn laparoscopic surgery during residency or fellowship, and who lacks prior documented experience in laparoscopic surgery, the basic minimum requirements for training are as follows:
   a. completion of a residency in general surgery with privileging in the comparable open operation for which laparoscopic privileges are being sought.
   b. privileges in diagnostic laparoscopy.
   c. training in laparoscopic surgery by a surgeon experienced in these procedures or completion of a university-sponsored or academic society-recognized course which includes didactic instruction as well as animal experience.
   d. first-assisting in laparoscopic operations performed by an experienced surgeon.
   e. proctoring by a laparoscopic surgeon who is experienced in the same or similar procedure until proficiency is observed and documented in writing.

The basic premise underlying the SAGES guidelines is that the surgeon must have the training, ability, and judgment to proceed immediately to a traditional, open abdominal procedure when circumstances so indicate. This premise excludes nonsurgeons from performing laparoscopic general surgery.

New Laparoscopic Procedures

New procedures and laparoscopic methods of performing traditional procedures are introduced frequently. The surgeon who is experienced in laparoscopic surgery can learn minor modifications at courses and by viewing videotapes that now are available from various sources, but operations that demand new skills require a return to the animal laboratory.[15] Simulators are in development, and they could prove very helpful in the future, but for now it is necessary to obtain experience by practicing with animals.[2,5] Courses in advanced laparoscopic surgery are given at some universities, and others are endorsed by SAGES. Typically, such courses include basic instruction in laparoscopic suturing techniques and hands-on experience with laparoscopic inguinal hernia repair, antireflux procedures, intestinal resection, and various thoracoscopic procedures.[15]

Cholecystectomy, the first laparoscopic operation to be performed with any frequency, has the same objectives and follows the same anatomic principles whether performed open or through the laparoscope. Other laparoscopic procedures likewise are virtually identical with open operations, including appendectomy, common bile duct exploration, pelvic lymphadenectomy, some forms of vagotomy, and some types of antireflux procedures. It seems appropriate that privileges in these procedures can now be granted to surgeons who have documentation of sufficient training or experience to meet the criteria suggested in SAGES guidelines.

Other laparoscopic procedures are quite different from open operations for the same conditions, and in other operations there is good reason to question whether the laparoscopic method can produce results equal to those of established open techniques. Examples of the former type of investigational procedure include laparoscopic inguinal herniorrhaphy, some forms of vagotomy, and some varieties of antireflux surgery. The chief example of the latter type of unproven laparoscopic operation is curative resection of the colon or rectum for cancer. The development of these operations by experts should be encouraged, but objective evaluation of these new techniques should likewise be encouraged.[18] Ideally, objective evaluation implies prospective controlled clinical trials; at a minimum, there should be close prospective monitoring and prompt reporting of outcome. If the pioneering surgeons do their work in an atmosphere of creativity tempered by scientific objectivity, all of our patients will benefit. If controlled studies are not initiated as soon as there is a new operative technique worth studying, vested interests will make it increasingly difficult to perform such studies as time passes.[18] As a consequence, the true value of a procedure may remain obscured by anecdote and opinion.[18] Pending sufficient data regarding the safety and effectiveness of investigational procedures, privileges to perform them should be granted only to surgeons who are engaged in objective evaluation, preferably a clinical trial.[5]

Monitoring Quality

Quality assurance programs are required to monitor the results of laparoscopic surgery as well as all other aspects of hospital medical care. If data reveal that a surgeon has results that fall below established standards, remedies include additional training, proctoring, or limitation of privileges. Continuing education is essential as it is in any other rapidly changing field.

Summary

The JCAHO has charged hospitals in the United States to evaluate the credentials of physicians and surgeons, to grant specific clinical privileges for medical practice, and to monitor the quality of care rendered by the staff. Laparoscopic surgery is a changing field, and new procedures are introduced frequently. The hospital must determine if the new procedure is investigational or if privileges may be granted now. The concept of categories or levels of privileges in laparoscopic surgery may be useful. In the *basic* category are privileges to perform diagnostic laparoscopy, staging procedures for cancer, and probably laparoscopic cholecystectomy and laparoscopic appendectomy. In the *established* category are procedures such as laparoscopic common bile duct exploration, certainly not a technically easy operation but one that raises few questions about its appropriateness to solve the pathologic problem. The *investigational* procedures described above require further supportive data before surgeons generally can be privileged to perform them.

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Section II
Laparoscopy and Thoracoscopy in General Surgery

11
Biliary Tract Disease

11.1 The Development of Laparoscopic Cholecystectomy and Its Impact

Jacques Périssat

Laparoscopic cholecystectomy is six years old. In this short period of time, it has created a veritable revolution in the surgical world. This swift conquest has been achieved by the pioneers of the method, thanks to the favorable opinion of their patients, who were immediately won over by the short and painless postoperative course, the quick return to normal physical activity, and the absence of functional or aesthetic sequelae. The patients themselves promoted the method, when the medical and surgical spheres remained indifferent or skeptical, not to say hostile.

The laparoscopic approach of digestive lesions has a short history. It owes its creation and its improvement to urologists and gynecologists. A purely exploratory technique in the 1950s, laparoscopy gradually became more and more interventional, especially after 1975.[1] The first digestive organ to be removed laparoscopically (in 1983) was the appendix. The appendix was first because of its accessible location and its pathological entanglements with the genital sphere. A gynecologist (Kurt Semm) who performed laparoscopic appendectomy was severely criticized at the time,[2] and even condemned by the board of German surgeons.

Who at that time could have considered performing cholecystectomy laparoscopically? Cholecystectomy, a century-old, perfectly codified procedure that could be performed by any competent surgeon, had reached a degree of near-perfection. Why attempt to modify the technique? Even P. Mouret, who was aware of the latest laparoscopic techniques, was not thinking of it.[3] Not even on that day of March 1987, as he was completing a gynecological procedure on a woman who was also suffering from symptomatic gallbladder lithiasis. He originally intended to remove the gallbladder through laparotomy. However, once he had completed the gynecological procedure, he shifted his laparoscope to the subhepatic area. Finding a comparatively free and supple gallbladder, he decided to remove it laparoscopically instead of opening up. He was able to do so after two and a half hours of effort. He probably did not think that this rather lengthy and difficult procedure would have any future. Perhaps that is why he did not publish this "world-first" operation.

François Dubois of Paris heard of Mouret's operation only by accident. Dubois had been practicing cholecystectomy by mini-laparotomy for several years, in an effort to minimize his patient's stress. Mouret's idea appealed to him and he soon gave up mini-laparotomy for laparoscopy.[4]

At that same time, following the example of urologists who performed internal lithotripsy using a percutaneous approach to the kidney, I was approaching the gallbladder percutaneously under laparoscopic control, introducing a lithotriptor and destroying calculi under visual control.[5] The procedure would end either with cholecystostomy by inserting an external biliary drain, or with cholecystectomy by dissection of the triangle of Calot, elective ligating of the cystic duct and artery, severing of the hepatic attachments, and removal of the gallbladder, emptied of its stones, through the 10-mm incision that had served to introduce the lithotriptor. By the end of 1988 and in 1989, cases multiplied, and our first results, all of them favorable, were published.[6] The procedure spread like wildfire thanks to video films, so easily produced in laparoscopic surgery, that were shown at professional meetings.

In April 1989 at the annual Society of American Gastrointestinal Endoscopic Surgeons congress in Louisville, KY, I presented a video of my initial technique, which included intracorporeal lithotripsy and was performed exclusively with electrocautery. It created a sensation. Most American surgeons still had not heard of the technique, although two of their colleagues, J.B. MacKernan[7] and E.J. Reddick,[8] had performed a few cholecystectomies in 1988 using a laser to dissect and cut. The laser made things more difficult, however, and delayed the popularization of the procedure. Confined at first to free papers and fringe video-forums, laparoscopic cholecystectomy became overwhelmingly present at congresses.

One of the turning points was the annual congress of the American College of Surgeons in San Francisco in October 1990, where a special session on laparoscopic cholecystectomy was organized. The session took place on Friday afternoon, the very last day of the congress, and this late session, normally poorly attended, was packed.

The novelty of the history of laparoscopic cholecystectomy lies in the fact that its success sprang from the patients themselves: the first successes of the pioneers generated massive demand from the patients, motivating surgeons to learn this technique. The traditional stages of scientific evaluation were bypassed, hence the *revolutionary* flavor of this movement, hence too the appearance of serious complications in the hands of overeager people, which sometimes threatened to bring the procedure into disrepute.

Following in the wake of laparoscopic cholecystectomy, laparoscopic appendectomy showed the way to new applications of laparoscopy in digestive surgery: acute abdominal emergencies, vagotomy, fundoplication, colectomy, inguinal hernia repair, etc. In a word, the race was on. Societies devoted to the promotion, development, and teaching of endoscopic and laparoscopic surgery appeared in Europe (European Association for Endoscopic Surgery), in Japan (Japanese Society for Surgical Laparoscopy and Endoscopy), and in Southeast Asia (Endoscopic and Laparoscopic Surgeons of Asia), following the example of the American surgeons who created the Society of American Gastrointestinal Endoscopic Surgeons. Congresses focusing specifically on the theme of digestive endoscopic surgery were organized and attracted huge audiences. The Second World Congress of Endoscopic Surgery was held in Atlanta in 1990 and the Third World Congress of Endoscopic Surgery in Bordeaux in 1992. The Fourth World Congress was held in Kyoto in June 1994. In 1993, no respectable scientific congress devoted to digestive surgery would fail to include laparoscopic surgery on its agenda, for fear of attracting only a poor audience.

Laparoscopic surgery, in short, took off thanks to the success of laparoscopic cholecystectomy. What is the current status of this procedure? After the age of the pioneers it has now entered the phase of popularization, which means that it has reached its *most hazardous phase.* A surgeon cannot expect to perfectly master laparoscopic technique overnight, even if he has excellent open-surgery skills. Premature switching to clinical practice may lead—and has led—to dramatic accidents. Fortunately enough, the repeated warnings of the pioneers seem to be bearing fruit at last. They no longer have to convince, but rather to temper excessive enthusiasm. The percentage of accidents and incidents is stabilizing at rates similar to those obtained in open surgery (mortality is 0 to 0.2%; morbidity is 3 to 5%, common bile duct injury is 0.1 to 0.6%). It is in this respect that progress is needed.[9–11] Laparoscopic surgery is acceptable only if the patient is not exposed to increased risk. The rule should be that only the surgeons who have been specifically trained in this technique, and who master open surgery perfectly and can revert to it if necessary, should be allowed to practice laparoscopic surgery.

For the institutions specializing in laparoscopic surgery, laparoscopic cholecystectomy has become routine. There is nothing left to say about laparoscopic cholecystectomy except that it must be well taught, so that in the years to come those accidents and incidents will no longer be reported during our meetings that make the few stubborn opponents to the laparoscopic approach laugh scornfully. A procedure that works well is one that everyone performs successfully and is never mentioned. This was the case of conventional cholecystectomy from 1882, when Karl Langenbuch opened the way, until 1987. Laparoscopic cholecystectomy is gradually becoming the treatment of choice for gallbladder lithiasis. Such was the conclusion of the Consensus Conference[12] held in Bethesda in September 1992. In view of the quick progress of technology, the odds are that laparoscopic cholecystectomy will not live to be 100. Will laparoscopic cholecystectomy then fall into oblivion? Certainly not. It will remain a landmark in the development of surgery, marking the point where a new era began, that of less-aggressive surgery.

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11.2 Laparoscopic Cholecystectomy

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Laparoscopic cholecystectomy has rapidly become the standard of care for the management of symptomatic cholelithiasis throughout North America and Europe. The revolutionary nature of this procedure has been unprecedented in surgical history, and has been compared to such surgical mileposts as the development of vascular surgery and organ transplantation. Since the safety, efficacy, and patient benefits of laparoscopic cholecystectomy have been established, the surgical community has begun to expand endoscopic surgical techniques beyond the biliary tract. In this chapter, our technique of laparoscopic cholecystectomy will be presented. Realize, however, that variations exist. The most important concept for surgeons to remember as they make the transition from conventional to laparoscopic surgery is the need to adhere to those sound surgical principles developed over the past century.

Gallstone Disease

Cholelithiasis is a common disorder estimated to affect 10% of the United States population. Of these, 20% are symptomatic at the time of diagnosis, while as many as 80% may remain asymptomatic during the individual's lifetime.[1] Natural history studies of incidentally discovered gallstones have shown that 10 to 50% of asymptomatic patients will develop symptoms secondary to their gallstones over a 5- to 15-year period.[1–4]

Symptomatic cholelithiasis can present in a wide variety of ways. The most common mode of presentation is with recurrent bouts of typical biliary colic, that is, postprandial epigastric or right upper quadrant (RUQ) pain, with radiation to the back or right scapula, lasting several minutes to several hours. Other presentations include nonspecific complaints of fatty food intolerance, flatulence, bloating after meals, dyspepsia, or atypical abdominal discomfort or pain. Up to 30% of patients may initially present with a complication of cholelithiasis such as acute cholecystitis (20%), choledocholithiasis (5%), or gallstone pancreatitis (5%).[5,6]

Although there is no doubt that symptomatic gallstones should be treated, there has been a long debate over the role of prophylactic treatment for asymptomatic gallstones. Recent data suggest that there is no increased morbidity or mortality associated with waiting for symptoms prior to initiating treatment for cholelithiasis. The only exceptions to this hands-off approach are diabetics who do not tolerate complications of cholelithiasis or emergency surgery as well, and transplant candidates who will be subjected to prolonged immunosuppression. Another controversial indication for treating asymptomatic gallstones is the patient who may not have access to adequate healthcare facilities for prolonged periods of time—missionaries and military personnel, for example.

Therapeutic Options

Until recently, the only viable treatment for symptomatic cholelithiasis was traditional open cholecystectomy. Since 1980, several other therapeutic options have been introduced. These include oral dissolution therapy with bile acids, extracorporeal shock wave lithotripsy (ESWL), contact dissolution with methyl-tert-butyl-ether (MTBE), and laparoscopic cholecystectomy. Of these, only traditional open cholecystectomy and laparoscopic cholecystectomy provide definitive treatment. Disadvantages of ESWL, MTBE, and oral bile acid dissolution therapy are increased expense, significant failure rates, the need for prolonged therapy, and significant gallstone recurrence rates. Currently ESWL, MTBE, and oral bile acid therapy are generally offered only to patients who are not surgical candidates, or to those who do not wish to undergo a surgical procedure.

Patient Selection

As surgeons gain experience with laparoscopy, and technology advances, the indications and contraindications change. In general, indications for attempting laparoscopic surgery in patients with gallbladder disease are expanding dramatically. Currently the most important factor in determining which patients can be safely offered laparoscopic intervention is the experience and expertise of the surgeon. With increasing experience, the surgeon can attempt more difficult cases with the laparoscope. Laparoscopic cholecystectomy is now offered to virtually all patients with symptomatic cholelithiasis, acute cholecystitis, chronic cholecystitis, acute acalculous cholecystitis, gallstone pancreatitis, and asymptomatic patients noted above.[7] In general, any patient who is a candidate for traditional open cholecystectomy is a candidate for laparoscopic biliary tract surgery.

Relative Contraindications to Laparoscopic Cholecystectomy

Contraindications to attempting laparoscopic intervention have been divided into absolute and relative. Recently, numerous clinical investigators have demonstrated the feasibility of laparoscopic cholecystectomy in most clinical situations. Perhaps the only remaining absolute contraindication is surgeon inexperience. Relative contraindications should be considered in the context of the surgeon's skill and patient dependent variables (Table 11.2.1). In up to 20% of patients, acute cholecystitis may be the first manifestation of gallbladder disease.[7,8] Previously, many surgeons believed that the risk of laparoscopic surgery when the patient has acute inflammation would be too excessive to justify this approach.[9] Fortunately, this has not proven true, and with only minor modifications to surgical techniques many surgeons now routinely offer such patients the option of laparoscopic surgery.[7] Choledocholithiasis remains a contraindication to laparoscopic cholecystectomy only in those institutions without the availability of therapeutic biliary endoscopy (endoscopic retrograde cholangiopancreatography (ERCP)), or the experience to perform laparoscopic common bile duct explorations. This topic is discussed at length elsewhere in this text.

TABLE 11.2.1. Relative contraindications to attempting laparoscopic cholecystectomy.

Untreated choledocholithiasis
Acute cholecystitis
Pregnancy
Untreated cholangitis
Coagulation disorders
Gallstone pancreatitis
Morbid obesity
Extensive prior upper abdominal surgery
Generalized peritonitis
Known carcinomatosis
Moderate or advanced liver disease

Pregnancy is perhaps one of the more controversial relative contraindications to attempting laparoscopic cholecystectomy. In the vast majority of pregnant patients with symptomatic cholelithiasis, surgical intervention can be delayed until after delivery of the baby. In a small number of such women, however, the symptoms are too severe or complications of cholelithiasis may develop, mandating urgent surgical intervention. Unfortunately any major surgical procedure during pregnancy carries the risk of fetal loss. Some surgeons believe that the minimally invasive approach associated with endoscopic surgery may be safer for the fetus than conventional open surgery.[10] Although several reports of successful laparoscopic cholecystectomy in pregnancy exist, there is no long-term data demonstrating the effects of pneumoperitoneum on fetal blood flow and well-being.[10–12] Until such information exists, most surgeons still consider pregnancy a relative contraindication to laparoscopic cholecystectomy. Any pregnant patient being offered this approach should be fully informed of the potential risks of fetal loss and the limited data concerning the safety of laparoscopic surgery in this setting.

Moderate and severe coagulation disorders are also relative contraindications to attempting laparoscopic biliary tract surgery. At first this may seem somewhat of a paradox as routine blood loss associated with laparoscopic surgery is far less than in open biliary tract surgery. Improved suction and irrigation devices, a greater selection of monopolar cautery instruments, and the expanding use of laparoscopic suturing and knot tying have now given surgeons more options in safely controlling bleeding. However, in general, methods to ensure hemostasis laparoscopically are inadequate in the face of major intraabdominal hemorrhage. Therefore, patients with known coagulation defects should be aggressively treated in the perioperative period with appropriate blood products, vitamin K infusions, etc. The decision whether to offer such individuals laparoscopic surgery should depend on the surgeon's expertise and the severity of the bleeding disorder.

Although untreated acute cholangitis should be considered an absolute contraindication for laparoscopy, most patients can be easily stabilized with either percutaneous (transhepatic) or flexible endoscopic (ERCP) biliary decompression, parenteral antibiotics, and fluid resuscitation. In selected individuals with choledocholithiasis as the etiology of the obstruction, laparoscopic biliary tract surgery may then be considered an appropriate surgical option. Ideally, the common duct should be cleared of stones prior to surgical intervention. However, laparoscopic common bile duct exploration is now being performed routinely in some centers (see Chapter 12).

In many situations, the findings of generalized peritonitis in a patient suspected of having acute cholecystitis should also be considered a relative contraindication to the laparoscopic approach. In this setting, diagnostic uncertainty may exist, and the individual surgeon's ability to deal with nonbiliary tract disease laparoscopically may be limited. In those centers experienced with laparoscopic management of perforated peptic ulcers, appendicitis, and benign and malignant colon disease, the laparoscopic approach may be feasible.

Previous upper abdominal surgery should be considered a contraindication to laparoscopic surgery only if the surgeon has had limited experience with this method of surgery. Even dense adhesions can be taken down under laparoscopic guidance and, with experience, surgeons learn to recognize the appropriate tissue planes and how to expose the vital structures within the porta hepatis.[11] If the adhesions appear too dense for safe laparoscopic dissection, the procedure can be abandoned in favor of open laparotomy. A useful rule of thumb is to continue laparoscopic dissection as long as progress is being made and the surgeon feels comfortable with the recognition of the important anatomic landmarks.

Advanced liver disease is another relative contraindication to laparoscopic biliary tract surgery. The firm, immobile liver is difficult to retract cephalad, and this makes exposure of the portal triad and Calot's triangle more difficult. Other factors to consider include potential or real coagulation defects, portal hypertension with increased liver bleeding and collateral venous tributaries, and the presence of ascites. Although reports of successful laparoscopic cholecystectomy in patients with cirrhosis exist, there is no evidence to suggest that the increased morbidity and mortality from cholecystectomy in this patient population is improved by utilizing a laparoscopic approach. Each patient should be evaluated on a case-by-case basis.

Other relative contraindications to a laparoscopic approach include the presence of an ostomy, peritoneal carcinomatosis, acute (unresolved) pancreatitis, or presence of any contraindication to general anesthesia. Again, these relative contraindications should be evaluated on a case-by-case basis.

Preoperative Evaluation and Patient Preparation

Individuals presenting with symptoms or physical findings suggestive of biliary tract disease are usually evaluated with a standard battery of blood tests and radiographic examinations. Of particular importance to the laparoscopic surgeon is the presence of common bile duct stones as their presence may dramatically alter the patient's management. A complete blood count, coagulation profile, and a set of serum chemistries, including total and direct bilirubin, alkaline phosphatase, hepatic transaminases, pancreatic amylase or lipase, and electrolytes are routinely ordered. Other laboratory exams are performed on a selective basis.

Virtually all patients will undergo preoperative right upper quadrant ultrasound to confirm the presence of cholelithiasis, and to evaluate the size and anatomy of the common bile duct. The role of nuclear medicine biliary imaging for the diagnosis of gallbladder disease remains unclear. Although often used to confirm the diagnosis of acute cholecystitis, most patients who present clinically with fever, elevated white blood cell count, positive Murphy's sign, and known gallstones do not need a nuclear hepatobiliary scan to confirm the diagnosis. At our institution, nuclear medicine biliary imaging is reserved for complex patients whose possible diagnosis of gallbladder disease remains uncertain after performing ultrasonography (for example, acalculous cholecystitis). In patients with atypical symptoms or presentations, every effort is made to rule out nonbiliary causes of the patient's complaints, for example, peptic ulcer disease, gastroesophageal reflux, or inflammatory bowel disease. Flexible upper or lower endoscopy are utilized where indicated, as are radiographic studies (CT scans, barium studies of the upper and lower GI tract, etc.).

Patients suspected of having choledocholithiasis on the basis of their history, laboratory findings (elevated total and direct bilirubin, elevated serum amylase), or ultrasound findings (dilated common bile duct, dilated intrahepatic biliary tree) may be managed in any of several ways, depending upon the patient and the expertise of the surgeon (Table 11.2.2). Previously, patients were advised to undergo either an open laparotomy and formal common bile duct exploration or preoperative biliary endoscopy and possible stone extraction. It was soon discovered, however, that a large number of patients were undergoing unnecessary open laparotomy or ERCP since as many as 60 to 75% of these individuals did *not* have common bile duct stones.[13–15] As intraoperative cholan-

TABLE 11.2.2. Therapeutic options for the management of choledocholithiasis.

Conventional common bile duct exploration CBDE by laparotomy
Endoscopic retrograde sphincterotomy with stone extraction
Laparoscopic transcystic CBDE
Laparoscopic choledochotomy with CBDE
Laparoscopic antegrade sphincterotomy
Extracorporeal shock wave lithotripsy
Transhepatic instillation of gallstone dissolution agents

giography became more routine, a number of surgeons began offering laparoscopic surgery to many patients with preoperative evidence of choledocholithiasis. If stones were demonstrated, the surgeon would decide whether to convert to open laparotomy and common bile duct exploration or continue with laparoscopic cholecystectomy and perform postoperative therapeutic biliary endoscopy. Recently, some surgeons have demonstrated the safety and efficacy of attempting laparoscopic common bile duct exploration on individuals either suspected pre-operatively to have choledocholithiasis or stones were discovered at the time of surgical intervention.[15] DePaulo of the Hospital of Samaritano of Brazil has described a technique of laparoscopic antegrade sphincterotomy that can be used in selected patients with ampullary stenosis or if one or more stones are impacted at the distal common bile duct.[16] As a result of these techniques, the need to do open laparotomy or additional invasive procedures has been dramatically reduced. Various options for managing individuals with proven or suspected choledocholithiasis are discussed in more detail in Chapter 12.

Patients with acute gallstone pancreatitis are initially managed with nasogastric suction, IV fluids, and antibiotics. In most patients, the pancreatitis will rapidly resolve and any stone in the common bile duct will pass through the ampulla. In this situation, laparoscopic surgery may be safely performed during the same hospitalization. Most of these patients do not require preoperative biliary endoscopy unless there is evidence of persistent biliary obstruction (for example, jaundice or elevated LFTs). If the acute pancreatitis does not resolve, the patient should undergo urgent biliary endoscopy or open surgical intervention.

All patients considered for laparoscopic cholecystectomy are advised regarding the risks of laparoscopic surgery in general, as well as the specific risks of cholecystectomy, such as bile duct injury. Particular emphasis is placed on the potential need for conversion to open cholecystectomy. The odds for conversion to an open procedure are quoted to the patient based on surgeon and institutional experience as well as patient dependent variables such as the presence of a contracted gallbladder on ultrasound, acute cholecystitis, choledocholithiasis, previous abdominal surgery, or other factors that may increase the conversion rate. In most clinical series, the need to convert to open laparotomy in uncomplicated patients ranges from 5 to 10% while rates as high as 30% are reported for patients operated upon for acute cholecystitis.[7,17] It is also important to stress to patients that conversion to an open cholecystectomy implies utilization of sound surgical judgement rather than a technical failure.

In general, symptomatic patients are scheduled for laparoscopic cholecystectomy at the earliest possible elective date. Patients with acute cholecystitis are placed on antibiotics and are usually scheduled for semiurgent laparoscopic cholecystectomy within 48 hours of admission. We have found that waiting longer than this allows for the development of denser adhesions, more friable inflammatory changes, increased edema, and generally a more difficult dissection.[7,18,19] Early operation in acute cholecystitis (< 48 h) also tends to reduce the length of hospital stay and decreases healthcare expenses.

Most patients undergoing cholecystectomy should receive some form of deep venous thrombosis (DVT) prophylaxis according to NIH consensus guidelines.[20] Many clinicians feel that the reverse Trendelenburg position and pneumoperitoneum used when performing laparoscopic cholecystectomy will impede lower extremity venous return and increase the risk for development of lower extremity or pelvic DVT[21] (see Chapter 7). In our institution, patients scheduled for laparoscopic biliary tract surgery routinely have pneumatic leg compression devices placed on both lower extremities just prior to starting the operative procedure. Previous clinical studies have shown that such devices are as effective as low-dose heparin and yet avoid the potential complications associated with the use of anticoagulants.[20]

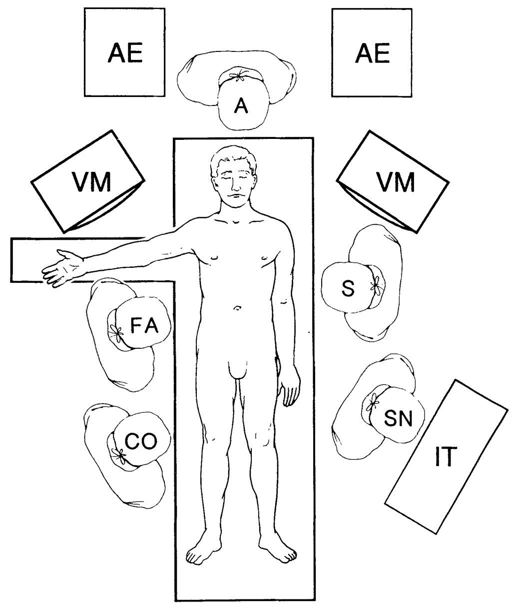
Most surgeons administer a short course (one to three dosages) of perioperative antibiotic prophylaxis to patients scheduled for laparoscopic biliary tract surgery. This was initially done because many operating room teams were unfamiliar with laparoscopic instrumentation and surgeons were concerned that deviations from sterile technique would be common. As most surgeons have experienced few, if any, infectious wound problems with this regimen, the practice of administering antibiotics has continued despite the fact that there is not data to support their routine use in this setting. Patients with acute cholecystitis, cholangitis, or gallstone pancreatitis will usually continue receiving parenteral antibiotics postoperatively until their fever and leukocytosis resolve.

Most patients undergoing laparoscopic biliary tract surgery will receive general endotracheal anesthesia with controlled mechanical ventilation. Although a few select patients may be candidates for regional anesthetic techniques, this option is rarely utilized[21] (also see Chapter 8).

An indwelling urinary catheter along with an orogastric or nasogastric tube are routinely placed for bladder and gastric decompression. These tubes allow for improved upper and lower abdominal exposure, and reduce the risk of inadvertent bladder or gastric puncture with the insufflation needle or trocar insertion. These tubes are invariable removed when the procedure is complete prior to returning the patient to the recovery room.

Most patients in North America are operated on while lying supine, while in Europe the lithotomy position is often preferred. The abdomen is prepped from the nipple line to below the inguinal ligament, and out laterally to the posterior axillary line, just as for open laparotomy. The patient is covered using standard laparotomy drapes, or specialized laparoscopic covers. Great care is taken to create an organized field with the numerous light cords, insufflation tubing, and irrigation tubing. These should all be securely fastened to the drapes to prevent inadvertent contamination or dislodgement during the operative procedure. An open laparotomy instrument set should be kept in the room in case there is an urgent need to convert to laparotomy.

If the patient is in the supine position, the surgeon is usually positioned on the patient's left side, with the first assistant located on the patient's right (Figure 11.2.1). If using the lithotomy position, the surgeon stands between the patient's legs with the assistants on both sides of the table (Figure 11.2.2). Several types of videolaparoscopic holders have been developed that obviate the need for a second assistant, often whose only role is to hold the videolaparoscope. In addition, some surgeons utilize a two-handed technique providing his or her own gallbladder traction with one hand, and dissection with the other. In general, patient positioning and the number of assistants is dependent on surgeon preference and experience.



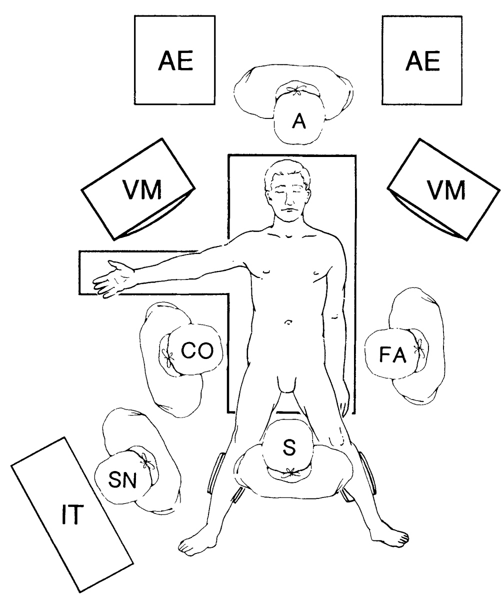
A - Anesthesiologist
AE - Anesthesia equipment
CO - Camera operator
FA - First assistant
IT - Instrument tray
S - Surgeon
SN - Scrub nurse
VM - Video monitor

FIGURE 11.2.1. Supine patient positioning. The primary surgeon stands to the patient's left side.

Operative Technique

To safely perform laparoscopic surgery a "space" must be created so that the surgeon can see and manipulate his or her instruments. The most common method of creating this space is to distend the peritoneal cavity with carbon dioxide. This gas may be introduced using either a closed or open technique. With the closed method a specialized insufflation or Veress needle is used. A 12- to 15-mm transverse incision is made in either the upper or lower folds of the umbilicus. This is the most popular site for insufflation needle insertion as the abdominal wall is thinnest at this location and the fascial layers are fused. The operating table is tilted to approximately 20° of Trendelenburg position to allow the intraperitoneal contents to shift cephalad out of the pelvis. The needle is inserted caudal and below the bifurcation of the aorta and vena cava (Figure 11.2.3). Confirmation that the needle is in the free peritoneal space is obtained by observing free flow of saline through the bore of the needle (saline drop test) and ensuring that the initial pressures when insufflating the abdomen are less than 8 to 10 mm Hg.

The open or Hasson technique is generally used whenever there has been a previous lower abdominal, periumbilical, or midline surgical procedure or if there are difficulties with percutaneous insertion of the insufflation needle. With this method, a slightly larger (18 to 20 mm) incision is made in the umbilicus and the peritoneal cavity is opened under direct vision. Large sutures are then



A - Anesthesiologist
AE - Anesthesia equipment
CO - Camera operator
FA - First assistant
IT - Instrument tray
S - Surgeon
SN - Scrub nurse
VM - Video monitor

FIGURE 11.2.2. Lithotomy patient positioning. The primary surgeon stands between the patient's legs.

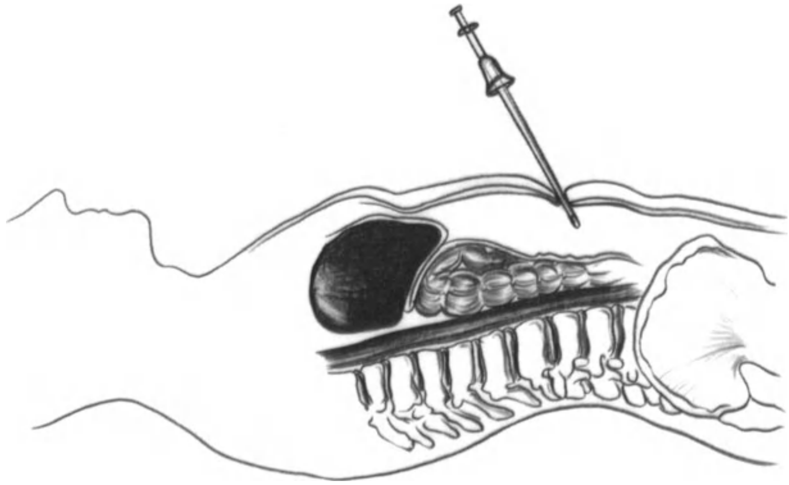


FIGURE 11.2.3. Veress insufflation needle insertion with the patient in Trendelenburg position.

placed in the adjacent fascia that are then secured to a special olive-shaped adapter incorporated onto the Hasson cannula (Figure 11.2.4). This maneuver minimizes gas leakage around the larger fascial opening and secures the cannula in place. Some surgeons have adopted the practice of utilizing the open or Hasson technique for all of their patients undergoing laparoscopic surgery.[22] Many authors have reported that when used routinely, the open method can be performed without any significant increase in operative time.[23] These surgeons also maintain that the open technique is associated with a lower incidence of complications related to initial insufflation needle and trocar placement; however a prospective study actually comparing these two techniques has never been reported.

Once access to the peritoneal cavity is gained, the abdomen is distended to a maximum pressure of 14 to 15 mm Hg. Lower pressures of 8 to 11 mm Hg are recommended for pediatric patients, for those receiving regional anesthesia, or in patients with significant cardiac or pulmonary compromise. Several commercial brands of automatic high flow insufflators are available that can infuse CO_2 at flows ranging from 0.5 to 15 L/min. Contemporary insufflators automatically stop the gas flow when the intra-abdominal pressure reaches a preset figure.

Once the initial 10-mm umbilical trocar is in place, and the pneumoperitoneum has been established, visual inspection of the abdominal cavity is carried out in a systematic fashion looking for any injuries related to needle or trocar insertion or unsuspected intra-abdominal pathology. Additional cannulas are placed under direct laparoscopic visualization. In North America the four-puncture technique as described by Reddick and Olsen is most commonly used.[24] In addition to the 10/11-mm cannula near the umbilicus a second 10/11-mm sheath is placed in the midepigastrium just to the right of the falciform ligament, and two 5.0-mm cannulas are placed in the right upper abdomen two finger breadths below the right coastal margin (in the midclavicular and the midaxillary

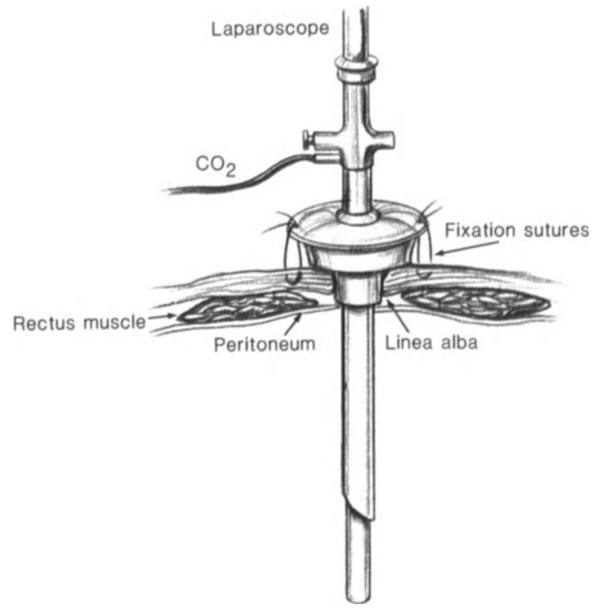


FIGURE 11.2.4. Open or Hasson cannulas insertion under direct visualization of the peritoneal cavity.

line (Figure 11.2.5). If the patient has been placed in the lithotomy position, the same puncture sites may be used or an alternative scheme as described by Perrisat may be used (Figure 11.2.6).[25]

The patient is placed in reverse Trendelenburg position (20 to 30°) with the table tilted downward to the patient's left. This allows the transverse colon, omentum, and stomach to fall away from the porta hepatis (Figure 11.2.7). The gallbladder fundus is then secured with a 5-mm ratcheted grasping forceps inserted through the mid-axillary port. The gallbladder and right lobe of the liver are retracted cephalad and to the patient's right to expose the cystic duct and portal triad structures. Any adhesions to the body of the gallbladder are carefully taken down with instruments inserted through the subxiphoid cannula beginning near the fundus and proceeding down-

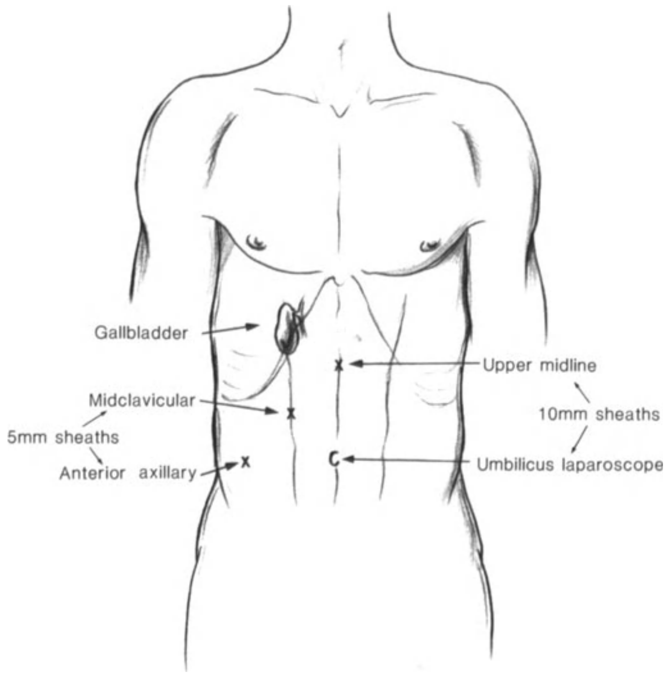


FIGURE 11.2.5. Standard four-puncture cannulas placement as described by Reddick and Olsen.

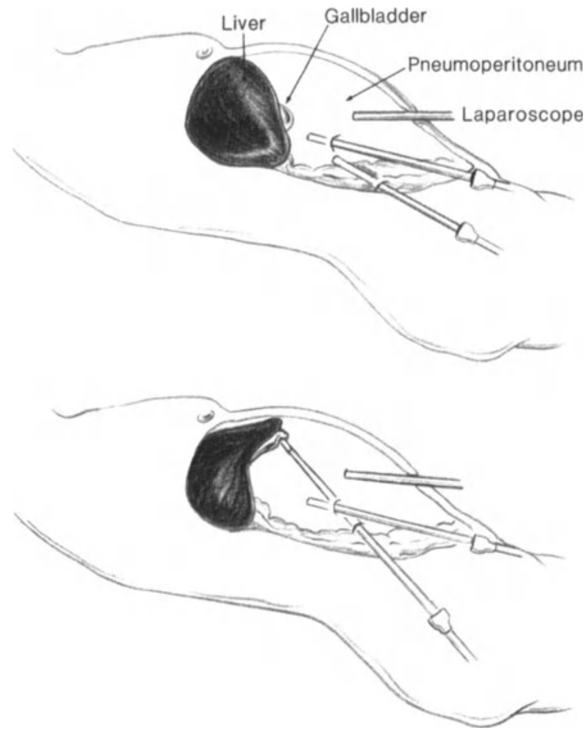


FIGURE 11.2.7. Reverse Trendelenburg positioning improves porta hepatis exposure.

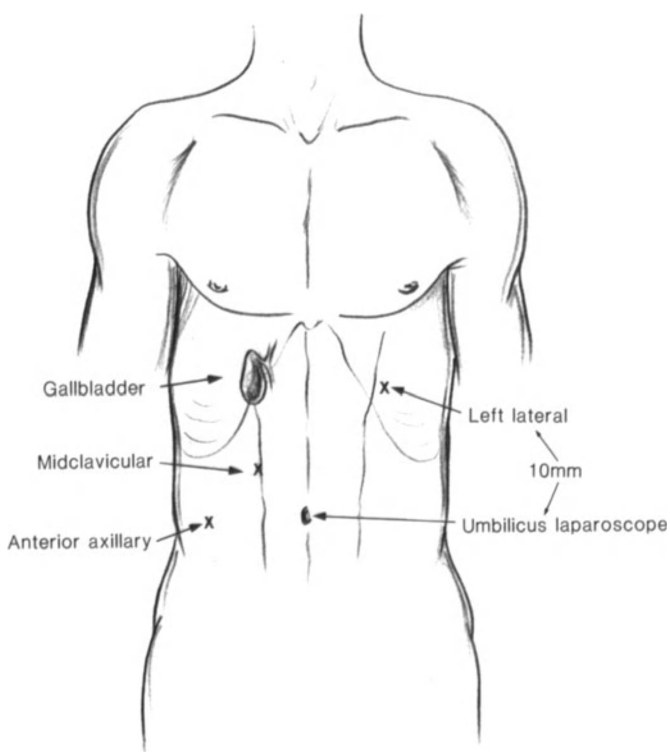


FIGURE 11.2.6. Alternative cannulae placement sites used in conjunction with the lithotomy position as described by Perrisat.

ward toward the neck. A second 5-mm grasping instrument is passed through the midclavicular port and placed on the neck of the gallbladder near the juncture with the cystic duct. This forceps is used for lateral and caudal traction on Hartmann's pouch which widens the Angle of Calot and places the structures within on tension.

Numerous laparoscopic instruments and techniques exist for dissection of the cystic triangle structures. The most popular device for identifying and freeing the cystic duct and artery is a curved dissector. To facilitate the operative procedure, surgeons have used laser energy, monopolar, and bipolar electrocautery for dissection and hemostasis. Considerable controversy exists as to which energy modality is the safest but it now appears as if the most important determinate is the experience of the surgeon. Foremost in importance is absolute identification and delineation of biliary ductal and vascular anatomy prior to ligation or division of any structure. This is generally accomplished by gentle blunt dissection along the gallbladder in a downward direction until the junction with the cystic duct is reached. The peritoneal covering overlying the Angle of Calot is gently dissected by elevation of this thin tissue and inferomedial blunt traction. Electrocautery (or laser) is used sparingly, but as necessary to maintain adequate hemostasis. At no time is an energy source used in close proximity to the common hepatic or common bile duct. Once the peritoneal covering is dissected off of the cystic triangle, the cystic duct and cystic artery are identified utilizing blunt dissection within the cystic triangle. The cystic duct is first identified at its junction with the gallbladder, and is then followed down to the junction with the common hepatic duct, again utilizing a gentle blunt dissection technique (Figure 11.2.8).

Once the cystic duct has been adequately identified, delineated, and cleaned, attention is directed at identifying the cystic artery along with its anterior and posterior branches. This is accomplished by continuing the blunt dissection within the cystic triangle along the gallbladder wall. Particular attention is given to avoiding any potential avulsion of the cystic artery off of the right hepatic artery by overzealous traction on the gallbladder or cystic artery. In addition, attempts are made to identify any unusual vascular or biliary tree anomalies.

Once the cystic duct and cystic artery are identified and dissected, many surgeons routinely perform intraoperative cholangiography. This is accomplished by placing a clip on the cystic duct at its junction with the gallbladder, and creating a small opening in the cystic duct just distal to the juncture with the gallbladder. The cystic duct is then "milked" back away from the junction with the common hepatic duct to remove any stones retained within the cystic duct (Figure 11.2.9). A small (4 to 5F) catheter is inserted through the lumen of a specialized cholangiogram clamp and guided into the cystic duct (Figure 11.2.10). Usually the right midclavicular cannula is used to introduce this clamp and catheter. A ureteral whistle-tipped catheter, long intracath tubing, or specially designed cholangiogram catheter may be used for this purpose. Gentle lateral traction on Hartmann's pouch tends to straighten the cystic duct and place it on moderate tension that facilitates insertion and threading of the cholangiogram catheter. Although not practiced by all surgeons, we feel that the delineation of anatomy provided by the cholangiogram minimizes the risk and severity of bile duct injuries, and may also reveal any inadvertent and unrecognized bile duct injuries that may have occurred during dissection of the cystic duct and artery. Other methods of laparoscopic cholangiography and the controversies of routine versus selective cholangiography are discussed in depth elsewhere within this text (see Chapter 11.4).

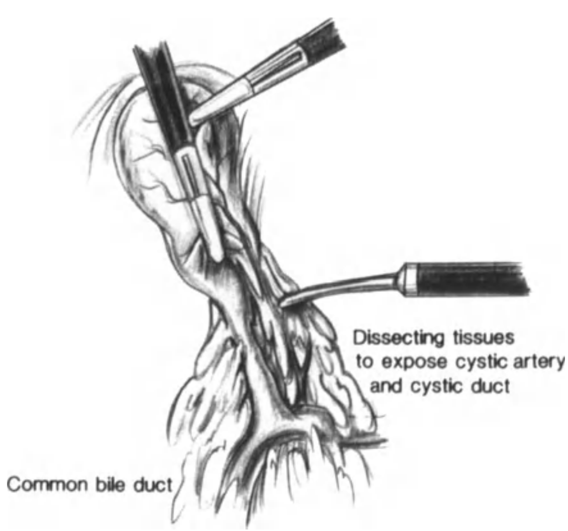


FIGURE 11.2.8. Careful blunt dissection of the cystic triangle and exposure of the cystic duct, cystic artery, and common hepatic and common bile ducts.

If the cholangiogram reveals no evidence for injury or choledocholithiasis, we proceed with ligation and division of the cystic duct and cystic artery. The cystic duct is doubly clipped distal to the junction with the common bile duct. As with open cholecystectomy, care is taken to avoid leaving a long cystic duct remnant, and to avoid incorporating a portion of the common hepatic or common bile duct wall within the clips (Figure 11.2.11). The cystic duct is divided with scissors. If the cystic duct remnant is inflamed, dilated (> 5 mm), or edematous, we also place a pre-tied suture ligature between the titanium clips and the common bile duct (Figure 11.2.12). A pre-tied loop is also placed on the cystic duct remnant if there is a possibility of performing postoperative ERCP (for example, finding choledocholithiasis). This maneuver is recommended because retrograde cannulation of the bile ducts and their distension with contrast may result in high pressure being exerted on the cystic duct stump.

Equally important is the proper identification and dissection of the cystic artery. No arterial structure is assumed to be the cystic artery until its course can be clearly and unequivocally shown to pass directly onto the gallbladder. It is also important to ensure that the main trunk of the cystic artery is ligated and divided rather than just the anterior branch. The magnification afforded by the videolaparoscope along with the perspective associated with the endoscope inserted through the umbilicus can easily mislead the surgeon that the anterior branch is the main trunk. If the posterior branch is left unligated, it may later tear while dissecting the gallbladder off the liver bed. Cuscheri and his colleagues reported that 5% of their patients experienced major bleeding because of this error.[26] Occasionally, the anterior and posterior branches of the cystic artery are ligated separately. Once clipped, the cystic artery is divided, and the proximal stump inspected for hemostasis. At no point are clips placed blindly within the Calot triangle (or elsewhere). Pre-tied laparoscopic ligatures may also be used to further secure the proximal half of the cystic artery if the surgeon feels that metallic clips alone are not adequate.

Once the cystic duct and artery are divided, the gallbladder can be detached from the liver bed. This is accomplished by utilizing a combination of blunt and sharp dissection as well as judicious use of electrocautery (or laser) energy. Various instruments such as spatulas, hooklike probes, and curved scissors have all been used

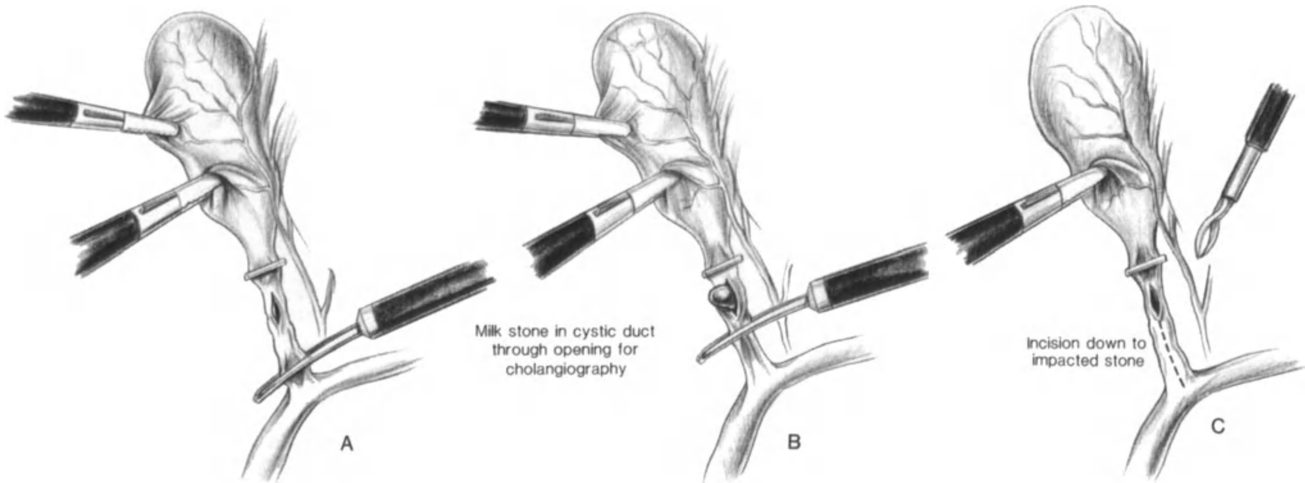


FIGURE 11.2.9. "Milking" the cystic duct to remove any stones within the cystic duct prior to cholangiography or cystic duct ligation.

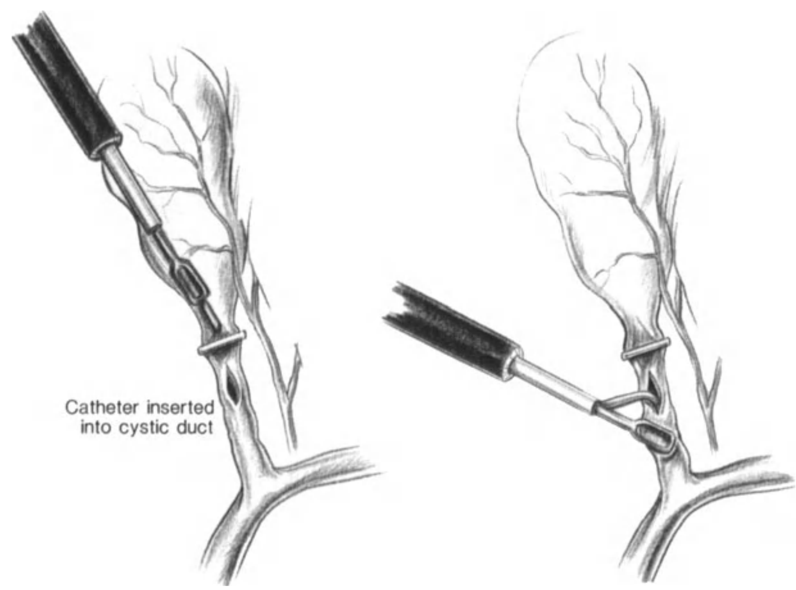


FIGURE 11.2.10. Intraoperative cholangiogram utilizing a small 4 to 5F catheter and a specialized laparoscopic cholangiogram clamp.

to divide the attachments between the gallbladder and liver. Once again surgeon experience and familiarity with a particular device are the most important aspects of choosing the best instrument for this purpose. Use of alternate anterolateral and anteromedial traction (right and left twist, respectively) on the gallbladder neck will greatly facilitate the exposure and dissection of the plane between the gallbladder and liver bed (Figure 11.2.13). Hemostasis is maintained throughout the dissection, rather than waiting until the gallbladder is excised from its bed. If hemostasis cannot be achieved through the careful use of cautery, laparoscopically placed sutures, or precise clip placement, then the surgeon should not hesitate to convert to an open laparotomy.

Any inadvertent spillage of bile and or stones from the gallbladder during the procedure should be immediately controlled by the use of clips, pre-tied loop sutures, or by reapplying the grasping clamps (Figure 11.2.14). Any spilled stones should be retrieved when feasible, using specialized laparoscopic stone grasping forceps. If multiple stones have spilled they may be placed within a sterile plastic or latex specimen bag to facilitate their extraction (Figure 11.2.15). In most cases the spillage of bile or gallstones alone is not sufficient reason to immediately convert to an open laparotomy. Experimental studies have shown that free gallstones within the peritoneal are usually isolated by the omentum.[27] Soper and his colleagues have also followed patients with documented bile or stone spillage and compared their postoperative course to a comparable group with no apparent spillage.[28] In this study there was no ill effect observed, however, case reports have appeared documenting the delayed

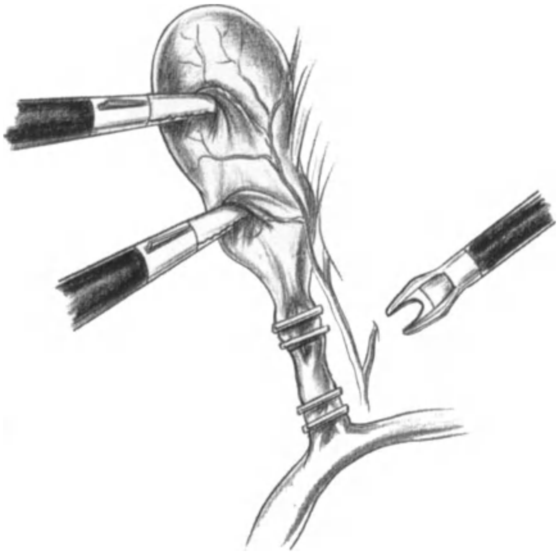


FIGURE 11.2.11. Care must be taken to avoid incorporating a portion of the common bile duct wall in the closure of the cystic duct stump. Cystic duct, common hepatic duct, common bile duct, and the junction of the cystic duct with gallbladder and with common hepatic duct should be clearly identified prior to clip or pretied loop placement and division.

presentation of intra-abdominal abscesses centered around previously spilled gallstones.[29]

Prior to complete detachment of the gallbladder, the liver bed is reinspected for adequate hemostasis or bile leak. In addition, the cystic duct remnant and ligated cystic artery are examined once again to ensure that the previously placed clips or sutures remain secure. The liver bed, Morrison's pouch, the right para-colic gutter, and perihepatic areas are irrigated with copious amounts of saline solution. The remainder of the excision is carried out and the gallbladder is extracted from the abdomen under direct laparoscopic vision. In most cases the videolaparoscope is removed from the umbilical cannula and reinserted through the subxiphoid sheath. Penetrating forceps are then introduced through the umbilical cannula and placed firmly on the gallbladder neck (Figure 11.2.16). The forceps, sheath, and neck of the gallbladder are pulled out of the umbilical fascial opening. If the gallbladder is too distended with bile or small stones, the neck is opened outside of the abdomen and a suction probe inserted (Figure 11.2.17). If the wall of the gallbladder is thickened or large stones still prevent its extraction, we do not hesitate to extend the skin incision or fascial incision to facilitate its removal. Some surgeons prefer to mechanically crush large stones with stone forceps or use lithotriptor devices inserted through the gallbladder neck and fascial opening.[30] In general, the surgeon should avoid the temptation to apply excessive traction, and should instead resort to extending the umbilical incision, crushing the stones within the gallbladder, and extracting the fragments, or extending the fascial incision. If the gallbladder is necrotic or obviously infected, it can be placed within a sterile specimen bag in order to facilitate its retrieval and prevent contamination of the trocar puncture sites (Figure 11.2.18).

Following gallbladder removal from the abdomen, the umbilical trocar is then reintroduced and pneumoperitoneum reestablished. The operative field is again irrigated with saline solution and inspected. The trocars are then removed under direct visualization to ensure there is no ongoing bleeding from the puncture sites. If persistent bleeding is noted, the trocar sites are explored and hemostasis obtained. The larger 10-mm trocar sites are routinely closed with absorbable sutures. No fascial closure is usually necessary at the 5-mm trocar sites. Skin closure is accomplished with 4–0 absorbable subcuticular suture or skin staples. The indwelling bladder catheter and gastric tube are removed prior to returning the patient to the recovery room unless otherwise clinically indicated.

Acute Cholecystitis

Acute cholecystitis is no longer considered a contraindication for attempting laparoscopic cholecystectomy. Although the conversion rate is higher (25% or more) than for elective gallbladder surgery, there does not appear to be any increased risk of bile duct injury.[7] Previous laparoscopic surgical experience and a willingness to convert to open cholecystectomy appear to be the most important factors in minimizing operative related complications.

Although the basic operative technique is similar to that earlier detailed, several modifications have been described in order to facilitate laparoscopic surgery in the setting of acute inflammation (Table 11.2.3).[7,8,18,19] Early surgical intervention (< 48 h) simplifies the laparoscopic approach since fewer adhesions and inflammatory changes are allowed to develop. If surgery is delayed beyond this interval, adhesions and other inflammatory changes may severely distort anatomy and lessen the probability for safe, successful completion of the procedure under laparoscopic guidance.

Some of the techniques found useful in patients with acute cholecystitis include the use of additional trocars as necessary for retraction, use of larger (10 mm) penetrating forceps or sutures for retraction of stiff, thick-walled gallbladders, partial gallbladder decompression with a percutaneously placed needle, frequent use of intraoperative cholangiography, careful and meticulous dissection of the Calot triangle, selective use of closed suction drains, and the use of angled (30 to 40°) laparoscopes for improved visualization.

Although postoperative drainage catheters are rarely used following uncomplicated biliary tract surgery, many

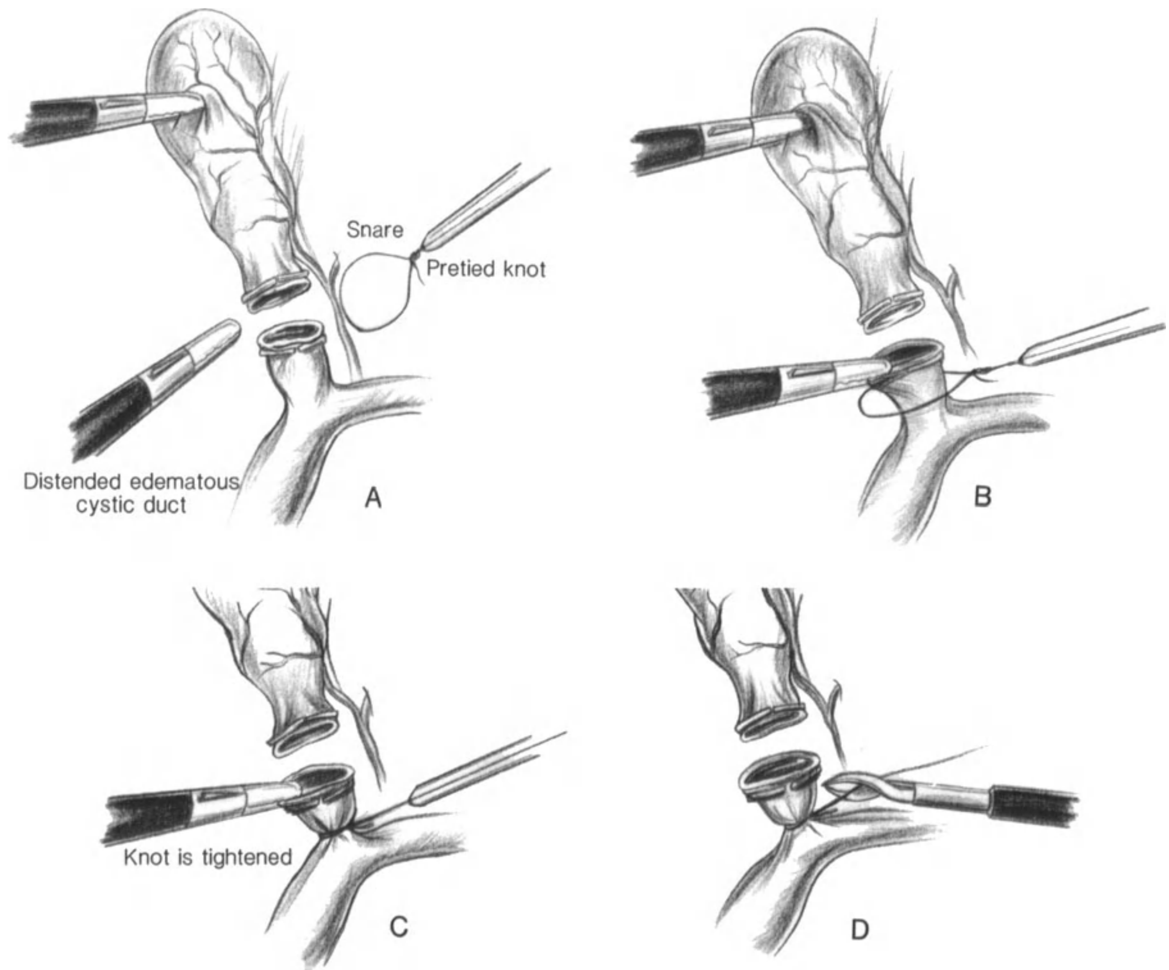


FIGURE 11.2.12. A pretied suture ligature loop is utilized in addition to titanium clips when inflammation or edema is present, when the cystic duct stump diameter is > 5 mm, or if postoperative endoscopic retrograde cholangiopancreatography is necessary.

surgeons have advocated their use in selected patients operated upon for acute inflammation.[7] Indications for closed suction catheter placement include persistent minor bleeding from the liver bed, excessive bile or stone spillage, persistent minor bile leak from the liver bed, or excessive residual inflammation. Either 5- or 10-mm drains may be used, although the larger catheters are preferred. These are trimmed to the appropriate length prior to insertion into the peritoneal cavity, and are brought through one of the right upper quadrant trocar sites. Care must be taken not to dislodge the clips used for cystic artery or duct closure while positioning the drain in Morrison's pouch.

As long as the surgeon maintains a low threshold for conversion to open laparotomy, laparoscopic cholecystectomy can be performed safely in patients with acute cholecystitis. Reasons for conversion should include the inability to recognize or identify biliary anatomy adequately for safe dissection, excessive bleeding unresponsive to usual laparoscopic hemostasis techniques, or failure to continue to make safe progress with the dissection.

Postoperative Care

Once patients have recovered from anesthesia, they are allowed liquids and then their diet is advanced as tolerated. Patients are encouraged to ambulate soon after surgery and the pneumatic antiembolism devices are removed once patients are ambulatory. Nonnarcotic analgesics are used routinely, and are only supplemented with narcotic medications when necessary. Antiemetics are often used for patients who experience postoperative nausea. Patients are generally discharged when they can tol-

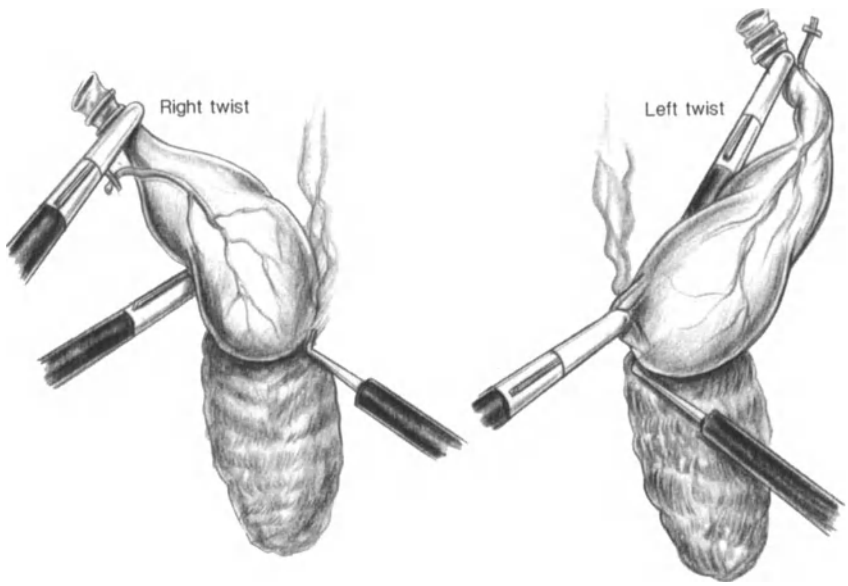


FIGURE 11.2.13. Sequential use of anterolateral (right twist) and anteromedial (left twist) retraction on the gallbladder facilitates dissection of the gallbladder from the liver bed.

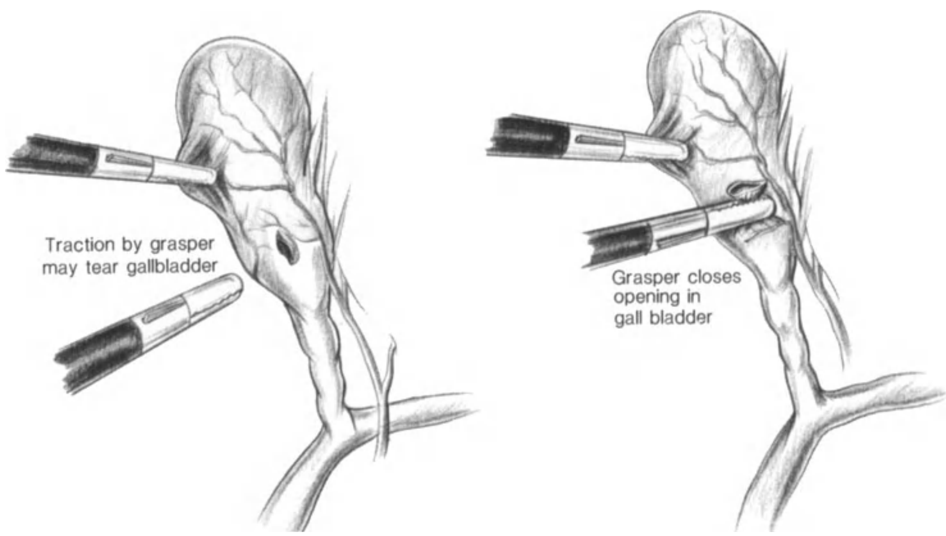


FIGURE 11.2.14. Inadvertent tears in the gallbladder wall should be immediately controlled with clips, a pretied suture loop, or with one of the assistant surgeon's grasping clamps as shown in this illustration.

erate a regular diet, ambulate without difficulty, and manifest no evidence of early postoperative complications (urinary retention, wound infection, etc). Most patients are able to leave the hospital within 24 hours of laparoscopic surgery unless there are other comorbid illnesses.[17] Some surgeons have been able to perform laparoscopic surgery on an outpatient basis in individuals who are in otherwise good health, operated upon electively for biliary colic, and undergo an uncomplicated procedure.[31] Those patients operated on for acute cholecystitis are discharged after their course of IV antibiotics is completed and any drains placed intraoperatively have been removed.

Patients who require postoperative biliary endoscopy for residual choledocholithiasis generally can tolerate ERCP by the first or second postoperative day. If this procedure is successful and without complications (pancreatitis, cholangitis, duodenal perforation, for example) the patients can often be discharged the following day.

Patients are generally allowed to resume their normal physical activities within one week of discharge. Most patients require only nonnarcotic analgesics for several days following discharge, and are generally pain free within one to two weeks. Follow-up visits are usually conducted one week and one month following discharge. No postoperative blood or imaging studies are conducted unless clinically indicated.

Results

Although the vast majority of studies currently published reflect early surgical experience, it has become apparent that laparoscopic cholecystectomy can be performed

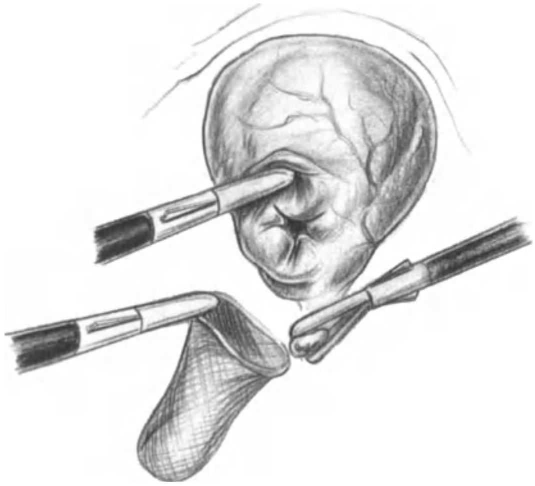


FIGURE 11.2.15. Collection of spilled gallstones within a sterile plastic or latex pouch. The pouch is removed in a fashion similar to gallbladder extraction (see Figures 11.2.17 and 11.2.18).

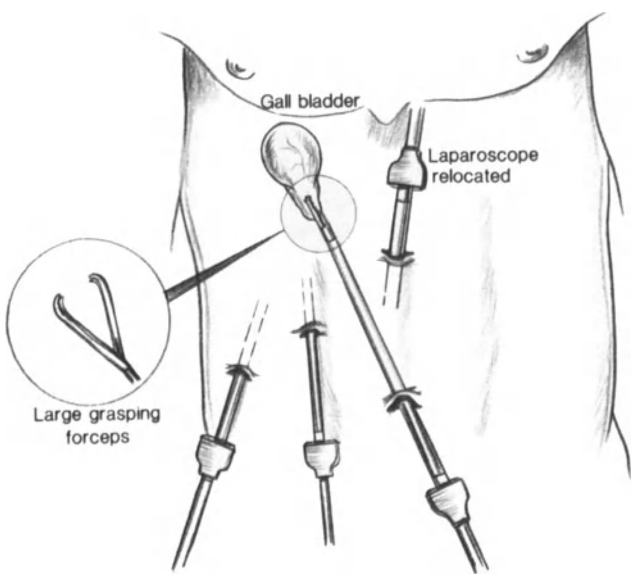


FIGURE 11.2.16. Gallbladder extraction through the umbilical port using 10-mm penetrating forceps. The forceps, umbilical cannula, and gallbladder are removed as a single unit through the umbilical fascial opening.

safely with minimal morbidity and virtually no mortality. Scott and colleagues recently published the largest collective retrospective review of 12,397 patients reported in 23 previously peer-reviewed published reports. The series reported in this review represented the cumulative early experience from both academic and private institutions both in Europe and the United States from May 1988 to July 1991. Demographic information, conversion rates, use of cholangiography, morbidity and mortality data, and management strategies for choledocholithiasis were reviewed (Table 11.2.3). Ninety-five percent of the patients reported in these publications were operated upon electively. This is a higher figure than reported in most other large series of patients undergoing surgery for gallbladder disease and undoubtedly reflects the fact that many surgeons selected only ideal candidates for laparoscopy early in their experience. The overall rate of conversion from laparoscopic to conventional surgery was surprisingly low. Of those reporting the reasons for conversion, 52% were due to adhesions and inflammation, and 20% due to the presence of acute cholecystitis. Other common reasons cited for conversion to open cholecystectomy included excessive hemorrhage, iatrogenic trocar or cautery-induced injury, gallbladder perforation, unclear biliary anatomy, and choledocholithiasis. The much higher rate of conversion for those individuals with acute cholecystitis is similar to that reported by other authors.[7] Ten centers reported the use of preoperative ERCP in 156 (3%) of 6,113 patients. Indications for preoperative ERCP included obstructive jaundice, a history of gallstone pancreatitis, cholangitis, abnormal liver function studies, or a strong clinical suspicion of choledocholithiasis. Of the 156 patients, 62 (40%) were found to have choledocholithiasis, and 55 of the 62 patients (90%) were successfully managed with endoscopic sphincterotomy or stone extraction. Intraoperative cholangiography was attempted in 40% of 9,231 patients undergoing laparoscopic cholecystectomy. It was successful in 84%. This low number of cholangiograms suggests that most surgeons are performing this study on a selective basis. Five percent of intraoperative cholangiograms were described as abnormal (filling defect or stricture identified) and their management consisted of intraoperative ERCP with sphincterotomy and stone extraction (2%), postoperative ERCP with sphincterotomy and stone extraction (39%), laparoscopic common bile duct exploration (28%), conversion to laparotomy with conventional common bile duct exploration (24%), and observation only (7%).

The overall mortality reported by these 23 medical centers was a surprisingly low 0.08%, which is considerably lower than other large series of conventional gallbladder surgery. Once again this may reflect an early selection bias by many of these surgeons for healthier patients. The overall morbidity was also quite low (4%). Three deaths were due to pulmonary emboli; two each were due to myocardial infarction and cerebrovascular accidents; and one each was caused by unrecognized small bowel injury, unrecognized colon injury, and rupture of a previously unrecognized abdominal aortic aneurysm. The most serious complication was the 0.3% incidence of major bile duct injuries. This figure is in accordance with other published data looking at large series of conventional cholecystectomies (0 to 0.5%). This would be in contrast to the perception by some individuals that laparoscopic cholecystectomy is inherently more dangerous

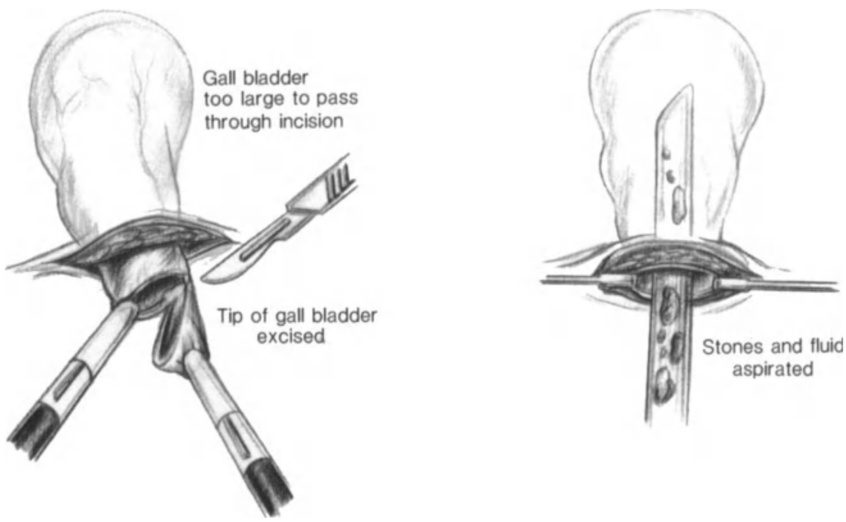


FIGURE 11.2.17. Decompression of a gallbladder distended with bile or small stones is accomplished prior to gallbladder extraction by opening the gallbladder neck and inserting a suction probe.

than conventional surgery.[32] Of even greater interest was that these authors contacted nearly all of the surgeons reporting bile duct injuries and determined when in their experience the injury occurred. Scott discovered that over two-thirds of the major bile duct injuries occurred in the surgeon's first 25 cases of attempted laparoscopic cholecystectomy (Figure 11.2.19) This data supports the concept of a "learning curve" associated with this technique as first proposed by Meyers and the Southern Surgeons Club.[33] If true, this would imply that the low incidence of bile duct injuries may drop even further as surgeons throughout the world become more adept at laparoscopic surgery. It also suggests that a greater emphasis should be placed on training and credentialling than there has been in the past.

The length of hospital stay was reported by all series. The mean length of stay ranged from 1 to 3.5 days. Overall, 54 to 98% of patients were discharged on the first or second postoperative day, and 77 to 98% returned to full activity within five to eight days.

Future Directions

Within a very short time, laparoscopic cholecystectomy has become the standard of care for management of symptomatic cholelithiasis. The most important issues to be addressed in the future include improvement and refinement of the operative technique and equipment, especially in individuals presenting with complications of their gallbladder disease. In addition, the role of cholangiography (selective versus routine), management of choledocholithiasis, and the prevention and management of bile duct injuries will remain priority topics for years to come.

Other issues that will be addressed include strategies to maximize the cost-effectiveness of laparoscopic cholecystectomy. The risk-benefit ratio for disposable versus reusable instrumentation and equipment needs to be determined, as does the most cost-effective management strategy for suspected or known common duct stones.

Finally, the search for a cost-effective, safe, and effective means of preventing gallstones should continue. Until such a treatment exists however, laparoscopic cholecystectomy will remain the primary therapeutic modality for symptomatic cholelithiasis.

Summary

Laparoscopic cholecystectomy has rapidly become the treatment of choice for symptomatic cholelithiasis. Comparative data suggest that laparoscopic cholecystectomy can be performed with morbidity and mortality rates similar to those for open cholecystectomy. One clear advantage to laparoscopic cholecystectomy is substantially reduced incision related morbidity, with reduced pain, length of stay, and reduced time away from productive activity. The procedure offers clear cost savings both to the patient and to society from reduced length of hospital stay and earlier return to work. All surgeons performing laparoscopic cholecystectomy should be trained in conventional biliary tract surgery as well, and should not hesitate to convert to conventional cholecystectomy whenever anatomy is obscured, or patient safety is in question. Conventional cholecystectomy remains a safe and effective alternative when laparoscopic cholecystectomy is not feasible or safe. In the future, stricter guidelines for training, certification, and credentialling, along with improvements in technique and equipment should improve the safety of laparoscopic cholecystectomy.

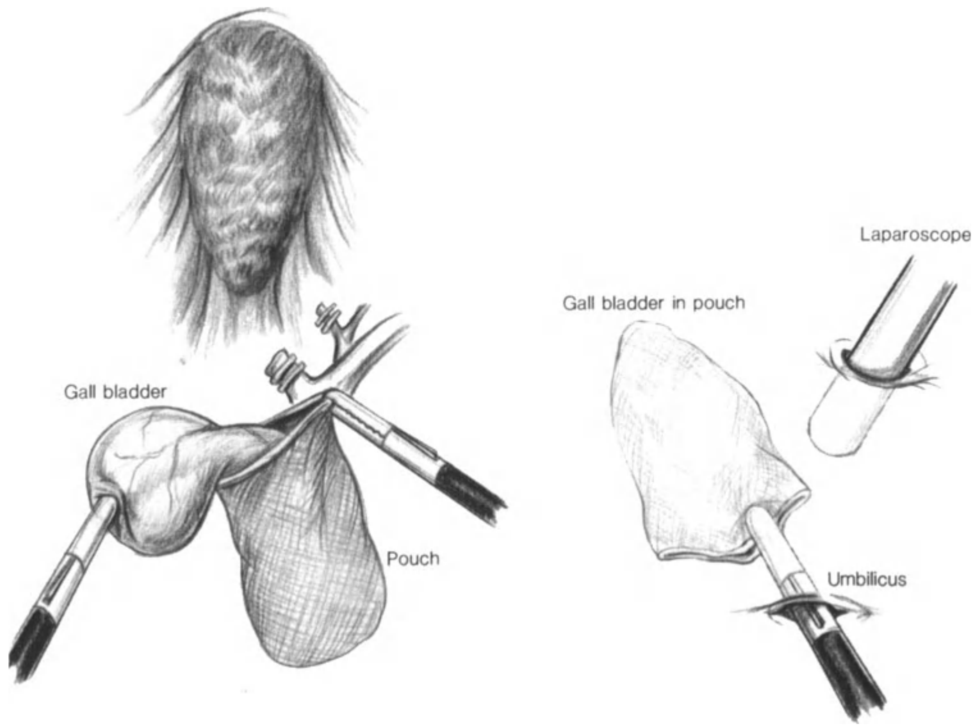


FIGURE 11.2.18. Acutely inflamed, infected, or necrotic gallbladders are removed via the umbilical port after being placed inside a sterile plastic or latex pouch.

TABLE 11.2.3. Review of 12,397 patients undergoing laparoscopic cholecystectomy*.

Female/Male	77%/23%
Indications for surgery	
biliary colic	90%
acute cholecystitis	8%
gallstone pancreatitis, cholangitis, and acalculous cholecystitis	2%
Overall conversion to conventional surgery	4%
acute cholecystitis	22%
Preoperative ERCP**	3%
Intraoperative cholangiography***	40%
successful study	84%
Mortality	0.08%
Morbidity	4%
wound (trocar site) infection	0.6%
bile leak	0.4%
visceral injury	0.3%
minor bile duct injury	0.1%
major bile duct injury	0.3%

*Data combined from 23 medical centers reporting their results in a peer-reviewed journal.
**10/23 centers reported information of the use of preoperative biliary endoscopy.
***16/23 centers reported data on the number of attempted and successful intraoperative cholangiograms.

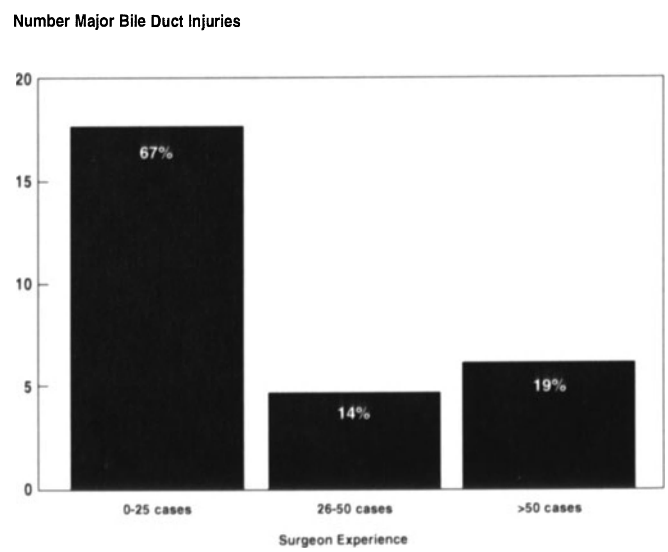


FIGURE 11.2.19. Two-thirds of major bile duct injuries associated with laparoscopic cholecystectomy occur in a surgeon's first 25 cases. N = 27 major bile duct injuries. (From Scott, et al., *Surg Laparosc Endosc.* 1992; 2:191–198. With permission.)

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11.3 Intraoperative Cholangiography—Routine

Jonathan M. Sackier

The editors of this volume have chosen to address the issue of intraoperative cholangiography by dividing it into two halves: the first, by this author, explaining that this test should be performed as a matter of routine, the second by Dr. Talamini, suggesting the investigation should be used on a selective basis.* This is an interesting approach, for it assumes that both rationales are reasonable. As every physician is aware, much of medicine is not "black or white" but varying shades of gray, and so it is with cholangiography. These two sides to the argument should prove intellectually stimulating to the reader. Obviously, it would be impossible for me to contribute such a work without being absolutely convinced of the validity of my position: Intraoperative cholangiography (IOC) should be performed routinely in every laparoscopic cholecystectomy. I have broken my reasoning down into a number of discreet arguments but perhaps the most compelling of these is that, in my opinion, the laparoscopic operation is different from conventional cholecystectomy and that cholangiography has numerous benefits and no significant disadvantages.

Historical Review

The Argentinean, Mirizzi, is duly credited with development of intraoperative cholangiography.[1] The first presentation in 1931[2] on completion T-tube cholangiography with lipoidol was followed by a number of papers that spurred interest in this approach. The first operative cholangiogram was reported in 1936 by Hicken.[3] Also in that year Robins and Hermanson used cholangiography as an aid in deciding when to explore the common duct.[4]

*Editor's Note: Perhaps there is nothing in general surgery which excites more of an emotional debate than the issue of routine versus selective operative cholangiography, whether one is dealing with conventional or laparoscopic cholecystectomy. This issue will almost certainly be debated until general surgery itself is obsolete. RJF

The current debate over whether to perform operative cholangiography routinely or selectively in laparoscopic cholecystectomy (LC) is as surprising as the discovery by Reich in 1918.[5] This doctor unexpectedly visualized the biliary tree after injecting petrolatum paste and bismuth into the cutaneous fistula of a woman who had previously undergone pelvic exploration. It is surprising that the debate between selective or routine cholangiography has raged all through the era of conventional cholecystectomy. The differences between the operations introduced by Langenbuch[6] and the laparoscopic variant are so profound that we must re-examine every phase of the operation. Doing so in a critical fashion, we discover that cholangiography is a vital step and not a mere bagatelle. In the early days of LC some authors did not obtain an intraoperative cholangiogram (IOC) because of the difficulty inherent in doing so. Others used the gallbladder as a route to introduce contrast and although not ideal, this was a step in the right direction.[7]

Technique

In the preoperative phase, a history should be obtained of any allergy to iodine containing contrast material so that the anesthesiologist can take appropriate precautions. A history of jaundice or cholecystitis with ultrasound findings of a thick-walled gallbladder, pericholecystic fluid, or a dilated common bile duct (CBD), or common duct stone all give indications that there may be stones outside the gallbladder.

The patient must be placed on the correct operating table—nothing is more frustrating than to bring in an image intensifier only to discover that the table is not radiolucent or that a bar occludes the area under consideration. When preparing the operating schedule, IOC should be included so that radiology personnel and nursing staff are not caught unaware. Likewise, the consent form should reflect a full and frank discussion of the need to perform a cholangiogram and possible duct exploration.

It is thoroughly worthwhile to spend time with the nursing and auxiliary staff to ensure that they understand how cholangiography is performed. This investment of time will pay huge dividends. For instance, the tendency to fill the contrast or saline syringe too rapidly leads to multiple small bubbles that can give a misleading x-ray appearance. Nurses should be instructed to draw the fluid up in a relaxed fashion. As stated by Sir Charles Bell,

> One word more. If it be a great operation and especially if the assistants and nurses are not habituated, be careful to appoint them their places and their duties: for nothing tends more to the right performance of an operation of magnitude, than that composure and quietness which result from arrangement.[8]

Laparoscopic operations are "operations of magnitude" and much frustration inherent in performing any step of an LC is avoided by teaching the operating room staff.

X-ray Equipment

Static films are of little value. Very often the penetration will be poor, the positioning will be suboptimal, and possibly too much contrast will have been injected, so that the early filling phase will be missed and small stones obscured.[9] It is far better to use a fluoroscopy unit, for this may be rotated to avoid overlying structures, gain an impression of the spatial relationship of ducts, and one may then choose the ideal moment to shoot a hard copy.[10] An audio-visual link may be provided by means of a coaxial cable to the radiology department, allowing the surgeon to discuss the findings with a consultant radiologist during the IOC instead of waiting for a result.[11]

Modern fluoroscopy units have digital enhancement capabilities that give quite splendid results[12] (Figure 11.3.1). It is useful to consider having a ceiling mounted C-arm, for this also reduces the time delay in obtaining films[13] (Figure 11.3.2). One of the charges leveled against routine cholangiography is the time taken, but this is usually estimated on the basis of static films. Utilizing either a ceiling mounted C-arm or a mobile digital enhancement fluoroscopy unit, the entire procedure may be completed within a few minutes.

Cost

Sometimes cost is cited as a reason not to perform cholangiography routinely. The charges involved relate to the cost of the cholangiogram catheter, contrast material, operating room time taken to complete the procedure, and professional fees charged by radiologists to interpret the films. I will discuss the different varieties of catheter below, but the device I routinely use, a 4F ureter catheter costs approximately $25. The contrast material adds another $10 and the average length of time to complete the entire procedure is five minutes. This leads to a total cost of $350–$500. Certainly one could factor in the capital cost of the X-ray equipment, but considering that it may be used for the placement of vascular-access catheters, orthopedic, and complex vascular procedures, that is perhaps not valid.

The most common reason given for the performance of routine IOC is the detection of stones. Assuming that there is an unsuspected common duct stone rate of 5%[14] and that some of these patients present later with jaundice or pancreatitis, often the intention is to treat them by endoscopic retrograde cholangiopancreatography and sphincterotomy (ERCP and ES). We may also assume that there is a failure rate for this endoscopic procedure of 10%.[15] If one performs 200 LCs one would expect to see 10 patients returning with missed CBD stones. Of these, one would have failed ERCP (which has an inherent cost of about $3,500) and would then need a conventional operation with perhaps another $10,000 charge. Yet 200 IOCs cost only $7,000.

The numbers become even more compelling when one factors in common bile duct injury. As will be seen on the following pages, the occurrence of this dreaded complication is difficult to ascertain, but one common bile duct injury often results in multiple hospitalizations, repeated operations, and may even progress to liver transplantation. The minimum hospitalization for hepaticojejunostomy may incur costs of up to $100,000 and a liver transplant frequently costs a quarter of a million dollars. From a cost perspective, one can easily justify routine IOC.

Cholangiocatheters

An enormous number of devices of varying lengths, stiffness, composition, and methods of retention within the duct have been marketed. Basically, there are two approaches and the approach used will help decide which catheter is chosen. Utilizing the cholangiography grasping forceps (Figure 11.3.3), any straight catheter may be chosen after an incision has been made in the cystic duct.[16] I prefer a modification of the cholangioclamp whose hole is in the center of rhomboid jaws, making it easier to grasp the duct[17] (Figure 11.3.4). The catheter is introduced and held in place with the grasper. I find it useful to use a "trumpet valve" cannula to house the cholangiograsper, for the pressure of the valve allows one to set the grasper and prevent it from falling into the abdomen and impinging on the common duct as tends to happen with the "flap-valve" cannulae. Other catheters

FIGURE 11.3.1. A mobile fluoroscopy unit capable of producing enhanced images and providing hard copies.

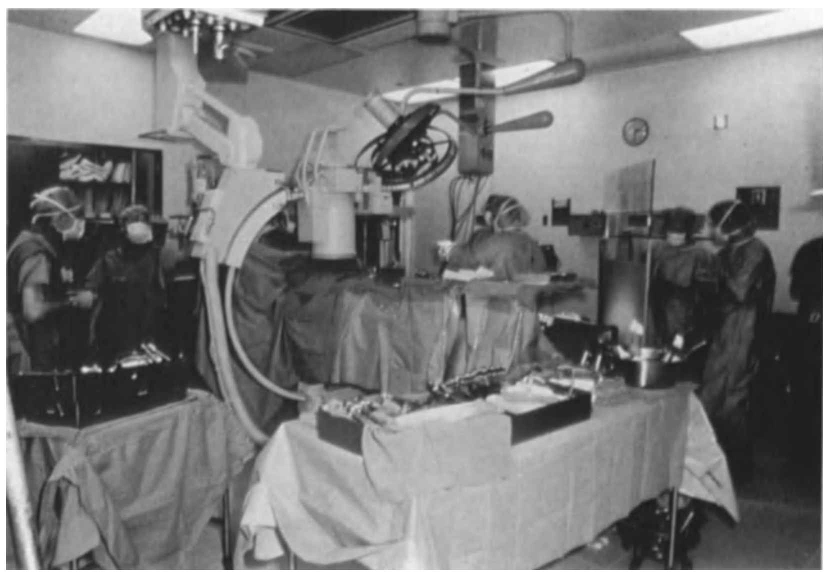

FIGURE 11.3.2. A ceiling-suspended C-arm with coaxial cable audiovisual link to the radiology department provides the surgeon with rapid and efficient cholangiography.

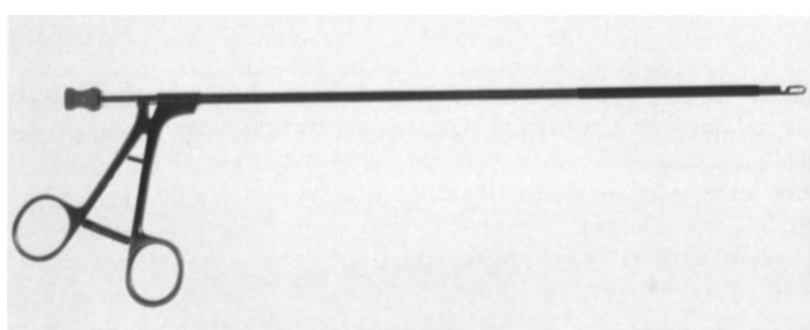

FIGURE 11.3.3. The standard cholangiocatheter grasping forceps.

use inflatable balloons or Malecot devices.[18] Some surgeons simply choose to insert the catheter and then hold it in place with a clip. I do not find this appealing, as having placed a clip one then needs to remove it, and this takes additional time and causes additional trauma to tissue. This is of special concern if the dochotomy has inadvertently been made in the common bile duct. The alternative technique is to introduce the catheter percu-

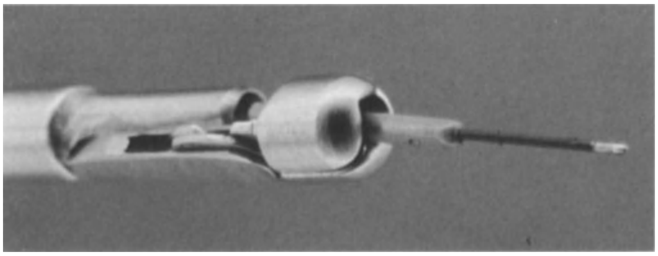

FIGURE 11.3.4. A modified cholangiocatheter grasping forceps that aids in securing the cystic duct seen here with a 4F catheter and guide wire (Karl Storz, Culver City, CA).

taneously through a vascular-access needle and sheath, and then either inflate a balloon, deploy the Malecot tip, or clip it in place.[19] This has the advantage of allowing one to select the ideal position for the percutaneous approach and does not "use up" a cannula.

Cholecystocholangiography

This technique was the first used[7] to obtain IOC during LC, but it has a number of drawbacks. First, one must puncture the gallbladder and run the risk of spilling potentially infected bile and stones. Second, the gallbladder may, once distended with contrast, obscure the very anatomy one wishes to visualize. I reserve this approach for patients with a great deal of inflammation and in whom the thick gallbladder wall makes getting purchase with graspers difficult. One then introduces a pre-tied Roeder loop from one cannula, a needle probe from another, and aspirates the gallbladder, the needle probe being placed through the loop. Once the gallbladder has been entered, through the same needle probe, I inject contrast material under fluoroscopic control. Obviously, if "white bile" has been withdrawn, then one would expect the cystic duct to be occluded and no visualization of the hepatic ducts will be obtained. However, it is somewhat valuable in that the length of gallbladder that must be dissected free will be defined. Once the needle is withdrawn, the pre-tied Roeder cat-gut loop is tightened, thereby closing the hole in the gallbladder and providing a "ledge" of tissue that may be grasped.[20]

Cystic Duct Cholangiography

One of the basic tenets of biliary surgery is that nothing should be clipped, tied, or cut until it has been defined and that ideally it must be seen to enter the gallbladder. Obviously, it is not possible to perform a completely retrograde or "fundus first" dissection in LC but, one may go some way toward this by creating a window between the gallbladder and the liver. Using a 30° forward oblique telescope, one may look at the medial aspect of the gallbladder and free up the peritoneum here and then move to the lateral aspect and do likewise until one is totally behind the gallbladder. At the junction of gallbladder and cystic duct a clip should be securely positioned.[21,22] Using scissors (I find the hook variety to be preferable) a small incision is made on the anterolateral aspect of the duct until bile is seen to issue forth. It is a useful step to "milk" the cystic duct gently toward the gallbladder so that any small stones in the duct will not be pushed down into the common duct. Of course, my detractors will state that if one has been able to clearly identify this junction then there is no need to proceed with IOC. The evidence below would suggest otherwise.

The blood supply of the CBD has been clearly characterized and consists of vessels running along its length, very often near where the cystic duct enters the CBD.[23–25] Too much dissection in this region may lead to ischemia and later stricture formation; in fact this has been proposed as a mechanism for such late injuries in patients undergoing cholecystectomy.[26] Any work in this area whether from a thermal energy source or from blunt or sharp dissection could lead to the same effect. Indeed, in a number of cases where bile duct injury has occurred, in retrospect the surgeon will note that more bleeding than usual was seen and this is a good indication that the junction of the cystic duct and common duct has been reached. The laparoscopic and open varieties of cholecystectomy differ in the visualization. At open surgery, the assistant's hand is placed around the duodenum and provides traction towards the left iliac fossa, while the surgeon raises the gallbladder toward the right shoulder. This separation and the three-dimensional appreciation is missing during LC, for only upward traction, causing tenting of the CBD is present and only a two-dimensional view is available. For this reason, cholangiographic proof of the anatomy will be seen to be vital.

Attachment of Syringes and Catheters

It is useful to have a three-way tap at the end of extension tubing with two syringes, one containing saline and one contrast. The contrast syringe should be marked by either a silk suture or by the fact that it is the larger of the two syringes. Air bubbles should be excluded from both syringes and tubing. Prior to introduction of the catheter into the duct it is useful to inject gently to clear it of residual air. Occasionally, it will be difficult to place the catheter into the duct and two tricks are of value. The first is useful when using grasping forceps. The catheter should be advanced with the jaws open, bent against the liver, and then held in this angulated condition (Figure 11.3.5A, B). It is useful when approaching a sharp corner. The second technique is to introduce a hydrophilic

A

B

FIGURE 11.3.5. (A) The catheter is advanced through the grasper and the jaws are opened. (B) The catheter is bent into the appropriate angle by gently pushing against an object such as the liver and is then held in that position by closing the jaws.

floppy-tipped guidewire through the catheter, advance this through the obstruction (usually valves of Heister), and then bring the catheter down over this. One should bear in mind that this will lead to a column of air in the catheter unless one allows the catheter to lie below the level of the patient for a few minutes, so that by capillary action bile may enter the syringe and prevent inadvertent introduction of air bubbles resulting in films that are misleading.

Clear View of Common Duct

The use of radio-opaque cannulae can obscure the view of the duct and it is valuable to use either a radiolucent plastic cannula or to replace the metal cannula over a plastic obturator.[17] After the IOC has been completed, the cannula can be repositioned over the obturator, which is then withdrawn. The falciform ligament will appear as a dark line and can be mistaken for other structures. Rotation of the table to left or right will move the ligament, and the spine, out of the way of the view of the common duct. Before commencing the operation, a scout film should always be obtained to check that the equipment is working, the patient is correctly positioned on the table, and to obtain the right settings for penetration.

Alternative Techniques to Visualize the Bile Duct

A number of other methods have been proposed for preoperative evaluation of the extrahepatic biliary tree. Certainly it will be usual to obtain an ultrasound, but this is not an accurate way to detect common duct stones and gives no information about exact anatomical relationships. Oral cholecystograms are of limited use, and in the presence of a nonfunctioning gallbladder or jaundice, are of no value whatsoever. Intravenous cholangiography has its supporters in Europe, but due to unavailability of the contrast medium in the United States, it has not gained wide acceptance. Preoperative ERCP has certainly been used with great frequency but my feeling is that this modality has been grossly overemployed. Even the avowed experts at ERCP accept that it has a morbidity of 10%, a mortality of 1%, and a failure rate of 10%.[15,27] Even if the selection criteria for preoperative ERCP are stringent and include a history of jaundice or cholecystitis and elevated enzymes, a large percentage of those coming to ERCP will not have stones at the time of the investigation.[28] This has an enormous cost impact and may lead to unnecessary investigation for many people. Additionally, the "road map" provided is of no value at the time of surgery for one does not know exactly which part of the extrahepatic biliary tree one has dissected free. In one recent study,[29] 28 patients had preoperative ERCP and only 12 had a positive finding (9 stones, 2 strictures, 1 cancer, 1 papillary stenosis, and 3 failures). My own preference would be to request ERCP in those patients who present with ascending cholangitis, a history of painless progressive jaundice, or unremitting jaundice where one is suspicious of a biliary or pancreatic neoplastic lesion.

Reasons to Perform Routine Cholangiography

The detection of unsuspected common duct stones has been a premier reason to recommend IOC. A number of tests, such as elevated alkaline phosphatase, may predict the presence of stones, but these are not reliable.[30] A history of jaundice or cholecystitis increases the likelihood of stones, but unsuspected stones are still seen in 6 to 10% of cases.[14] In the laparoscopic literature, a lower incidence has been reported,[31,32] but this is almost certainly due to case selection early in a surgeon's experience—this is certainly the case with me.[33] Intraoperative cholangiography is the most sensitive method of detecting common duct stones[34] and will allow one to progress to removal of the stones in one operation (Figure 11.3.6). It is preferable to referring the patient for postoperative ERCP and ES. Indeed, if one performs cholangiography routinely, one will become facile at the procedure and also become familiar with manipulating small catheters into the cystic duct, which is a vital component of the cystic duct extraction of common duct stones[35,36] (see Chapter 12). Certainly one also needs to know which stones can be extracted via the cystic duct, which patients should have laparoscopic choledocholithotomy, and which patients can have postoperative ERCP and ES (if one believes in this approach). Just because the stone is present in the CBD at the end of the operation, does not mean it will be present postoperatively. While a further discussion of CBD stones is beyond the scope of this chapter, it is appropriate to note that if one does perform an IOC and an abnormality is seen that may be a stone or an air bubble, one may leave a rubber tube in the cystic duct and secure it with a cat-gut loop, bringing it out percutaneously. This enables one to perform postoperative cholangiography to confirm or refute the presence of stones. If a stone is seen, one then has a route of access for percutaneous stone extraction or to pass a guidewire to help an endoscopist perform ERCP and ES. Obviously, if the patient has multiple intrahepatic stones they perhaps need a drainage procedure, and thereby conversion to conventional surgery unless one is extremely adept at laparoscopic suturing and equal to the challenge of performing laparoscopic choledochojejunostomy or sphincteroplasty.

Accessory ducts. When one performs an IOC and the gallbladder fills when the cystic duct-gallbladder junction is secured with a clip, this implies the presence of an accessory duct of Luschka (Figure 11.3.7). Obviously, it would be necessary to review the scout film to ensure the patient does not have a porcelain gallbladder that could also give this appearance.[37] This information will allow the surgeon to carefully locate the duct during extraction of the gallbladder from the liver bed, and secure it with clips or suture. Failure to do this may result in postoperative biloma. Additionally, accessory ducts may drain into the cystic duct. The cholangiogram will provide the surgeon with exact information about the location of this junction so that trauma to this duct may be avoided in the dissection, which might also result in a postoperative biloma (Figure 11.3.8).

Anomalous anatomy. The surgical texts suggest that the cystic duct joins the common duct at a right angle in

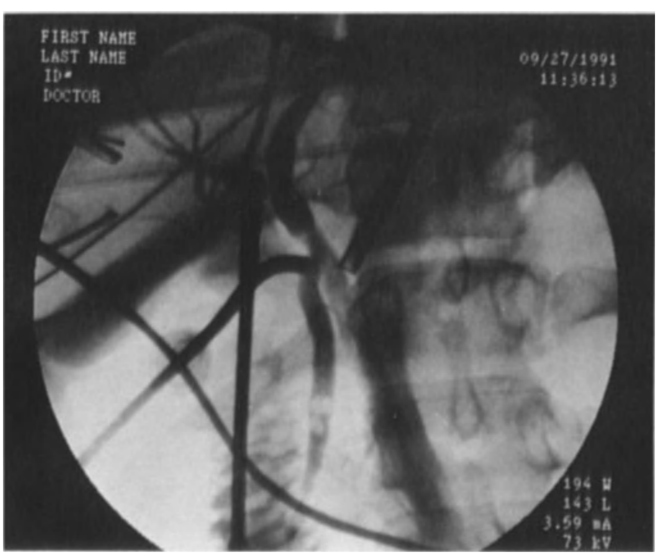

FIGURE 11.3.6. An IOC demonstrating two stones in the distal common duct.

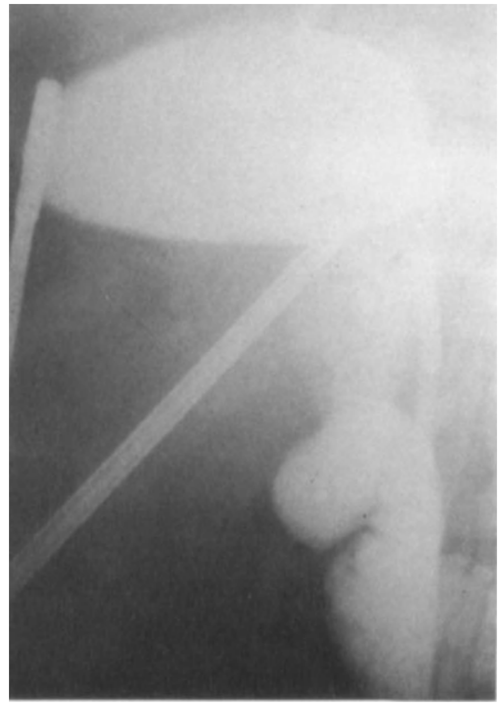

FIGURE 11.3.7. The cystic duct-gallbladder junction has been occluded with a clip, yet the gallbladder has filled with contrast. A duct of Luschka caused retrograde filling.

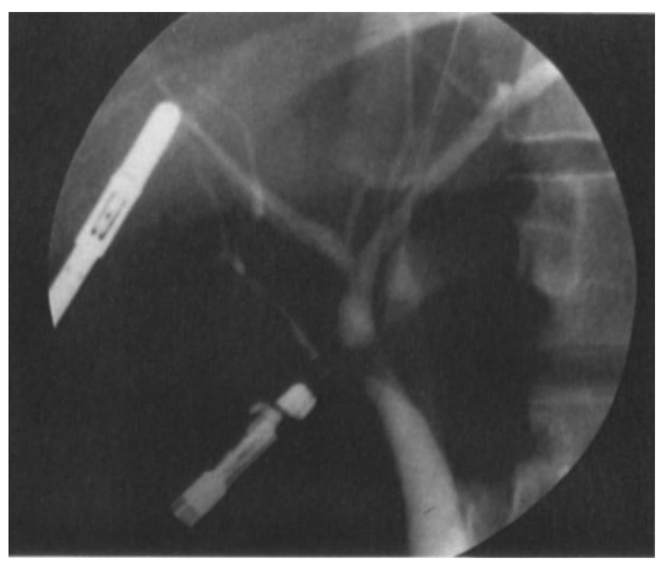

FIGURE 11.3.8. An accessory duct, probably draining a right posterior hepatic segment enters the cystic duct. This "road map" will prevent inadvertent injury.

75% of cases[38] but recent review has demonstrated that this is not the case.[13] Should the cystic duct run parallel to the CBD and the patient is obese, the close proximity of the two may lead the surgeon to inappropriately, clip, secure, and divide the common duct together with the cystic duct at the time of cholecystectomy if no IOC is performed. Indeed, this is the mechanism of injury that has been seen in numerous cases.[39]

Any surgeon doubting the validity of this claim should recall his or her own experience at open choledocholithotomy: on incising the duct, on occasion, one will discover that only the cystic duct has been entered, for the common duct lies deep to this. One can certainly be misled when Mirizzi's syndrome is encountered, making this problem even more profound. Attempting to merely follow the duct will result in an even more serious injury.

When the cystic duct drains into the right hepatic duct, very often the junction will be so obscure that one may be misled, follow the right hepatic duct, and inadvertently divide it, thereby causing total dissociation between right and left systems, with subsequent biloma or biliary peritonitis.

Short cystic duct. The tenting of the CBD that is a function of LC, makes this anomaly all the more obvious, more so in hydrops of the gallbladder (Figure 11.3.9). In our previously published series, this anomaly was seen in 23 of 464 cases (4.9%).[37] A short cystic duct was defined as one which is too short to safely place two clips and leave a gap between the clip nearest to the common duct. Failure to appreciate this anomaly, which is so easy with the tented duct, may lead to later stricture, bile leak, and all the attendant morbidity and mortality.

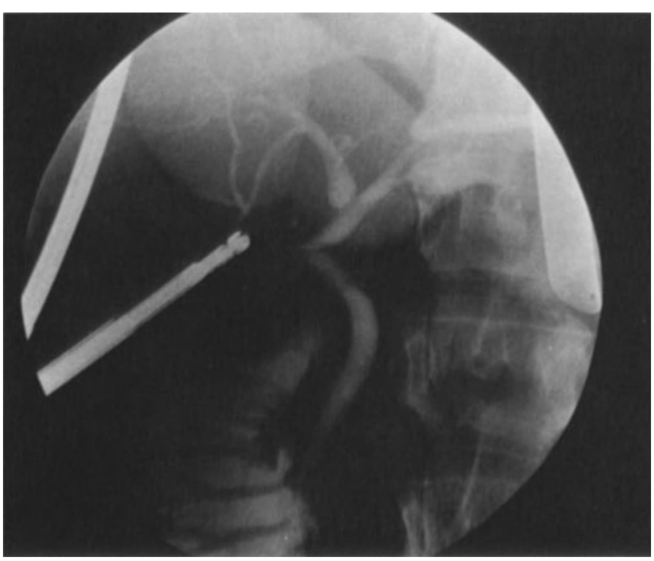

FIGURE 11.3.9. The common duct is "tented" due to traction on the gallbladder. In the presence of a short cystic duct this is a potentially dangerous situation.

Iatrogenic injury. If, at IOC, the proximal biliary system is not visualized, there may be a number of reasons. Certainly the cholangiograsper may be impinging upon the duct, the sphincter may be flaccid, there may be an overlying hepatic artery, or the patient's position may mitigate against filling.

One can certainly tilt the patient into the Trendelenburg position, give morphine and fentanyl to induce spasm of the sphincter, and inject more contrast. If these maneuvers fail, then withdraw the cholangiograsper a small distance. These measures may certainly be attempted, but if they fail to demonstrate the proximal ducts, the surgeon should understand that the unthinkable has happened—the common duct has been misinterpreted as the cystic duct.[40] If this were identified at IOC, then the injury to the common duct would consist of merely a small incision large enough to accommodate the catheter (this is why I do not like the catheter to be held in place by a clip) (Figure 11.3.10). If, however, no IOC was performed, the next stage in the operation would be clipping and division of the CBD. This has far more serious implications. If at the original operation, the error was not noted, then the patient will develop biliary peritonitis or biloma and must sustain a second operation. This increases the likelihood of a poor outcome.

Certainly, there is no value in performing IOC unless the surgeon looks at the films and makes sure that he or she interprets them correctly. Unfortunately, on a number of occasions, surgeons have failed to do this, and the evidence was there postoperatively—a distal duct only, a

FIGURE 11.3.10. This IOC shows filling only of the distal duct—the common duct had been mistaken for the cystic duct. The film enabled recognition of the error and prevented the surgeon from excising a segment of the duct.

small degree of extravasation, and filling of the duodenum. The presence of so-called "surgical shrapnel," more than the three or four clips one should see, is also a good indication that the integrity of the common duct has been breached, as bleeding would have been encountered in this area.

Why not? Many opponents of routine cholangiography maintain that the positive yield is so small that doing routine IOC is not productive. As demonstrated previously, a small number of unsuspected common duct stones will be seen, allowing for primary management. Accessory and anomalous ducts will be noted and injury avoided that might otherwise lead to troublesome biloma and most importantly, the severity of an iatrogenic injury may be minimized.

However, it is my contention that a normal cholangiogram is *not* a negative finding: quite the opposite, it is a major *positive* finding. It allows the surgeon to assure the patient postoperatively that they have an intact biliary system and any "post-cholecystectomy syndrome" will almost certainly not relate to the CBD. In the past, many cases of cystic duct syndrome were due to retained stones within the cystic duct and were a primary reason to recommend not leaving a long cystic duct remnant. If one performs IOC, one will be sure that no stones are present in the cystic duct and will have no need to "chase" it to its junction with the CBD.

As a caveat to the likelihood of postoperative pain emanating from the biliary tree, I recommend securing the cystic duct stump after cholangiography is complete with chromic cat-gut loops, pretied or knotted intra- or extracorporeally. Metal clips have been known to migrate into the common duct and become the nidus for CBD stones,[41] and even bioabsorbable clips have been known to migrate into the common duct and cause obstructive jaundice.[42]

Other modalities to evaluate the ductal system such as intraoperative ultrasound have been proposed, and we have certainly looked at this from without and within the ductal system. Currently, the time taken and the expertise required mitigate against intraoperative ultrasound gaining widespread acceptance.

Results

Authors have been reticent to publish rates of common duct injury, so it is extremely difficult to obtain meaningful statistics. However, it is likely that the rate of common duct injuries has increased significantly since the introduction of LC.[31,39,40,43] Common duct injury is the most serious complication of biliary surgery and we must do all in our power to avoid this dreadful sequel. In the SAGES retrospective LC study, there were four CBD injuries and in the prospective study, one injury.[31] In none of these five cases had IOC been performed. In a series published by Davidoff and colleagues in 1991, reporting 12 patients with common duct injuries, only three IOCs had been performed.[39] In two, a hepatic duct stricture occurred after several weeks and was probably caused by excessive manipulation or thermal injury, and the other was found to have partial ligation of the common duct. Clearly, performance of the cholangiogram alone does not guarantee a successful outcome. One must continue to use good surgical judgment and follow the anatomical relationships demonstrated on the x-rays. In a series reported by Rossi in 1992,[44] 11 patients undergoing biliary reconstruction were reviewed. Only 1 of the 11 had undergone a cholangiogram and in this patient the result was misinterpreted. This study had demonstrated good flow of contrast from the cystic duct to the common duct and into the duodenum but no retrograde flow was seen and the patient was subsequently found to have a complete transection of the common duct. This mechanism was described previously.

In a paper by Moossa and colleagues in 1992, out of six patients who were referred for repair of injured common ducts, none had undergone IOC and all had a complex injury.[40] In a series from Cedars-Sinai Medical Center, Sackier and colleagues followed 464 LCs with cholangiography.[37] In one additional patient, cholangiography was not performed because the cystic duct was avulsed earlier in the dissection and the stump was repaired successfully at open surgery. One common duct injury occurred similar to the case described in the paper by Rossi, but the abnormality on the cholangiogram was noted and conversion to open surgery prevented a more serious injury. A report from Flowers in 1991,[45] compared 364 patients in whom 165 IOCs were attempted, successfully in 150. There were no bile duct injuries in those undergoing cholangiography and 11% were deemed to be abnormal (utilizing my philosophy, though, 100% were contributory!). In the patients not undergoing cholangiography, 3 of 214 patients (1.4%) had retained common bile duct stones and one biliary injury occurred in a patient with aberrant anatomy.

There were no sequelae to performing the cholangiogram. A single case reported by Cantwell in 1992, demonstrated that aberrant arterial anatomy could lead to obstruction of the CBD when a clip was placed. Had a cholangiogram not been performed, this obstruction would not have been noted until the postoperative period. A similar experience with recognition of injury was reported by Graves and colleagues in 1991.[47] In their series, a single common duct injury occurred in 304 LCs. This was due to incorrectly identifying the common duct as the cystic duct, incising it, and performing an IOC. Had this not been done, complete transection would have ensued. In a number of series, such as that by Peters and colleagues, cholangiography is performed selectively but the article does not distinguish in which patients IOC was obtained.[48] In a number of patients, there were complications: inadvertent common duct injury recognized and repaired at primary laparotomy, one patient with a retained stone, and two patients with bile extravasation presenting postoperatively. It is easy to see how these complications could have been averted or recognized earlier by the use of IOC.

Indeed, a number of authors have recommended IOC as a procedure that helps the surgeon avoid injuring the CBD in addition to use of a 30° optic, maintaining a blood free field, and of course, a meticulous dissection.[21,22] Intraoperative cholangiography during LC is an additional means of guaranteeing safe completion of the surgery and is not, in and of itself, a guarantee.

Finally, one should evaluate the time taken to perform this procedure. It takes about five to seven minutes[37,49] and as demonstrated at the beginning of this chapter, this minimizes the cost impact. Additionally, in no series, has any morbidity or mortality been attributed to the performance of IOC.

Selective Cholangiography

In a 1992 paper from Lillemoe and colleagues, 400 patients were reviewed.[28] Preoperative or postoperative ERCP was performed when stones were clinically suspected. ERCP was performed preoperatively in 44 patients 14 of whom had ES with extraction of common duct stones, suggesting that 30 had an unnecessary investigation. Intraoperative cholangiography was performed in eight patients (2%). Two patients had a significant CBD injury that was recognized and repaired at the first operation. In one patient with significant inflammation, the injury seemed to have occurred earlier in the operation. The second patient had a low hepatic duct bifurcation with a short cystic duct. It is impossible to predict whether IOC Tuld have limited the extent of these injuries. In six patients in this series, postoperative ERCP was performed. Three required ES, so 50% of these patients had an unnecessary investigation.

Conclusions

Hopefully, the evidence presented in this paper will encourage the reader to perform cholangiography routinely during LC. In the author's personal experience, it has been invaluable in avoiding intraoperative disasters. In medicine, convincing statistical arguments may be found to support two sides of an argument, but more compelling reasons against routine IOC need to be proposed to change my mind. Because there seem to be so many good reasons to do IOC routinely and few arguments against it, surgeons should consider the benefits and not rationalize reasons to omit this important step.

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11.4
Selective Cholangiography

Mark A. Talamini

The issue of selective versus routine operative cholangiography during laparoscopic cholecystectomy is an old debate that is now being revisited.* In surgical texts of 10 to 20 years ago, and in surgical literature of that period, there was frequent debate regarding the indications for cholangiography during conventional cholecystectomy. A range of opinions existed even then, with some strongly advocating cholangiography on every single case.[1] Others believed that cholangiography should only be performed when the anatomy was unclear, or when there was reasonable suspicion of a common duct calculus.[2] As endoscopy has developed over two decades, the indications for operative cholangiography have been modified.[3] Skilled endoscopists can now perform ERCP, papillotomy, and stone extraction with a minimum of morbidity and mortality.[4] Even prior to the era of laparoscopic cholecystectomy, many surgeons found that patients referred by gastroenterologists had already undergone removal of the common duct stone via ERCP with sphincterotomy. Thus, prior to laparoscopic cholecystectomy, surgeons were already moving towards selective cholangiography, with fewer and fewer cholangiograms being performed in the operating room.

The era of laparoscopic cholecystectomy has brought this debate back to center stage. It became obvious early in the development of laparoscopic cholecystectomy that laparoscopic cholangiography could be performed without a great deal of additional technical difficulty.[5] Some surgeons immediately proposed that laparoscopic cholangiography be routinely performed.[6] The arguments for routine cholangiography during laparoscopic cholecystectomy fall into four broad categories:

1. Avoidance of common bile duct injury
2. Detection of common duct calculi
3. Training of residents
4. Legal protection

Common Bile Duct Injury

The argument regarding duct injury appears to make good common sense. If the surgeon is able to delineate the anatomy radiographically prior to dividing and ligating structures, then the incidence of injury to the common bile duct should be reduced, or possibly eliminated. A closer look reveals flaws in this logic. The most common technique of laparoscopic cholangiography involves identification of the cystic duct as the first step. The cystic duct is dissected and encircled. After it is isolated, a clip is placed on the gallbladder side of the cystic duct, and an incision is made below the clip. A fine catheter is placed through the incision into the cystic duct. A variety of methods are available to hold the catheter in place. Initially, the most common was to place a snug surgical clip around the structure to hold the catheter in place. Subsequently, catheters have been designed with internal mechanisms to help achieve the placement, that is, balloon-tipped catheters. The problem with this technique is that the very act of performing the cholangiogram can cause injury. If the common duct has been mistaken for the cystic duct, it will have been encircled and dissected for several centimeters, perhaps devascularizing it, and then clipped and incised before the cholangiogram has correctly identified it and the common bile duct.

Some argue that an injury consisting of clip placement and incision of the duct is not as severe as a common duct transection. However, in most cases of mistaken identity of the cystic duct and subsequent injury to the common duct, significant anatomic abnormalities exist that have confused the surgeon. A major reconstruction will prob-

*Editor's Note: Perhaps there is nothing in general surgery that excites more of an emotional debate than the issue of routine versus selective operative cholangiography, whether one is dealing with conventional or laparoscopic cholecystectomy. This issue will almost certainly be debated until general surgery itself is obsolete. RJF ably have to be performed because of the unusual ductal anatomy and the resultant injury. It is also possible to injure the common duct during cholangiography even when it has *not* been mistaken for the cystic duct. A stiff catheter placed through the cystic duct and into the common duct can puncture the back wall of the common bile duct, creating a difficult injury to repair. The surgeon's best protection against common duct injury is adherence to the first principle of laparoscopic cholecystectomy, which is identification of the cystic duct–gallbladder junction. If this junction cannot be clearly identified, the surgeon should convert the operation to a conventional cholecystectomy.

The most challenging anatomic variant for the laparoscopic surgeon is the very short, or nonexistent cystic duct. Fortunately, this is rare.[7] In this situation, pursuing identification of the cystic duct–gallbladder junction can easily result in common duct injury. Therefore, this initial step must be pursued very carefully. If confusion or difficulty arises in the initial dissection, one useful strategy is to dissect the infundibulum and the inferior areas of the gallbladder along the liver to define the shape of the gallbladder. If such a dissection demonstrates these structures to be close to the hilum or too close to portal structures, the dissection should be abandoned and converted to a conventional procedure. Unfortunately, many of these cases will result in ductal injuries despite the surgeon's best efforts. The safety net for this operation is not cholangiography, it is conventional cholecystectomy. In fact, concern exists that reliance upon cholangiography as a means of avoiding ductal injury could allow a surgeon to be less compulsive in pursuit of this most important first step: identification of the cystic duct–gallbladder junction.

Among the large series of laparoscopic cholecystectomies now published, there is ample evidence that routine cholangiography does not necessarily protect the surgeon from common duct injury. There are series where routine cholangiography has been employed that report common bile duct injuries.[8] Conversely, there are series where selective or rare cholangiography was performed with extremely low common duct injury rates.[9] Thus the literature published to date has not demonstrated that routine cholangiography protects the surgeon from common duct injury. In fact, Soper's study randomized laparoscopic cholecystectomy patients to either undergo routine cholangiography (56 patients) or selectively (59 patients). Cholangiography added 16 minutes to the procedure, and added about $700 to the procedural cost. Cholangiography did not reveal aberrant bile ducts that would be at risk of injury from the laparoscopic dissection. This is the only study to date that investigates the issue of laparoscopic cholangiography in a prospective randomized fashion.[10]

Common Duct Calculi

Another argument for routine cholangiography is the ability to detect common bile duct calculi in the operating room. The argument used is that the risk of leaving a common duct stone behind inadvertently justifies the performance of a cholangiogram on every single patient. The optimal treatment of common duct calculi has become complicated. Multiple acceptable alternatives are available. Early in the laparoscopic cholecystectomy experience, some surgeons recommended a preoperative endoscopic cholangiogram for everyone. This provided a "road map" of the biliary tree and ensured that common duct stones did not exist. The risks and costs involved have led to abandonment of such protocols.

All candidates for laparoscopic cholecystectomy should undergo preoperative screening for common bile duct stones. This usually consists of the measurement of blood AST, ALT, alkaline phosphatase, bilirubin, and amylase. Additional information is gained from sonographic or CT indications of the size of the common bile duct and intrahepatic ducts. If a common duct stone is suspected preoperatively, the surgeon has two options. One is preoperative endoscopic retrograde cholangiopancreatography, with papillotomy, followed by stone extraction if one is found. Another possibility is to confirm suspicions in the operating room by performing laparoscopic cholangiography. The stone or stones can be managed in one of three ways: laparoscopic common bile duct exploration; conversion to laparoscopy for bile duct exploration; or ignore the stone or stones with the hope that they can be successfully removed postoperatively with papillotomy and stone extraction. The decision usually depends upon the surgeon's level of skill, the availability of sophisticated tools, and the skill of colleagues in gastroenterology and invasive radiology, who may be called upon for the postoperative management.

The most important question for surgeons is how to use information obtained from routine cholangiography. Laparoscopic common bile duct exploration has a variety of meanings to surgeons. It can be as simple as giving glucagon to relax the Sphincter of Oddi and threading a balloon catheter through the cystic duct into the common duct and out into the duodenum. Such procedures have a high likelihood of success with small stones or gravel material within the common duct. Such techniques are well within the abilities of most laparoscopic surgeons. At the other end of the spectrum is a laparoscopic choledochotomy with common duct exploration followed by placement of a T-tube and suture closure of the duct. Surgeons capable of laparoscopic surgery at this technical level currently are in the minority. Other arguments against the use of routine cholangiography include the fact that routine cholangiography will in some cases reveal small stones. If undetected most small stones would simply pass. Once discovered, however, many surgeons feel compelled to attempt removal of the stones by some means. Additionally, artifacts (air bubbles) on cholangiography can lead to needless common duct exploration.

In a recent series from Johns Hopkins,[11] 400 patients underwent laparoscopic cholecystectomy with a protocol of selective preoperative ERCP. Patients presenting with a preoperative suspicion of common duct stones had an endoscopic cholangiogram before laparoscopic intervention. If a stone was found, sphincterotomy and stone extraction was accomplished, followed by laparoscopic cholecystectomy. Only eight cholangiograms were performed in the operating room. Postoperatively if suspicion of a common duct stone developed, an endoscopic retrograde cholangiogram (ERC), sphincterotomy, and stone extraction were performed. Out of this series, 44 (11%) patients preoperatively required ERC and 14 (3.5%) actually had stones. All of the stones were successfully removed. In the postoperative period, 6 (1.5%) patients developed symptoms consistent with common bile duct stones and underwent ERC. Three of these patients actually had stones, all of which were successfully extracted. In summary, out of the series of 400 patients, common duct calculi were removed in all patients without the need for an open or a laparoscopic common bile duct exploration. This has led us to conclude that laparoscopic cholangiography is *not* necessary for the diagnosis of common bile duct calculi. Similar series have now been published by other surgeons using a similar protocol. Series such as these leave doubt as to whether even selective cholangiography needs to be performed. However, it is expected that as surgical laparoscopic approaches to the exploration of the common bile duct for calculi become easier, more selective cholangiograms will be performed with an eye towards laparoscopic treatment of common duct stones to avoid the need for a second procedure.

Training

An argument commonly used in favor of routine cholangiography is that of training. This argument states that surgeons must perform the procedure on a regular basis to become facile with it. Then when the procedure is necessary, it can be performed safely and efficiently. An extension of this argument in academic medical centers is that surgeons must perform routine cholangiography to train residents in the technique. It is indeed true that surgeons must train themselves in appropriate techniques in order to train future surgeons. However, this is hardly an argument for performing a cholangiogram on every patient, if medical reasons to do so are nonexistent. This is an expensive procedure. Routine cholangiography nationwide would be costly. Further, cholangiography has risks and benefits like any procedure. The common duct can be injured by virtue of the action of the cholangiogram. Therefore, the procedure should be evaluated on a risk versus benefit basis like any other intervention.

There is no justification to expose patients to expense and risk merely for the training of residents. For instance, it would not be correct to perform a certain percentage of cholecystectomies conventionally merely to train residents in the technique. Rather, the conventional technique should be performed when it is better for the patient. Surgical residents benefit not only from participating in procedures, but also from observing sound medical decision-making. If surgeons must teach the technical aspects of this procedure to residents, perhaps an animate tissue laboratory experience would accomplish this.

Current Practice

Current practice in the general surgical community is an important consideration when discussing routine versus selective cholangiography. Data are available from state and society specialty surveys to determine what the practice of general surgeons across this country happens to be. A series recently published from Connecticut demonstrated that only 42% of the general surgeons performing laparoscopic cholecystectomy are actually doing routine cholangiography.[12] In another series done in Oregon, only 55% are performing routine cholangiography.[13] The Southern Surgeons Club reported in the *New England Journal of Medicine* that only 29% of patients underwent cholangiography. Routine cholangiography was being performed by only 3 of the 20 surveyed surgical groups.[14] These practice patterns have developed despite strident voices in the surgical community stating that routine cholangiography is essential.

What cost issues are involved? As we become more and more aware of cost benefit ratios, this must be considered. If one assumes the average professional fee for a cholangiogram during laparoscopic cholecystectomy is $500 and the additional materials are $200, each laparoscopic cholangiogram represents a cost of $700. Since 500,000 cholecystectomies are performed each year, the total cost to the healthcare system of routine cholangiograms in every single case would be $350 million. If cholangiograms are performed in 20% of cases, the cost would be $70 million. This represents an incremental expense of $280 million if the United States surgical community were to perform routine cholangiography during laparoscopic cholecystectomy. Some would argue this expense would be overridden by the savings in malpractice because cholangiography protects the surgeon. This is simply false. Bile duct injury cases are being filed and brought to court irrespective of the issue of cholangiography.

Summary

We have attempted to delineate the logical reasoning behind our decision not to perform routine laparoscopic cholangiography. It is our feeling that this argument will fade in its intensity over the coming years. When we look back 10 years hence, the majority of general surgeons will probably not be performing routine laparoscopic cholangiography, although there will be a minority who continue to firmly hold to this practice. Individual surgeons must develop their own safe, reliable protocol regarding laparoscopic cholangiography, depending upon their individual skill level, the availability of capable consultants, and the current literature.

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11.5 Laparoscopic Ultrasound of the Biliary Tree

M.A. Röthlin

With the worldwide introduction of laparoscopic surgery, the controversy over routine intraoperative cholangiography has started again. Laparoscopic sonography is a possible alternative to this technique. It has potential far beyond the intraoperative diagnostics of bile ducts.

Historical Review

In the 1980s, intraoperative sonography was successfully employed during conventional cholecystectomy by several groups.[1–3] It never gained wide acceptance because there were only a few surgeons trained in sonography and because some authors demanded a Kocher maneuver for better visualization of the bile ducts.[3] Since its beginnings in 1958, laparoscopic sonography has been invented several times. All the trials of laparoscopic sonography connected with diagnostic laparoscopy[4,5] were abandoned. There were vast improvements in pre- and intraoperative imaging techniques, which not only made laparoscopic sonography, but also diagnostic laparoscopy itself, all but obsolete. The pandemic spread of laparoscopic cholecystectomy reactivated the controversy about routine intraoperative cholangiography.[6,7] On one hand, the technique of intraoperative cholangiography became more difficult and the examination took more time. On the other hand, the demonstration of the anatomy of the hepatoduodenal ligament gained more importance[6] because of the loss of tactile sense with the laparoscopic technique. In April 1991, we decided to evaluate laparoscopic sonography as a possible alternative to preoperative cholangiography, thus applying this technique to operative laparoscopy for the first time.

Technique

When we started our studies, there were no commercially available ultrasound scanners for this specific application. We used a 360° sector scanner, mounted on a rod 31 cm in length, which was originally designed for endoluminal sonography of the urinary tract (Typ 1850 + 8523, Brüel&Kjær Instruments Inc., Marlborough, USA). Its sonographic focus lies at a depth of 1 to 4 cm, its ultrasound frequency is 5.5 MHz and the sonographic plain is at a right angle to the shaft. The tissue is protected from the rotating shaft of the scanner by a protective tube 9.5 mm in diameter with a plastic tip. The scanner can be introduced into the abdominal cavity through any 10-mm cannula. In the meantime, several linear, curved-array, and sector scanners have become available for laparoscopic sonography.

In preparation for laparoscopic sonography, the patient is brought from an anti-Trendelenburg position into a horizontal position and the subhepatic space is filled with 100 to 200 mL of saline for better acoustic coupling. Laparoscopic sonography may be employed at any time during the operation. In patients with atypical anatomy or acute cholecystitis, we suggest performing the examination before beginning the dissection of the cystic duct. In all other cases, it is easiest to do laparoscopic sonography after the dissection of the cystic duct and artery, but before clipping the two. This way, the dissection is not obstructed by the liquid used, and there is no danger of clips being dislodged by the scanner.

The scanner is inserted through the 10-mm cannula in a left paramedian position, which is also used for the dissecting hook and other instruments. The tip of the scanner is placed as high as possible in the hepatic hilum. It is then slowly retracted along the hepatoduodenal ligament; the axis is identical to the axis of the scanner's shaft. The picture transmitted is a cross section of the ligament and its structures. Special attention is given to the course of the right hepatic artery and the cystic duct and artery. At the lower end of the ligament, the scanner is shifted to the patient's right, thus demonstrating the intrapancreatic part of the common bile duct in a longitudinal view. There are five characteristic views of the normal anatomy. The first shows the branching of the left and the right hepatic artery (Figure 11.5.1). The second

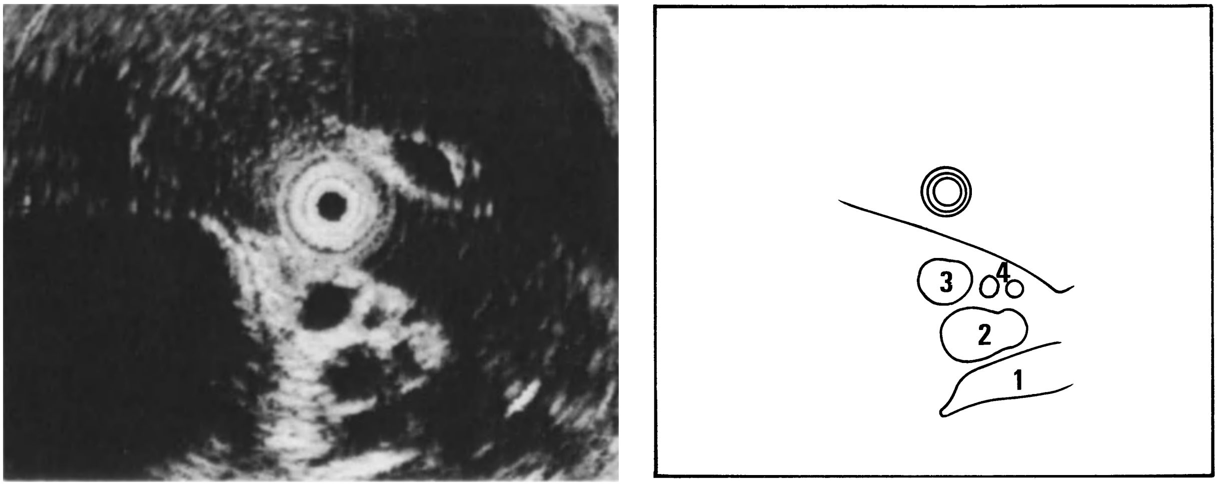

FIGURE 11.5.1. Sonographic view at the branching of the hepatic artery. Inferior caval vein (1), portal vein (2), common hepatic duct (3), hepatic arteries (4).

demonstrates the typical "Mickey Mouse" configuration of the structures of the ligament (Figure 11.5.2). In the third view, the junction between common hepatic and cystic duct is visualized (Figure 11.5.3). The fourth view shows the situation at the cranial border of the pancreas, where the common hepatic duct separates from the other structures and veers off to the right (Figure 11.5.4). The last view demonstrates the intrapancreatic part of the bile duct in a longitudinal fashion (Figure 11.5.5). Once the prepapillary part of the bile duct has been visualized, the examination is finished and the scanner is removed. To continue the operation, the patient is brought back into the anti-Trendelenburg position. Aspiration of the saline solution is not necessary in most cases and the operation can be continued without further delay.

Results

At Zürich University Hospital, we undertook a prospective, controlled study comprising 100 consecutive patients admitted for laparoscopic cholecystectomy. In all cases, first laparoscopic sonography, then cholangiography[8] was performed. Laparoscopic sonography could be concluded successfully in all cases, while intraoperative cholangiography was abandoned in six cases for technical reasons.

Bile Duct Calculi

Five patients were found to have nine preoperatively unsuspected bile duct calculi. The stones were demonstrated by laparoscopic sonography in all cases (Figure 11.5.6). Intraoperative cholangiography corroborated the findings in three patients, one of which had three stones, of which only one was visualized radiologically. All the stones could be removed intra- or postoperatively. In one patient there was a 2-mm stone, invisible on cholangiography. At the beginning of the study, there was one patient with a false positive finding on laparoscopic sonography. Debris in a juxtapapillary duodenal diverticulum was mistaken for a bile duct stone. The sensitivity and specificity of laparoscopic sonography in this context were 100% and 99%, respectively.

There are currently no other data available concerning the efficacy of laparoscopic sonography. On the other hand, there are several studies discussing the results of intraoperative sonography during conventional cholecystectomy.[1–3] In all these trials, sonography had a sensitivity at least as high as intraoperative cholangiography. It ranged from 93 to 96%. Lane and coworkers also found that sonography can demonstrate stones down to 1 to 2 mm in diameter, which are invisible on cholangiography. The scanners presently available do not allow efficient scanning of the intrahepatic bile ducts. This will become possible with the new mobile-tipped scanners.

Anatomical Variations

Anatomical variations of both bile ducts and hepatic arteries are frequently found at autopsy.[9] Knowledge of the biliary and arterial anatomy is important for the prevention of complications, that is, bile duct injuries or clipping of the right hepatic artery. Laparoscopic sonography demonstrated variations in 37 patients (Table 11.5.1). There were 20 variations of the bile ducts (Figures 11.5.7 and 11.5.8) and 22 variations of the hepatic arteries (Figures 11.5.9 and 11.5.10). The only three variations missed on sonography and demonstrated by cholangiography were the duodenal diverticulum mentioned above, as well as a long common channel between pancreatic and common bile duct and a cystic duct joining the hepatic duct on its left side, which was only seen retrospectively after

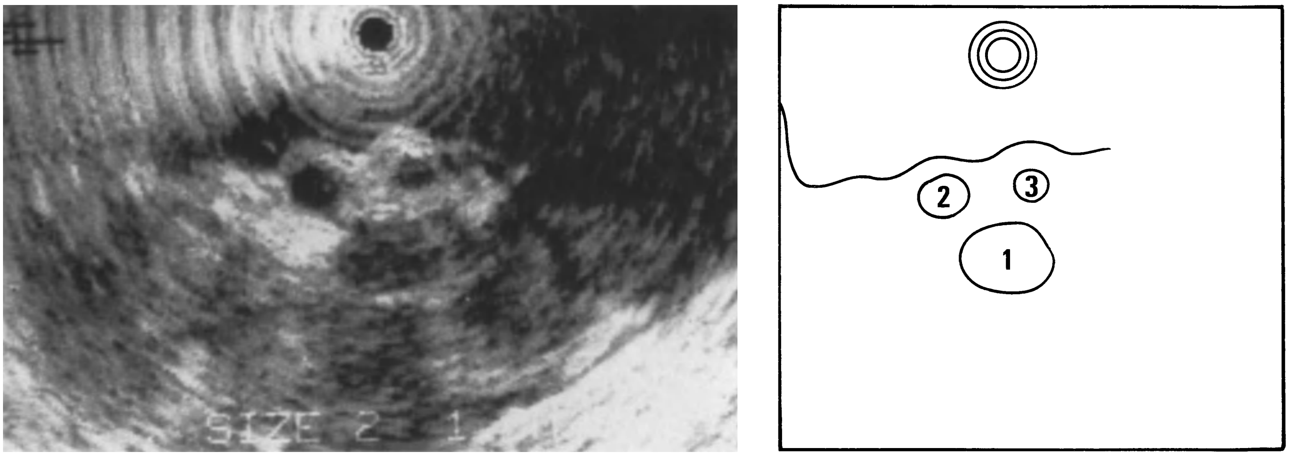

FIGURE 11.5.2. Sonographic view of the hepatoduodenal ligament. Portal vein (1), common hepatic duct (2), hepatic artery (3).

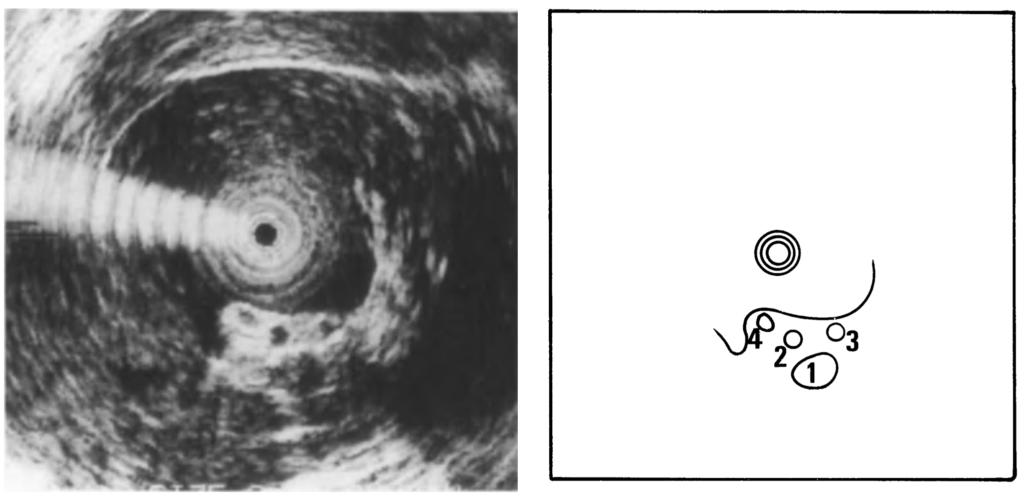

FIGURE 11.5.3. Sonographic view at the level of the cystic duct. Portal vein (1), common hepatic duct (2), hepatic artery (3), cystic duct (4).

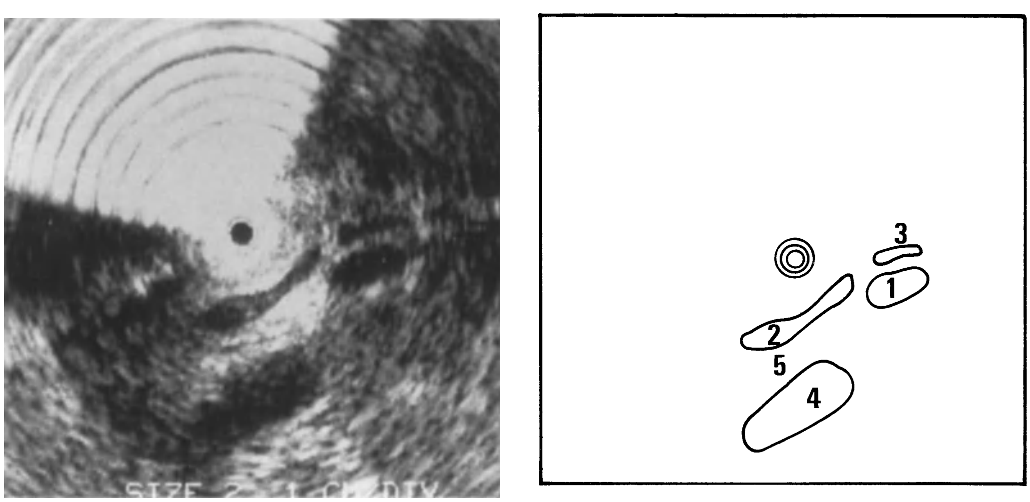

FIGURE 11.5.4. Sonographic view at the cranial border of the pancreas. Portal vein (1), common bile duct (2), hepatic artery (3), inferior caval vein (4), pancreas (5).

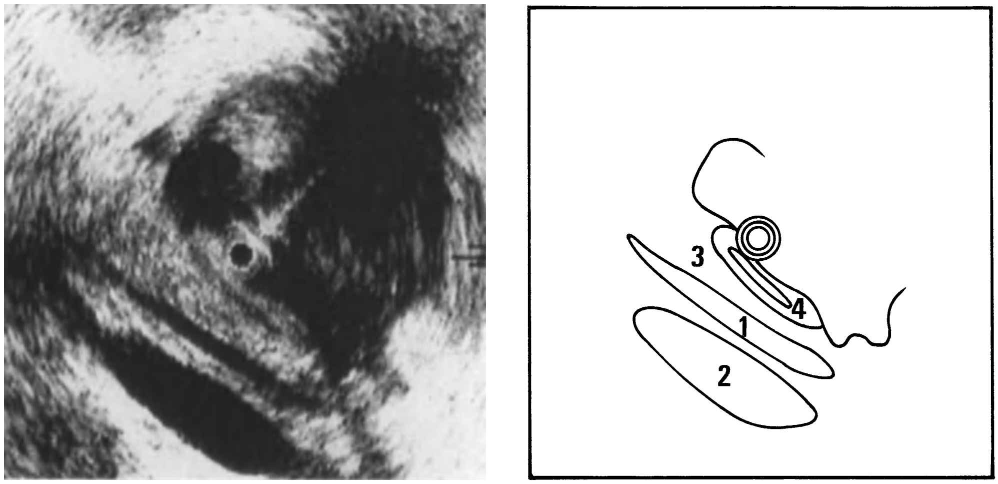

FIGURE 11.5.5. Sonographic view of the intrapancreatic duct (1). Inferior caval vein (2), pancreas (3), duodenum (4).

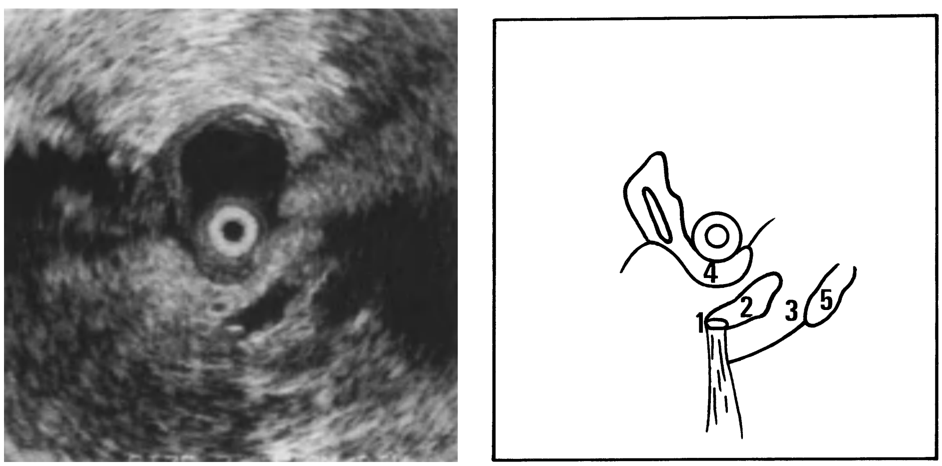

FIGURE 11.5.6. Sonographic demonstration of a prepapillary bile duct stone (1). Common bile duct (2), pancreas (3), duodenum (4), inferior vena cava (5).

TABLE 11.5.1. Anatomical variations seen with laparoscopic sonography and intraoperative cholangiography in 100 patients undergoing laparoscopic sonography.

Anatomical Variation	Laparoscopic Sonography	Intraoperative Cholangiography
Low hepatic junction	n=2	Ø
Cystic duct joining right hepatic duct*	n=1	Ø
Aberrant duct from right lobe joining with cystic duct*	Ø	n=1
Intrapancreatic junction of the cystic duct	n=6	n=6
Cystic duct joining on the dorsal aspect	n=7	n=7
Cystic duct joining on the ventral aspect	n=2	n=2
Cystic duct joining on the left side	n=2	n=3
Long common channel (>10 mm)	Ø	n=1
Duodenal diverticulum	Ø	n=1
Right hepatic artery originating from superior mesenteric art	n=6	Ø
Right hepatic artery crosses the bile duct ventrally	n=15	Ø
Cystic artery crossing the ventral aspect of the bile duct	n=1	Ø

*Same patient.

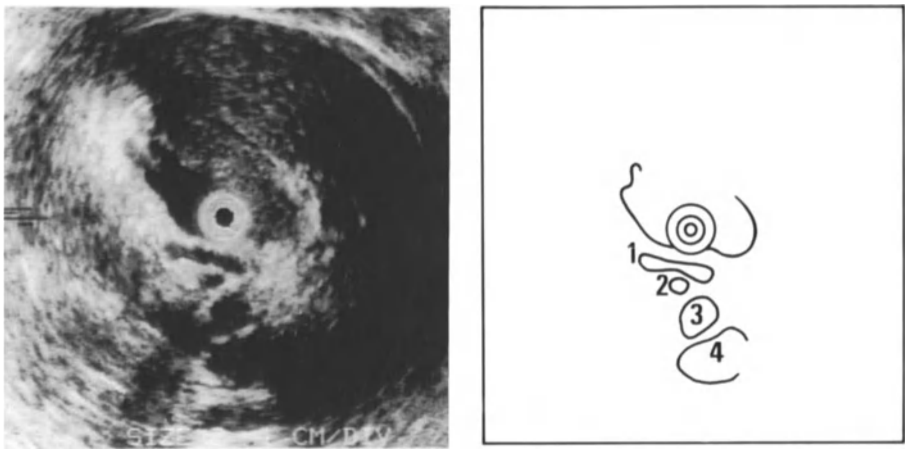

FIGURE 11.5.7. Dorsal junction of the cystic duct (1) and the common hepatic duct (2). Hepatic artery (3), portal vein (4), inferior caval vein (5).

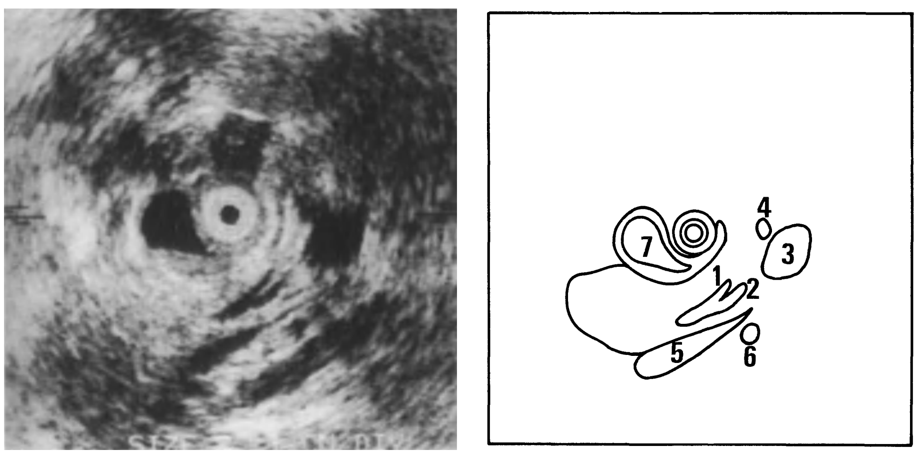

FIGURE 11.5.8. Intrapancreatic junction of the cystic (1) and common hepatic duct (2). Portal vein (3), hepatic artery (4), inferior caval vein (5), right renal artery (6), duodenum (7).

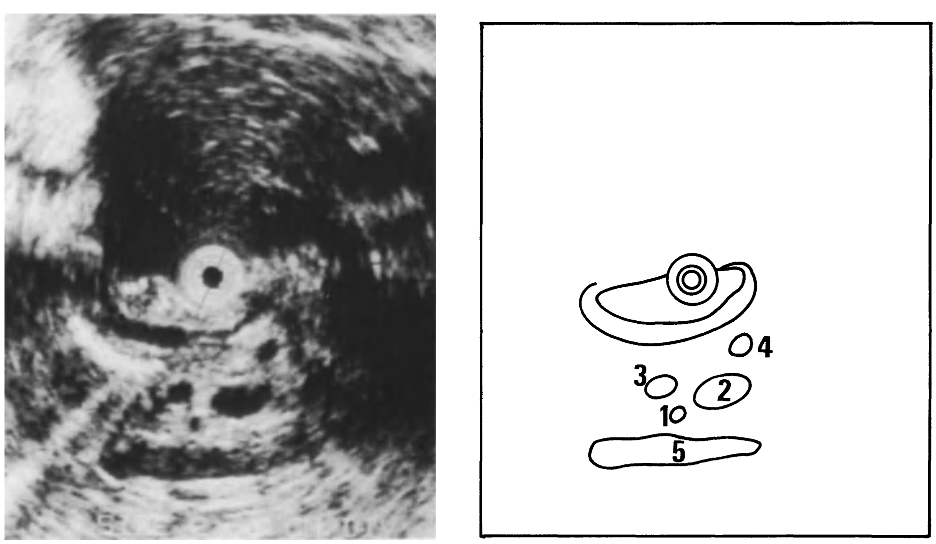

FIGURE 11.5.9. Aberrant right hepatic artery (accessory) (1) originating from the superior mesenteric artery. Portal vein (2), bile duct (3), common hepatic artery (4), inferior caval vein (5).

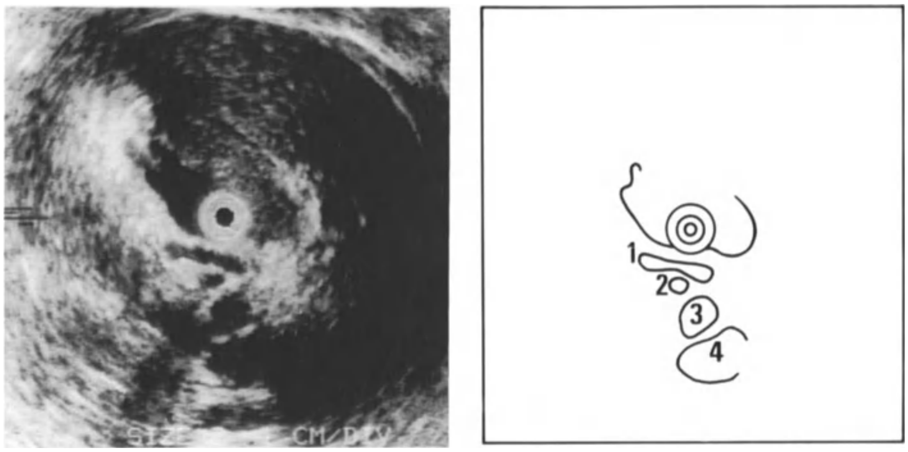

FIGURE 11.5.10. Right hepatic artery (1) crossing on the ventral aspect of the common hepatic duct (2). Portal vein (3), inferior caval vein (4).

being demonstrated by cholangiography. One patient had an aberrant bile duct draining a segment of the right hepatic lobe and a cystic duct draining into this duct. This anatomy was demonstrated on cholangiography. Laparoscopic sonography misinterpreted the anatomical variation as a low hepatic junction, with the cystic duct joining the right hepatic duct. Presently, hepatocystic ducts cannot be visualized sonographically.

Time Consumption

During our study, the time needed for the examination was recorded for both laparoscopic sonography and intraoperative cholangiography. The times measured for sonography ranged between 2 and 12 minutes (average: 5.4 ± 2.4 min). Cholangiography took between 4 and 37 min (average: 16.4 ± 7.4 min). The difference was highly significant ($p = 0.0001$, Mann-Whitney-U-test).

Discussion

Laparoscopic sonography has a number of advantages over intraoperative cholangiography. Time consumption is minimal and should not deter surgeons from routine use, as often happens with intraoperative cholangiography. Sonography can be employed anytime during the operation, thus facilitating visualization of the anatomy *before* any dissection has taken place. In contrast, cholangiography can only be performed after dissection of the cystic duct and there can be potential damage to the common hepatic duct or the right hepatic artery.[10] Ultrasound can be used repeatedly, if necessary. There are no contraindications and we saw no complications due to the examination. No contrast media and no x-rays are needed. Laparoscopic sonography not only demonstrates the biliary, but also the arterial anatomy of the hepatoduodenal ligament. Laparoscopic sonography is a reliable, safe, and efficient alternative to intraoperative cholangiography. It stands a much better chance of becoming widely used than intraoperative sonography had in the open cholecystectomy, because in Europe and lately in the United States, more and more surgeons are learning to use ultrasound. Lastly, the costs involved are much lower than for intraoperative cholangiography. The purchase of an ultrasound machine and a laparoscopic scanner is made more profitable by the fact that laparoscopic sonography can be used for a wide variety of operations (see also Chapter 28). Its scope goes far beyond the visualization of the biliary tree.

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11.6
Percutaneous Management of Gallbladder Stones

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The static state of gallbladder surgery in the early 1980s was in stark contrast to the minimally invasive techniques that were developed in the 1970s to deal with bile duct and renal stones. Early attempts to dissolve stones had not proved successful. Subsequent experience with oral dissolution therapy using bile acids showed an overall efficacy of 38% for complete stone dissolution, and a stone recurrence rate of 10% per year for the first five years.[1] This experience can be improved by using computed tomography to exclude all patients with calcified stones; complete dissolution can then be achieved in 64% of patients after 18 months of therapy, compared to 20% in unscreened patients.[2] The efficacy of extracorporeal shock wave lithotripsy (ESWL) for treatment of renal stones led to the concept of a combination of oral dissolution and lithotripsy. ESWL proved highly successful at fragmenting gallstones but less than 20% of fragments cleared spontaneously, the remainder depending on dissolution with bile acids that the patient had to take for up to two years. ESWL has not been the success that was envisaged and has the same drawbacks as oral dissolution therapy in that only 10 to 15% of patients with pure cholesterol stones are suitable for treatment that is prolonged, expensive, and carries the risk of stone recurrence.

A direct approach to the gallbladder appeared the logical next step in the quest for a minimally invasive technique for managing gallbladder stones. It was a reasonable progression from the experience gained with percutaneous puncture of intra-abdominal structures. Further, the concept of preserving the gallbladder was felt to be of importance as a means of avoiding postcholecystectomy symptoms, and fulfilling the criteria of minimally invasive surgery that must emphasize not only minimal access techniques, but also restoration of normal function, with preservation of the diseased organ.

Percutaneous Cholecystostomy

Diagnostic transhepatic puncture of the gallbladder has become well established and can be used for cholecystography, for transcholecystic cholangiography when percutaneous transhepatic cholangiography has failed, and for aspiration of bile or pus in patients with suspected cholecystitis or empyema. Transcholecystoscopic biopsy of carcinoma and removal of polyps has also been performed using this technique.[3]

Therapeutic percutaneous drainage of the gallbladder is a very effective and safe manner for managing the elderly and high-risk patient with acute cholecystitis, an empyema, or localized gangrenous perforation of the gallbladder. Under local anesthesia and with or without sedation, the gallbladder is imaged by ultrasound. Under antibiotic cover, an 18-gauge needle is introduced subcostally or intercostally and passed transhepatically into the gallbladder. The needle is exchanged for a guidewire and a pigtail catheter is passed over the guidewire into the body of the gallbladder. The opportunity should be taken to wash out the gallbladder with saline. No attempt should be made to remove the stones. The procedure dramatically relieves symptoms and carries no mortality. Urgent or emergency cholecystectomy in this group of patients carries a mortality of 10 to 14%[4,5] and even the lesser procedure of operative cholecystostomy has a mortality rate of 5%.[6] Percutaneous cholecystostomy may also be used to drain acalculous cholecystitis, a perforated gallbladder, and obstructive jaundice. Other therapeutic procedures include extraction or dissolution of gallbladder stones.

vanSonnenburg and colleagues reported the results of 127 patients who underwent puncture and percutaneous cholecystostomy over a nine-year period for a variety of indications.[7] Procedures were successful in 125 patients

(98%). The majority of procedures were therapeutic—33 were performed in the acute setting, and 24 at the bedside in an intensive care unit. There was a major complication rate of 9% that included bile peritonitis in three patients, bleeding in two patients, vasovagal reactions with bradycardia with or without hypotension in nine patients, catheter dislodgement in one patient, and acute respiratory distress in one patient. Minor complications occurred in 4% and the 30-day mortality was 3%, all deaths being due to underlying disease. Vasovagal reactions on puncture of the gallbladder have been well described. Such episodes are transitory and respond to atropine, which should be given if the bradycardia persists.

Endoscopic Gallbladder Drainage

Endoscopic transpapillary catheterization of the gallbladder was first described in 1984;[8] the technique has become almost standardized,[9] but its role has not yet been established. Direct contrast instillation may provide improved opacification of the gallbladder and per oral cholecystoscopy is feasible. In some cases, a prototype miniscope (Olympus XPF-5N-8, outer diameter 0.5 mm) has been inserted through the cannulation catheter and limited visualization of the gallbladder achieved.[10]

Endoscopic transcystic cannulation of the gallbladder is another technique that is available for decompressing and draining the acute gallbladder. Tamada and colleagues[11] treated 14 patients by placing an endoprosthesis in the cystic duct to drain an inflamed gallbladder. They reported that fever resolved in all patients so treated, with pain improvement in 64%. Edema in the gallbladder wall improved in 57%. In 88% of patients, sludge, characteristic of gallbladder stasis, drained. Soehendra[12] successfully managed 12 of 13 patients with acute cholecystitis, in 9 of whom a stone was obstructing the cystic duct. Four patients were treated with a cystic duct endoprosthesis and in eight, a fine catheter was placed in the gallbladder and brought out transnasally. The endoprosthesis is better tolerated by the patient. The nasovesicular catheter, however, has the advantages that it can be used to obtain a cholecystogram and for irrigation or instillation of antibiotics or dissolution agents for stone dissolution therapy.

Percutaneous Cholecystolithotomy

History

Percutaneous extraction of gallstones using radiological techniques was first reported in 1985 for the treatment of high-risk patients with acute cholecystitis.[13,14] The procedure was performed in several stages using a transhepatic tract. In 1988, a different technique for performing percutaneous cholecystolithotomy was described as an adaptation from the urological procedure of percutaneous nephrolithotomy.[15] The new technique could be performed in a single stage and used a transperitoneal tract, enabling larger tracts to be used for easier stone extraction. The limitation of the transhepatic route was that the use of larger tracts appeared to be associated with unpredictable bleeding or to cause "splitting" of the liver during manipulation. The new technique could be performed either in a single stage under general anesthesia or as a staged procedure under local anesthesia.

Selection and Contraindications

Patients are assessed both clinically and by ultrasound scanning. An ultrasound scan is performed in the fasting patient and repeated after a fatty meal. The number and size of stones, the gallbladder position, size, wall thickness, emptying, and bile duct size are assessed. Unlike all other nonoperative therapies for gallstones, the composition, number, and size of stones do not affect selection. Patients with acute complications can also be treated. It is preferable for the gallbladder to be thin-walled, although gallbladders with thick walls can be treated by this technique, provided there is an adequate fasting volume of greater than 15 mL. Almost 80% of patients with symptomatic gallstones fulfill these criteria. The absence of gallbladder emptying on its own is not a contraindication. The only patients unsuitable for the procedure are those with contracted, thick-walled gallbladders, not only because the gallbladder is diseased but also because of the technical difficulty in dilating a track through a thick-walled fibrosed gallbladder wall and working within the small lumen.

Technique

The procedure is performed with the patient supine on a fluoroscopic table under general anesthesia or local anesthesia, with intravenous sedation. Under ultrasound guidance, a 22-gauge spinal needle is passed transhepatically into the gallbladder to obtain a percutaneous cholecystogram. Alternatively, oral cholecystographic contrast can be given the night before the procedure.[15] With a combination of ultrasound and fluoroscopic guidance, an 18-gauge second needle (Longdwell, Becton Dickinson, Ontario, Canada) is introduced subcostally or occasionally intercostally and passed subhepatically into the fundus of the gallbladder. The needle is exchanged for a guidewire and its tip positioned in the proximal cystic duct. The tract is dilated to 28 to 30F with Teflon and telescoping metal dilators (Olympus, Lake Success, NY) in a coaxial fashion before inserting an Amplatz Teflon sheath (Lewis Medical, London, UK). The metal dilators are removed but a guidewire is kept in the gallbladder throughout the procedure as a safety measure. The gallbladder is inspected with a rigid cholecystoscope (Olympus, Keymed, Southend-on-Sea, UK) and stones up to 10 mm in diameter are flushed out or removed with triradiate forceps. Stones too large to pass down the Amplatz sheath are fragmented by intracorporeal electrohydraulic lithotripsy and removed piecemeal. Ultrasound of pulsed dye lasers have also been used for this purpose.[16] The gallbladder is carefully inspected and a spot film taken to ensure that all the stones have been removed. At the end of the procedure, a 14 to 16F Foley catheter is introduced through the Amplatz sheath and placed on free drainage. Patients are discharged from hospital after 24 to 48 hours and a "tubogram" is performed on an outpatient basis 10 days later. The catheter is removed, provided that the biliary tree is clear of stones and that there is no extravasation of contrast along the tract into the peritoneal cavity. Patients may return to normal activities as soon as the Foley catheter is removed, although many return to work before this (Figures 11.6.1, 11.6.2, and 11.6.3).

Most procedures can be performed in a single stage. In patients with acute inflammation or with a stone impacted in Hartmann's pouch, the gallbladder is electively decompressed by percutaneous cholecystostomy for 7 to 10 days before stone extraction is attempted. This allows the acute phase to resolve and a Hartmann's pouch stone will often disimpact.

FIGURE 11.6.1. Cholecystogram showing a guidewire coiled in the gallbladder lumen and the 30F Amplatz sheath through which the stones are removed. Contrast is also seen in the duodenum. (By permission of Cheslyn-Curtis, General Surgery. In: *Minimal Access Medicine and Surgery*. Radcliffe Medical Press, Ltd., London, 1993.)

Results

Our experience[17] of percutaneous cholecystolithotomy is summarized in Table 11.6.1. The gallbladder was cleared of stones in 106 patients (95%) but in 6 it was not possible to remove a cystic duct stone. The procedure was unsuccessful due to failure to dilate a tract into the gallbladder in six patients and due to loss of access in one patient. These patients underwent an interval cholecystectomy, whereas only two of the patients with residual cystic duct stones did so. Patients had a median of five gallstones (range 1 to 800) with a median diameter of 10 mm (range 3 to 30 mm). The duration of the procedure gradually reduced with increasing experience (Table 11.6.1) and compared favorably with cholecystectomy. The duration of the procedure depended on difficulties encountered during puncture and dilatation, the stone load, and the experience of the operators. Multiple hard stones, greater than 1 cm in diameter, each requiring lithotripsy and removal piecemeal took much longer to remove than a solitary stone less than 1 cm in diameter.

Fourteen patients with a median age of 70 presented with an acute complication and 24 were high risk for surgery with ASA gradings of III and IV. Cystic duct patency was regained in 15 of 16 patients with Hartmann's pouch stones. Decompression of 13 of 14 acute gallbladders for 7 to 10 days before stone extraction resulted in resolution of acute cholecystitis in six patients, mucocoeles in two patients, perforated empyemas associated with liver abscesses in two patients, and jaundice alone, with empyema or with pancreatitis in three people. Endoscopic sphincterotomy was performed to remove duct stones in two of the three jaundiced patients, following successful percutaneous cholecystolithotomy.

In their separate experience, Chiverton and colleagues reported successful stone clearance in 56 of 60 fit patients (93%) with nonacute gallstone disease and functioning gallbladders.[18] Other groups, using variations of our technique, have reported their experience of up to 21 percutaneous cholecystolithotomies.[7,19–21] The overall results of a large study using a different technique has been given in a preliminary report. Cholecystoscopy and stone extraction through an 18F transhepatic tract was successful in 163 of 165 patients.[3]

The 15 complications in the Middlesex Hospital series included transient cholangitis related to omission of antibiotic prophylaxis and four subhepatic bile collections that were drained percutaneously in one patient and

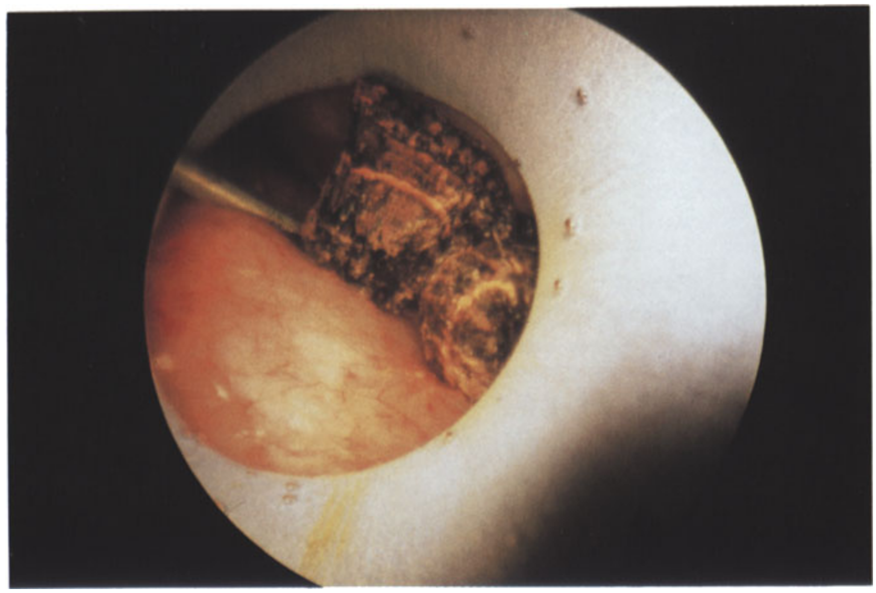

FIGURE 11.6.2. View through the Amplatz sheath of a solitary 2 cm diameter stone lying on the gallbladder mucosa. The stone has been fragmented by electrohydraulic lithotripsy to facilitate extraction. The guidewire is also visible. (By permission of Cheslyn-Curtis, General Surgery. In: *Minimal Access Medicine and Surgery.* Radcliffe Medical Press, Ltd., London, 1993.)

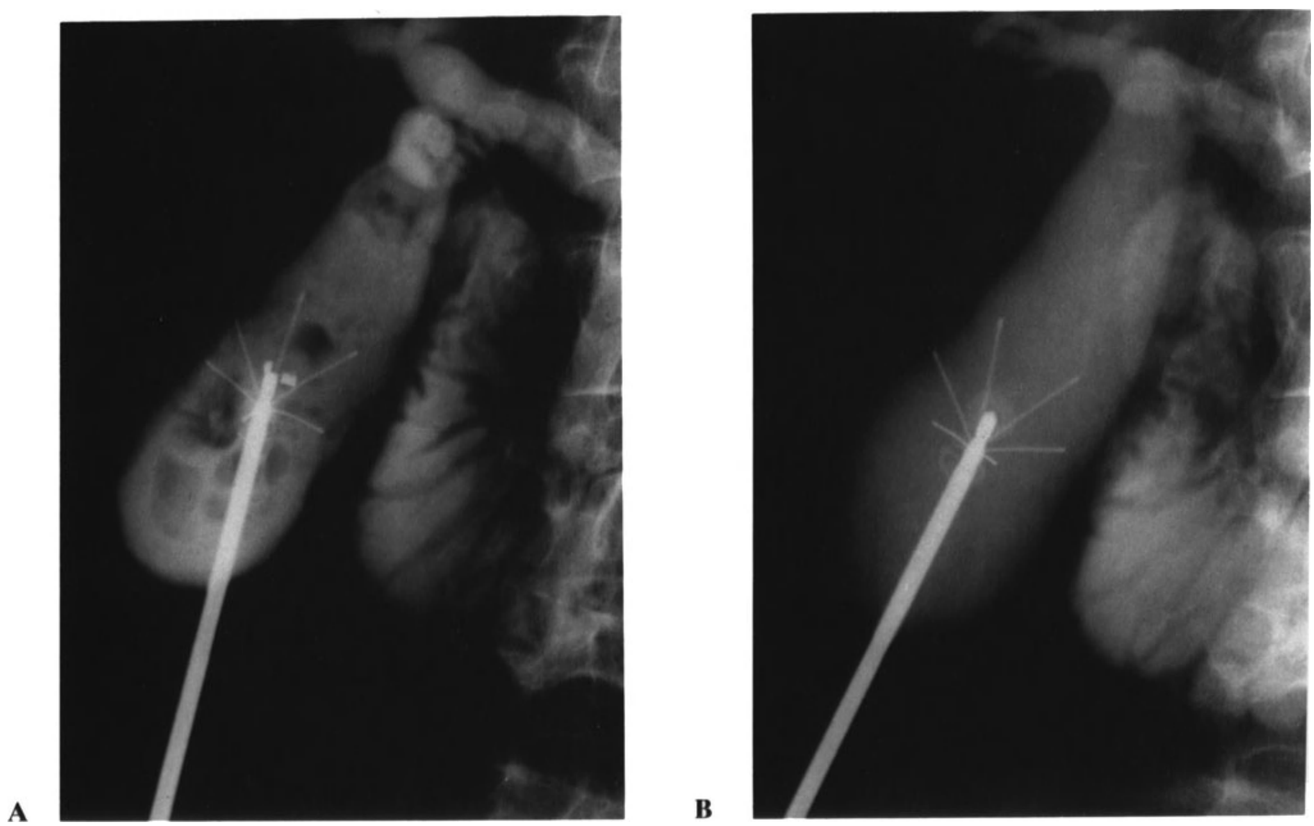

FIGURE 11.6.3. Cholecystogram of the Rotalith, (A) within a gallbladder containing stones and (B) after the stones have been reduced to sludge and flushed out. Contrast is also seen in the bile duct and duodenum. (By permission of Cheslyn-Curtis, General Surgery. In: *Minimal Access Medicine and Surgery.* Radcliffe Medical Press, Ltd., London, 1993.)

managed conservatively in the other three. Chiverton and colleagues reported eight complications, including colonic puncture and pancreatitis, which were managed conservatively.[18] There were no deaths in either of these studies, although one death was reported following the development of bile peritonitis in a study of 11 elderly and high-risk patients with acute cholecystitis, treated by percutaneous cholecystolithotomy, using a more pro-

TABLE 11.6.1. Summary of percutaneous cholecystolithotomy.

			n	%
Age	Median		56	
Sex	M:F		1:2.4	
Procedure	Success		100	89
(n = 113)	Failed puncture/dilatation		6	
	Residual cystic duct stone		6	
	Loss of access		1	
Stages	Single		72	72
(n = 100)	Multiple		28	
Duration of procedure—median (min)				
	PCCLs	First 10	166	
	PCCLs	Last 50	51	
Hospital stay (from initial stage)—median (days)				
	Elective	Single	2	
		Staged	5	
	Acute		12	
Convalescence—median (days)				
	Full recovery		12	
	Employment		18	

tracted technique with two to four stages and lasting a mean of 21 days.[19]

Outcome

In the Middlesex Hospital series, 92 of 100 patients who underwent successful percutaneous cholecystolithotomy were followed for a median of 14 months (range 6 to 37 months). The majority of patients were completely cured of their symptoms (79%) or had their major symptoms cured and occasionally experienced minor discomfort (11%). This contrasts with the 30 to 50% of patients who develop symptoms after open cholecystectomy, of whom 34 to 50% complain of persistent wound pain.[22,23] Nine of 92 patients reformed stones, although five were believed to be due to residual stones or fragments. None required treatment, seven were asymptomatic, and two had minimal symptoms. Latterly, patients were given a three-month course of adjuvant bile acid therapy. When gallbladder emptying was assessed, 86 (93%) showed a reduction in volume of greater than 30% following a fatty meal. This included 8 of 10 patients treated with an acute gallbladder and 11 of 13 patients with nonfunction due to an obstructing Hartmann's pouch stone.

Other Techniques of Cholecystolithotomy

Percutaneous Rotary Lithotripsy

This instrument is passed along a track into the gallbladder and has an impeller that acts like a liquidizer to emulsify stones. Patients are assessed in an identical manner to those candidates for percutaneous cholecystolithotomy and only those patients with an accessible thin-walled gallbladder of reasonable volume are considered suitable for this procedure. The advantage of this procedure over percutaneous cholecystolithotomy is that it can be performed along a 12F tract and, thus, the transhepatic route may be used if it appears appropriate, although the transperitoneal fundal route is invariably a better one. Because of the small size of the tract, the procedure may be performed under local or general anesthesia as a one-stage procedure.

The rotary lithotrite consists of a central rotating metal impeller surrounded by a basket of metal prongs mounted on a catheter. Rotation of the impeller to speeds of 30,000 rpm generates a vortex that sucks the gallstones into the basket and onto the impeller where the stones are reduced to a fine sediment. The metal basket holds the gallbladder mucosa clear of the impeller. The whole apparatus is collapsed down for introduction into and removal from the gallbladder via a 12F introducer sheath.

The procedure is performed with the patient supine on the fluoroscopy table, with continuous blood pressure, cardiac, and oximetry monitoring. Prophylactic antibiotics should be given. The technique for introduction is identical to that of percutaneous cholecystolithotomy but only a 12F tract is necessary. The procedure is monitored using fluoroscopy. The gallbladder is considered clear when the impact of stones on the impeller is no longer palpable. As much sediment as possible is aspirated and at the end of the procedure, a 13F Cope loop drainage catheter is left in the gallbladder on free drainage.

Experience with this technique is limited. A prototype was successfully used on human gallstones introduced into swine gallbladders.[24] Initial clinical results have been reported in 10 patients[25]; the procedure was successful in 9. Complications included bile leakage and one patient developed phlegmonous cholecystitis, necessitating cholecystectomy. Three to six weeks postprocedure, stones or fragment aggregates were present in six patients. At follow-up (median of 28 weeks, range 6 to 52) three patients had fragment aggregates and one patient had an intact calculus. In our own series, 25 patients were treated; 13 patients were considered unfit for conventional therapy (complex group) and 12 elected to have the procedure (noncomplex group). In the complex group, nine patients were treated under local anesthesia. Only 6 of the 13 patients had a clear gallbladder at the end of the first procedure, but after further treatments, which included percutaneous flexible cholecystoscopy, endoscopic sphincterotomy, and percutaneous cholecystolithotomy, 11 patients had a clear gallbladder. The morbidity was high, mainly due to pain and bile leaks, causing prolonged hospital stay (median 18 days). In the noncomplex group, six patients had the procedure performed under local anesthesia. Ten patients had a successful clearance of the gallbladder and the remaining two patients had stones removed at cholecystoscopy. Despite good clearance, the morbidity was high, with eight emergency admissions on account of complications, and a prolonged length of stay (median 13 days).

This technique remains experimental. Damage to the gallbladder wall is of major concern and is the probable cause for the high postprocedural morbidity. To aid removal of the gallbladder a similar instrument has been used for emulsifying stones at laparoscopic cholecystectomy. Histological examination of such gallbladders has shown microscopic submucosal hemorrhage with significant damage to the muscle wall and also serosal edema. This technique is not yet available for further clinical trials, but it is felt that, with modification, it may have value in the patient with acute disease and in whom it is necessary to remove the stones in order to drain the gallbladder completely.

Minicholecystostomy

Gibney and colleagues reported a technique of locating the gallbladder fundus with ultrasound and then placing a 24F catheter into the gallbladder through a mini-incision.[26] Stone extraction was performed on the seventh to tenth postoperative day, via the cholecystostomy tract, using radiological techniques. The procedure was performed under sedation and local anesthesia in 36 elderly, high-risk patients with acute cholecystitis or severe biliary colic. Gallbladder stones were successfully extracted in 35 of 36 (97%) patients, cystic duct stones in 6 of 7 (86%), and bile duct stones in 5 of 8 (63%).

Cholecystoscope

As an alternative to locating the gallbladder under ultrasound control, a cholecystoscope can be used. This instrument consists of two concentric tubes sealed at one end. Suction applied to the space between the tubes creates a ring of vacuum, which fixes the instrument to the gallbladder fundus. Under epidural anesthesia, a 2.5-cm incision is made in the right upper quadrant of the abdomen and the peritoneal cavity is entered. The cholecystoscope is introduced and the gallbladder fundus is identified using the cholecystoscope, which is then fixed to the fundus, and a vacuum created to ensure a seal between the instrument and the gallbladder. The gallbladder is incised under direct vision and the stones are removed, either with the aid of a scope, or by direct vision using grasping forceps. When the gallbladder is completely clear of stones, a Foley catheter is left in the gallbladder. Only Johnson's group has had experience with this instrument.[27] To date, 39 patients have been evaluated, and the gallbladder cleared of stones in 33. Two patients had residual stones that were extracted through the catheter tract under radiological control. The procedure was abandoned in four patients with dense omental adhesions. There were no major complications. The authors contend that this procedure is safe, inexpensive, and requires minimal training. It is ideal for those who do not have access to good interventional radiology. It is yet another technique of value in the sick, elderly person for whom operative intervention is inappropriate.

Laparoscopic Cholecystolithotomy

Unfortunately, many surgeons undertaking laparoscopic cholecystectomy are unaware of this procedure. Its intelligent use could save many patients a laparotomy and prevent the inexperienced laparoscopist from getting into problems with which he is unable to cope. When the laparoscopist unexpectedly encounters an acutely inflamed, pus-filled gallbladder with multiple adhesions, such that the anatomy around the porta hepatis is obscured, and in whom it is unwise to proceed to cholecystectomy, then the operation of laparoscopic cholecystolithotomy has great advantage. The surgeon exposes the fundus of the distended gallbladder. The right lateral trocar is then inserted directly into the gallbladder and the contents sucked out. Two courses of action are now open to the laparoscopist. Either a drainage catheter is placed in the gallbladder and the stones removed after a few days, as in the procedure of percutaneous cholecystolithotomy, or the stones are removed immediately, with the aid of an operating nephroscope, before the drainage catheter is placed. Perissat used this technique during his early experience with laparoscopic cholecystectomy and, with minimal morbidity, treated 17 patients with biliary colic.[28] It still has value if there is a big stone load that makes grasping the gallbladder difficult or obscures important anatomical landmarks.

Percutaneous Contact Dissolution Therapy

History

Thistle and colleagues introduced contact dissolution therapy with methyl tert-butyl ether (MTBE) in 1985.[29] MTBE is the most potent solvent for cholesterol stones and is at present the preferred agent for the dissolution of gallbladder stones.

Technique

A 5F transhepatic catheter is passed into the gallbladder under local anesthesia and intravenous sedation.[30] The gallbladder volume is estimated by determining the amount of contrast medium needed to produce overflow into the cystic duct. MTBE is then continuously infused and aspirated by hand for an average of five hours per day, over two to three days. Leuschner and colleagues[31] report a mean dissolution time for solitary stones of 4 hours and for multiple stones of 10 hours. The rate of dissolution can be improved by increasing the rate of solvent flow or the surface area of the stones. A microprocessor-assisted solvent transfer system has been developed to regulate the infusion and aspiration of MTBE at high flow rates and to control gallbladder pressure, preventing solvent escape into the duodenum.[32] Experimental studies have shown that combined ESWL wave lithotripsy and MTBE dissolution therapy can reduce dissolution time by about 25 to 69%.[33,34]

Selection

MTBE is effective only against cholesterol gallstones. Leuschner and coworkers carefully selected 120 out of 612 patients (20%) for MTBE therapy.[35]

Results

In the original study,[30] MTBE produced complete or > 95% stone dissolution in 72 of 75 patients (96%). Only 21 were completely stone-free, the remaining 51 had residual debris in their gallbladders, and the overall one-year stone recurrence rate was 29%. Leuschner and coworkers[35] obtained successful puncture of the gallbladder and dissolution in 113 of 120 (97%) patients. After treatment, 34% had residue in the gallbladder and two developed recurrent stones. McNulty and coworkers found that 4 of 18 patients (22%) developed recurrent stones within 6 to 18 months following complete dissolution of stones.[36] Other studies report dissolution rates of 50 to > 80%.[37,38] Of 24 patients given combined ESWL and MTBE dissolution therapy, 12 were stone-free within three to five days.[39] Oral dissolution therapy was administered for three months and at a median follow-up of five months, complete stone clearance had occurred in 11 (92%) patients with radiolucent stones and 8 (66%) with calcified stones. The clearance rate with the combined therapy may be greater than either therapy alone.

There are several side effects with this therapy including nausea, vomiting, burning pain, transient sedation due to systemic absorption of the solvent, intravascular hemolysis, duodenal erosion, hematobilia, and destruction of certain catheter materials.[30] Complete clearance of stones and fragments is difficult to obtain and recurrent stone formation might be expected to be higher than following other nonoperative methods.

Endoscopic Contact Dissolution Therapy

MTBE instillation via a nasovesicular catheter has the advantages that there is no intraperitoneal leakage along the catheter and extravasation into the duodenum is less likely as the catheter occludes the cystic duct. Foerster and coworkers[10] successfully catheterized the gallbladder in 30 of 39 patients (77%) and performed MTBE dissolution therapy in 26 patients. Complete stone clearance was obtained in 12 (46%) patients, the remainder having residual debris in the gallbladder. During the 13-month follow-up period, 2 of the 12 stone-free patients developed recurrence. In another study,[40] cannulation of the cystic duct was successful in 91% of (64 of 70) patients. In 52 patients, combined ESWL and gallstone dissolution with MTBE via the nasovesicular catheter was performed. The treatment lasted a mean of 10 days, patients receiving a mean of four ESWL sessions (range 1 to 9). Immediate, complete stone clearance was achieved in 34 patients (65%). During a follow-up period of 3.5 to 12.5 months, 11.8% still had debris in the gallbladder.

Discussion

The case for percutaneous management of gallbladder stones is weak in this age in which laparoscopic cholecystectomy is correctly pre-eminent in the management of gallstones. Percutaneous techniques must, therefore, be limited to a patient with a condition making the laparoscopic technique either very difficult, for instance previous abdominal surgery, or unsafe such as acute disease in the elderly or unfit. However, there are patients who steadfastly wish to retain their gallbladder, and some physicians support this concept on account of the interrelationship of the gallbladder with gastrointestinal function. For these patients, the key question is whether their gallbladder is normal or can return to normal once stones have been removed. The answer to this question is still uncertain.

The future of this technique, particularly in the patient who is ill for other reasons, may lie in the combination of cholecystolithotomy with permanent ablation of the gallbladder by thermal or chemical injury to reduce the risk of gallstone recurrence.[41,42] Alternatively, substances that alter cholesterol metabolism such as hydroxymethyl glutamyl coenzyme A reductase blockers and nonsteroidal anti-inflammatory agents may have a role in the prevention of gallstone reformation.[43]

Perhaps the future role for this procedure will be as an adjunct to laparoscopic cholecystectomy in those patients who prove technically difficult. Instead of undertaking a long and difficult procedure, the laparoscopic cholecystectomy could be converted to a laparoscopic-assisted cholecystostomy, with gallstone removal through the percutaneous puncture. The procedure can be controlled radiologically to ensure complete stone clearance, and the gallbladder puncture closed with the clips used for hernia repair. Subsequent cholecystectomy would then be necessary only in those patients who develop further stones and symptoms.

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11.7
Ablation of the Gallbladder Mucosa

Robert C. Hall

Although laparoscopic techniques have decreased the procedural invasiveness of cholecystectomy, solutions to the gallstone problem may be further simplified. Gallstone removal and the prevention of their re-formation by gallbladder mucosal ablation will be discussed in this chapter. Destruction of the entire mucosal lining of the gallbladder will lead to replacement of the lumen by scar tissue, and consequently, permanent protection from reformation of gallstones.

Ablation refers primarily to removal of a body part, secondarily to the destruction of its function. Since *to ablate* is chiefly to "remove by cutting, melting, evaporation, etc." we shall avoid the term "gallbladder ablation" in this chapter. The aim is to ablate the mucosa and obliterate the lumen.

The current interest in ablation of the gallbladder mucosa springs from the fact that numerous minimalist procedures have been developed for removing stones from the gallbladder. These techniques are reviewed in the previous chapter on percutaneous cholecystolithotripsy (PCCL). Let us suppose that PCCL has been carried out simply and quickly through a single cannula placed in the right upper abdomen. Through the access to the gallbladder established for PCCL,[1] mucosal destruction could be accomplished. The entire procedure combined might be carried out through a single puncture under local anesthesia as an outpatient.

Early Techniques of Mucosal Ablation

Surgical removal of the gallbladder mucosa was first described in 1899 by Doyen.[2] Early anesthetic techniques did not achieve adequate muscle relaxation, and deep planes of anesthesia with traction on the viscera were judged to be causes of "shock and a stormy convalescence."[3] To circumvent these problems, gallbladder mucosectomy was performed through a small incision, without significant traction on the gallbladder or surrounding viscera. Both "submucosal"[3] and "subserosal"[2] cholecystectomies have been described. The technique was popularized by Doyen in his three-volume text published in 1920.[4] He incised the serosal coat over the fundus and removed the entire inner lining from the outer layer, starting at the fundus and extending down to the cystic duct. Glass tubes were used to drain the subserosal space. The results were excellent, but as anesthetic techniques improved, cholecystectomy became the definitive operation. Most of these early procedures probably involved removing both the mucosa *and* the muscle layers, leaving behind the adventitia and the peritoneum. Although there is no submucosal collagen-containing layer in the gallbladder as there is in the intestine, there is a thin but definite membranous adventitia outside the muscle.

Nonexcisional destruction of the gallbladder mucosa has been attempted by numerous investigators. Curettement of the gallbladder mucosa was first attempted by Küster in Germany (1883) and McRedity in the United States (1884), but their technique was not accepted by others.[5] Pribram[6] and others opened the gallbladder and used electrocautery to destroy the mucosa. Gatch, an Indiana surgeon, used carbolic acid (phenol) on the inner surface of the opened gallbladder in approximately 100 patients between 1927 and 1941.[7] However, Gatch gave up the operation in 1941 after a resident (J.S. Battersby, oral communication, 1988) discovered that the method was effective in only 50% of experiments in dogs. In Gatch's patients, gallstones frequently re-formed, and surgeons found the reoperations to be difficult.

Review of Current Experience

Recently "chemical cholecystectomy" by the percutaneous approach has been studied. Complete obliteration of the gallbladder lumen has been achieved in experimental animals with varying degrees of success. Numerous noxious liquids have been used. Salomonowitz and others

(1984)[8] employed absolute alcohol or hot radiologic contrast solution. Pig gallbladders were treated with absolute alcohol in a 1984 report by Stein and colleagues.[9] In 1985 and 1986, Getrajdman and colleagues[10,11] used six different chemicals in rabbits and reported ethanol with trifluoroacetic acid as the most promising combination. Other contributors to experimental chemical ablation of the gallbladder mucosa in animals are: Remley et al.,[12] Widlus et al.,[13] Uchiyama et al.,[14] Becker et al.,[15] Cuschieri et al.,[16] Brakel et al.,[17] Lindberg et al.,[18] Leahy et al.,[19] Soulen et al.,[20] Majeed et al.,[21] Girard et al.,[22] and Lindberg.[23,24]

Techniques of Cystic Duct Occlusion

Percutaneous obliteration of the cystic duct as a prelude to the use of liquid proteolytic agents has been reported by several authors. In 1992, Girard, Saini, Mueller, and coworkers[25] reported that laser fiber thermocoagulation of the entire cystic duct in pigs led to immediate obstruction of the duct in 84% of cases, with subsequent complete cystic duct fibrosis in all cases. In 1991,[26] Ji and a group from Nanjing, China reported that a catheter emitting microwaves caused thermal coagulation of the cystic duct mucosa. The edema resulted in immediate obstruction and subsequent fibrosis. An Italian group[27] used silicone glue in the cystic ducts of three patients, but no follow-up was provided. McGahan and coworkers[28] initially reported some success in occluding the cystic duct of pigs using a microprocessor-controlled heater catheter in 1992 and recorded success in 10 of 11 animals in 1994.[29] Becker, Burhenne, and associates[15,30,31] have done the most extensive work. They developed a catheter for bipolar electrocoagulation of the cystic duct (Wilson-Cook, Winston-Salem, NC). Their work in pigs was reported in 1988[30] and 1989[15] (Figure 11.7.1); the clinical observations in eight patients were recorded in 1990.[31] Although the occlusion of the cystic duct was not immediate, it was successful and without significant complications. In 1991, Leahy and coworkers[19] reported that the electrocoagulation catheter produced the same results in dogs.

Current Methods for Gallbladder Mucosal Ablation

Besides the application of chemicals, only heat and ultrasound have been reported to ablate the gallbladder mucosa. Boiling radiographic contrast solution has been used with some success to obliterate the gallbladders of pigs.[32,33] Heating liquids within the gallbladder, controlled by a microprocessor, was partially successful in pigs as initially reported by McGahan and coworkers in 1992.[28] Having redesigned their catheter to alternately inject and aspirate hot saline, McGahan and coworkers (1994)[29] maintained the temperature of the gallbladder wall at 54°C for 30 minutes. They found that 9 of the 11 treated pigs had complete ablation of the mucosa, but in only 5 of the 11 was the lumen obliterated at three weeks. Surrounding organs were intact except for one instance of partial-thickness damage to the stomach. Aagaard and co-workers (1994)[34] used the same Thermoablation Catheter (InnerDyne Medical, Mountainview, CA) at the same temperature settings. However, they found complete ablation in only 25% of the animals and, by conducting the experiments with all the surrounding organs in contact with the gallbladder, found partial-thickness burns of the small intestine in four of eight animals.

Quite by accident, the use of high-intensity ultrasound energy focused on pig gallbladders filled with methyl-tert-butyl ether was found to cause obliteration of the lumen in a number of animals.[35] Rather than transmitting ultrasound to the intact gallbladder, Gagner, Blanco, and Rossi (1993)[36] applied vibratory energy at ultrasonic frequency to open human ex vivo gallbladders. Because the Cavitron Ultrasonic Surgical Aspirator (CUSA) has been used to selectively remove rectal and vaginal mucosas, Gagner and coworkers applied it to three gallbladders and found that it effectively removed the surface mucosa of the fresh gallbladder specimens. They made no attempt to remove the muscle with its mucosal diverticula.

Human studies reporting gallbladder mucosal ablation are limited to three series and a number of anecdotal reports. An Australian group[37] reported in 1992 the use of roller-ball diathermy in a single patient. After the stones were removed through a mature cholecystostomy tract, a rigid urological resectoscope and roller-ball device were used to perform unipolar coagulation of the mucosa. A small residual gallbladder persisted at the fundus at the six-month ultrasound evaluation. Martin,[38] in an editorial comment, reported that EJ Ring had treated one patient with alcohol and triflurocetic acid without success. In 1988, Iaccarino and coworkers[27] gave three case reports. After the cystic duct had been occluded with a detachable balloon and silicone glue, absolute alcohol was instilled into the gallbladder for one hour on the first day and for two hours on the second day. No follow-up data were given. Similarly anecdotal reports of one patient treated by Coleman and coworkers[31] with boiling radiologic contrast material, of one patient treated by Asfar and coworkers[39] with 95% alcohol, and two patients mentioned in an abstract by Boland and coworkers[40] lack follow-up information.

Burhenne's group in Vancouver, British Columbia, Canada has provided us with the best organized series, but thus far results in only eight patients have been reported.[31] All of these patients had mature cholecystostomy tracts. In seven patients, tubes had been sutured into the gallbladders. After the stones had been removed, a 7F bipolar electrocoagulation catheter was used to occlude the cystic ducts. After several weeks of catheter

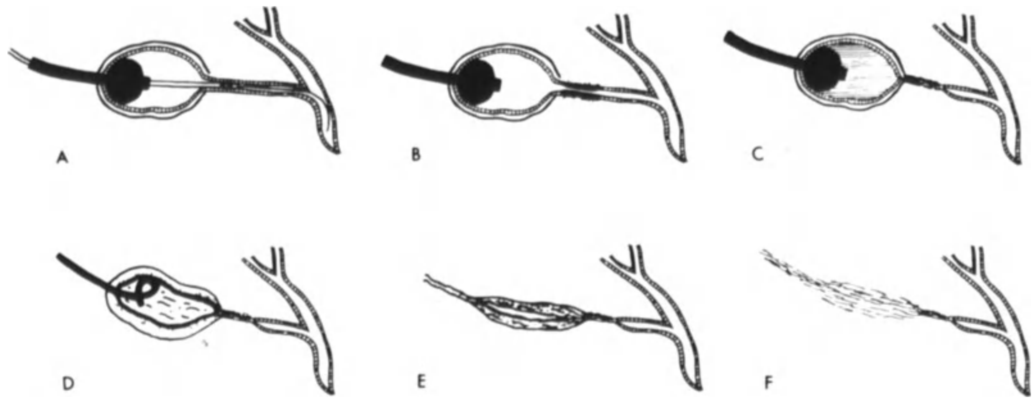

FIGURE 11.7.1. Technique used for cystic duct occlusion and ablation of the gallbladder mucosa. (A) Modified Foley cholecystostomy catheter has been inserted into the gallbladder, and RF electrocoagulation is performed with the bipolar catheter. (B) Inflammatory response and fibrogenic scar formation progressively results in cystic duct occlusion. (C) After two to three weeks, the scar is complete and cystic duct occlusion is verified by means of cholecystocholangiography. Sclerosants are then instilled through the Foley catheter into the gallbladder. (D) Gallbladder mucosa is necrotic, and there is inflammatory infiltration and edema of the gallbladder wall. Foley catheter has been exchanged for a smaller drainage catheter that drains necrotic debris from the gallbladder lumen externally. (E) Drainage has ceased, the lumen is collapsed, and the catheter has been withdrawn. (F) Progressive fibrotic organization has led to obliteration of the gallbladder lumen and the cholecystostomy tract. Bile ducts and the cystic duct distal to the area of occlusion have remained unaffected by the entire procedure. (From Becker CD, Quenville NF, and Burhenne HJ,[15] by permission of *Radiology.*)

drainage, the patients were brought back as outpatients for "sclerotherapy." No anesthesia or sedation was required. First 95% ethanol, then 3% sodium tetradecylsulfate, were instilled into the gallbladder for 30 minutes. The amount of drainage was a guide to further treatments. After the tubes were removed, the sinus tracts stopped draining mucus within two, seven, and eight weeks in three patients. Because tube drainage persisted, five patients underwent one to three repeat installations into the gallbladder. The sinus tracts ceased draining within 11, 17, and 25 weeks in three patients. In the other two, intermittent drainage of mucus occurred over periods of 29 and 56 weeks. In three patients, biopsies with forceps showed regeneration of epithelial monolayers in the gallbladders. During follow-up, which ranged from 1 to 12 months (with a mean of 5 months), ultrasound exams showed that in none of the patients did the gallbladders disappear. In most patients the lumen became smaller (average 10 mL). In none was an enlarging mucocele seen.

El-Mufti has reported the largest patient series in a short note in the *British Journal of Surgery* in 1993.[41] Over a span of two years, 20 patients with uncomplicated cholelithiasis were treated with open cholecystostomy through a short incision using local anesthesia. After the stones were removed and the cystic duct ligated, the gallbladder was filled with absolute alcohol for three minutes; next the mucosa was rubbed with gauze; and finally the gallbladder was closed leaving 2 mL tetracycline hydrochloride in the lumen. Three patients died of unrelated illnesses. The postoperative ultrasound showed that in 6 of 17 subjects the lumen of the gallbladder became obliterated, and in the remaining 11 patients, progressive shrinkage of the gallbladder with thickening of the walls occurred. No enlarging mucoceles or fistulae were encountered in the one- to three-year period of observation.

In 1994, Ji and coworkers[42] extended their 1991 animal studies[26] to eight elective gallstone patients. They drew the fundus of the gallbladder into a 3-cm incision. After the stones were removed, they inserted their previously described 2-mm microwave catheter into the cystic duct and coagulated the duct at several sites. Next, they verified that the cystic duct was occluded; they then instilled a mixture of alcohol and trifluoroacetic acid under pressure and retained it in the gallbladder for 40 minutes. A drainage catheter was left for 14 days. Complete obliteration of the gallbladder lumen was observed by ultrasonography in six of the eight patients at 3 to 10 weeks. One patient had a 1.5-cm mucocele at the fundus of the gallbladder. The last patient had a patent cystic duct and a shrunken gallbladder. All patients were free of symptoms at 10 weeks, but longer follow-up was not reported.

Several authors[17,32] have commented on the discrepancy between Becker and Burhenne's experimental[15] and clinical[31] results. In a letter to the editor of *Radiology,* we[43] predicted that human gallbladder mucosa would be difficult to ablate by liquid sclerosing agents. The histology of the stone-laden human gallbladder differs significantly from that of young experimental animals. In humans, the mucosa projects by narrow-necked folds into the muscle layer, forming Rokitansky-Aschoff (R-A) sinuses. Such sinuses do not exist in young pigs, dogs, or sheep (personal observations).

Difficulties Encountered with Mucosal Ablation

Multiple R-A sinuses occur in 90% of diseased human gallbladders.[44,45] The sinuses penetrate through the entire muscle 30% of the time and deeply into the muscle 46% of the time.[46] As a consequence, in the majority of patients, multiple islands of intact mucosa will escape chemical denaturation. The gallbladder epithelium will regenerate from multiple mucosal islands. Enlarging mucoceles of the isolated gallbladder may form, just as mucoceles formed in cystic ducts not in continuity with the biliary tree in liver transplants.[47,48] The regenerated mucus-secreting gallbladder might continue to drain through the sinus tract onto the abdominal wall or might become secondarily infected; reconnection with the biliary tree is less likely. The scarred gallbladder would be difficult to remove if salvage cholecystectomy became necessary. For the above reasons, the use of liquid sclerosing agents to ablate the mucosa of human gallbladders seems inappropriate. Likewise, heating the gallbladder wall holds little promise of safely obliterating the lumen. To reach the R-A sinuses the thermal injury would have to extend through the entire muscle wall. However, Aagaard and coworkers[34] have already stated: "It appears that the thermal range between complete gallbladder ablation and injury to adjacent structures is quite small." If that margin is small when heating only the mucosa, surely heating the muscle will prove unsafe.

Future Investigations

What constitutes an adequate experimental model for mucosal ablation?[43] Perhaps we should attempt to induce R-A sinuses in animals. In humans, R-A sinuses seem to be acquired defects. They are not seen in the gallbladders of children or young adults, and they occur only sparsely in older adults without stones. When there are stones, R-A sinuses are seen in abundance.[44] Artificial stones in the gallbladder of a pig might evoke R-A sinuses. An alternative experimental method might be to remove both the muscle and the mucosa. If the muscle layer, which harbors the deep extensions of the mucosa in diseased human gallbladders, can be safely and efficiently eliminated in an animal model, transfer of that technique to humans might be more feasible than ablation of the surface mucosa. In unpublished observations, we found that the CUSA safely and effectively stripped off both the mucosa and muscle from open canine gallbladders, leaving an intact adventitia. We do not, however, envision any way to deliver the CUSA vibratory energy to the mucosa of an intact gallbladder.

What can we conclude from the animal experiments and the limited attempts to ablate the gallbladder mucosa in humans? The peculiar anatomy of the diseased gallbladder, with multiple mucosal R-A sinuses penetrating deeply into the muscle,[44–46] does not auger well for the success of liquid mucosal-ablating agents. Thermal ablation might be more effective, but to expect heat to destroy all the mucosa that extends down to the adventitia and at the same time not damage the colon or common bile duct which reside 1 mm away, requires great optimism.

The dismal outlook I have outlined may yet prove wrong. Some way may still be found to force the proteolytic liquids into the R-A sinuses. The high-technology heating methods may prove to be safe and effective. Likewise, new approaches most certainly will appear. Few surgeons have, as yet, put their minds to a modern version of "subserosal cholecystectomy."

Conclusion

Our aging population deserves safer procedures, which, to be truly minimally invasive, must be delivered under local anesthesia. Surgeons must not remain mesmerized by the merits of, and their skills in, laparoscopic cholecystectomy. The logic that to reduce the surgical morbidity one should remove the least amount of tissue possible has led to new approaches in various organ systems, including ablation of the mucosa of the uterus and rectum. That same logic dictates that mucosal ablation be pursued in place of gallbladder removal. Surgeons have shown willingness to adopt new approaches and use new tools. Perhaps endocavitary ablative surgery will one day replace organ excision. If there were a single-puncture, outpatient, local-anesthesia technique to safely and permanently solve the gallstone problem, patients would, without a doubt, opt for that procedure over laparoscopic cholecystectomy.

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11.8
Complications of the Biliary Tract

Gene D. Branum and William C. Meyers

Laparoscopic cholecystectomy has rapidly become the treatment of choice for symptomatic cholelithiasis. Most series show low complication rates and high levels of patient satisfaction with the procedure.[1–3] It is also evident, however, that with the introduction of this technique, most established surgeons must undergo a period of learning. During this time their inexperience predisposes the patient to a higher rate of complications than traditional cholecystectomy. The complication of major common or hepatic bile duct injury has been reported to range from none to as high as 3%.[4,5] In a series of over 9,000 cholecystectomies, the risk of bile duct injury is increased during a learning curve of 15 cases, and reaches a nadir at approximately 50 cases.

The surgical,[6] endoscopic,[9] and radiologic[10,11] literature contain many case reports of biliary injury during laparoscopic cholecystectomy. Several clinical series of laparoscopic cholecystectomy contain analyses of injuries[1,12,13] and other series detailing mechanisms of injury have been published[6–8] and indicate common patterns of injury. Errors in identification of ductal or arterial anatomy may lead to direct injury of major ductal structures. Biliary leakage may occur either from ductal injury, inadequate management of the cystic duct, or the gallbladder bed and anomalous ducts. Thermal injury may occur from injudicious or overuse of the cautery or laser. Management of these injuries and other complications should begin with prevention. Recognition, diagnosis, and repair of the injuries remains challenging and requires the talents of a skilled and experienced hepatobiliary team.

The Classic Injury

Misidentification of the common bile duct or common hepatic duct as the cystic duct during the initial dissection results in the classic laparoscopic biliary injury (Figure 11.8.1). A small vessel accompanying or approaching the common duct gets misidentified as the cystic artery and is clipped and divided. The common hepatic duct is then dissected free from surrounding structures, clipped, divided, and then dissected free with the gallbladder. By this mechanism, then, not only is the common duct injured but a segment of the major biliary tree is missing, precluding primary repair. This injury is associated with right hepatic arterial injury as this artery passes immediately beneath the common duct through what is mistakenly thought to be the gallbladder bed. Profuse hemorrhaging may result, requiring conversion to open cholecystectomy. Depending on the angle and extent of dissection, division of the proximal biliary system may occur as low as the common duct and as high as tertiary biliary radicals.

A relatively common variation of this classic injury is seen when clips are appropriately placed on the proximal cystic duct, but because of tenting and inappropriate dissection clips, the clips are placed on the common duct instead of the distal cystic duct (Figure 11.8.2). The cystic duct is then divided near its junction to the common duct. The resultant complications are obvious: total biliary leakage from the divided, unligated stump of the cystic duct, along with complete obstruction of the common bile duct. This is particularly likely to happen in patients with very short or nonexistent cystic ducts (Figure 11.8.3) when traction on the portal structures tense the common bile duct and it is mistaken for the cystic duct.

Another variant of the classic injury occurs if the cystic duct has an anomalous origin from the right hepatic duct (Figure 11.8.4). The cystic duct is appropriately clipped, but distal clips are placed on the right hepatic duct, resulting in its division. Biliary leakage then results and bleeding is common. The classic injury, a variant, or another biliary injury should be suspected when unexplained intraoperative bile leakage occurs, there is persistent difficulty retracting the duodenum while attempting to dissect the "cystic duct" or, again, when excessive bleeding occurs during the ductal dissection.

Twenty-four of 38 patients with major biliary injury in

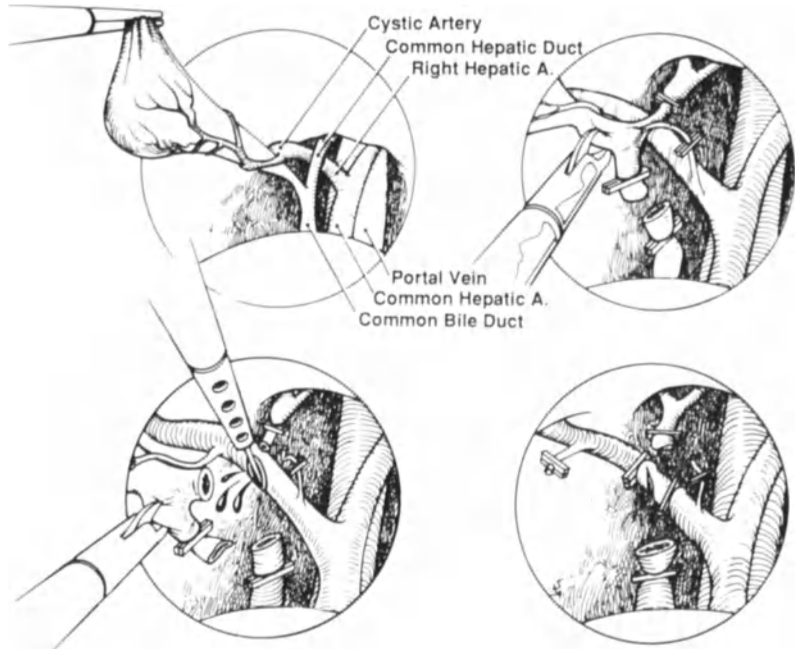


FIGURE 11.8.1. The classic injury (please see text). (From Davidoff AM, Pappas TN, Murray EA, et al.,[6] by permission of *Ann Surg.*)

the Duke series had the classic injury or one of the variants.[7] Only seven patients had injuries confined to the common hepatic duct, while the vast majority had injuries involving multiple ducts. Conversely, in the Lahey Clinic series, 8 of 11 patients with the classic injury or one of its variants had injuries confined to the common hepatid cut or common bile duct.[14] Others noted the remarkable absence of tissue in the extrahepatic biliary tree, postulating that overaggressive use of the laser had "vaporized" the structure.[15] In reality, these cases were probably examples of the classic injury with transection and removal of the extrahepatic biliary tree.

Burn Injury

Burn injury leading to biliary stricture is probably the second most common type of severe injury associated with laparoscopic cholecystectomy. The injury results from excessive use of cautery or laser dissection of the gallbladder bed or injudicious use of cautery or laser during the initial exposure of the cystic duct. In addition, early instructional tapes described division of the cystic duct with a laser or cautery. This practice can have disastrous results (Figure 11.8.5). When thermal injury occurs, the damage probably results from ischemia secondary to an interrupted blood supply to the damaged structure. Small caliber biliary systems and systems with anomalous blood supplies are particularly susceptible to this injury, so cautery or laser dissection should be judiciously applied in such patients.

Some degree of thermal injury also commonly accompanies the classic injury. The associated damage comes from the use of cautery or laser in the hilum during dissection of the common ductal system. The operator perceives that he is dissecting in the gallbladder bed, and cauterizes or lasers across the ductal and vascular structures in order to remove the gallbladder.

FIGURE 11.8.2. The classic variant. Appropriate placement of the proximal cystic duct clip with inappropriate clipping of the common bile duct instead of the distal cystic duct. (From Davidoff AM, Pappas TN, Murray EA, et al,[6] by permission of *Ann Surg.*)

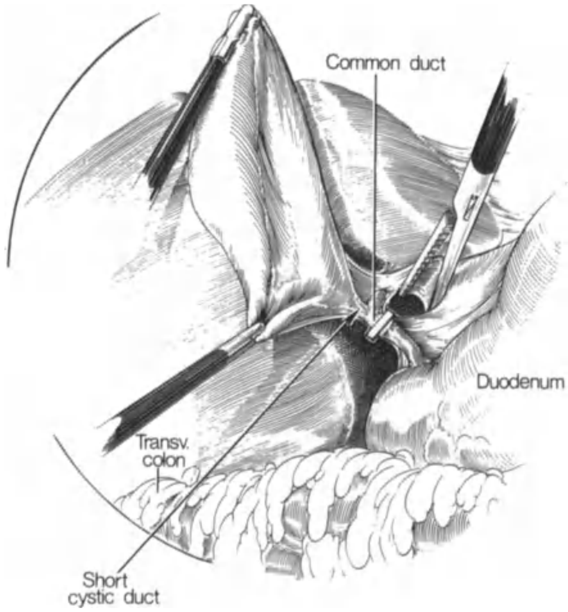


FIGURE 11.8.3. The short cystic duct predisposes to inappropriate clipping of the common bile duct if the cystic duct infundibulum junction is not accurately identified prior to the placement of clips. (From Peters JH, Gibbons GD, Innes JT, et al,[13] by permission of *Surgery*.)

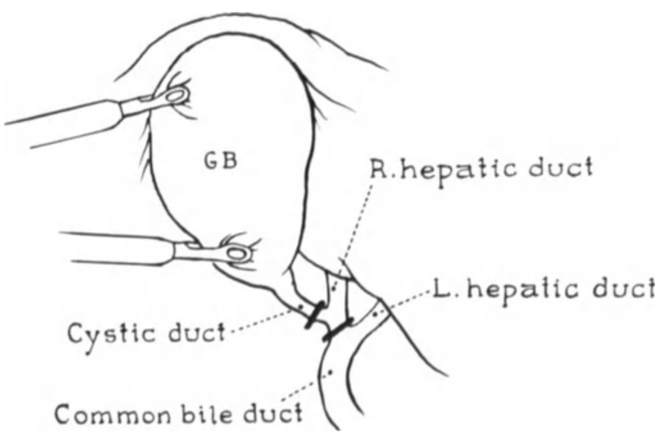


FIGURE 11.8.4. Anomalous origin of the cystic duct from the right hepatic duct with resultant right hepatic duct injury. (From Gelman R, Alexander MS, Zucker KA, et al,[11] by permission of *Gastrointest Radiol.*)

Biliary Leakage

Bile leakage following laparoscopic cholecystectomy may result from several injuries: the classic injury or one of its variants, partial interruption of the common bile duct, an accessory duct in the gallbladder bed, or an insecurely ligated cystic duct stump. Leakage from accessory ducts or the gallbladder bed are difficult to anticipate during surgery. Unanticipated leakage forms the basis for traditional, routine use of drains in gallbladder surgery. Nevertheless, most surgeons do not routinely drain following laparoscopic cholecystectomy. Significant leakage results in biliary ascites or pain, and in the absence of a major ductal injury, it is usually treatable by biliary stenting or papillotomy with percutaneous drainage of the biliary ascites or "biloma."

Cystic duct stump leakage occurs by a variety of mechanisms. Cystic duct clips may be inadequately placed, become dislodged in subsequent dissection, or perhaps most importantly, placed with excessive force, causing a crush necrosis of the cystic duct. Crush injury is most likely to occur when acute inflammation is present and tissues are edematous and friable. Traction injury may also result in a similar situation if excessive caudal tension is placed on the infundibulum of the gallbladder (Figure 11.8.6). At our institution, six patients were treated for cystic duct leak. All had postoperative endoscopic retrograde cholangiopancreatography (ERCP), stenting, or sphincterotomy. Nevertheless, two required open operation for repair or drainage.[7] The Southern Surgeons Club series of 1,518 laparoscopic cholecystectomies contained only two cystic duct leaks (0.01%),[1] while five collected series with 1,270 patients reported eight cystic duct leaks (0.6%).[2,4,16–18] The occurrence of crush type injury raises the question of whether endoloop ties on the cystic duct might be safer than multiple clips, particularly in the acute situation.

Unexpected Pathology

Pathology involving the distal or proximal bile duct is difficult to evaluate during laparoscopic cholecystectomy without cholangiography. Stones or tumors may cause biliary symptoms and go unrecognized. Persistence of symptoms may require evaluation or treatment with ERCP, or even reoperation. Intraluminal ultrasonography via the cystic and common ducts may help diagnose some unexpected biliary pathology.[19] Other uncommon but well-documented encounters during laparoscopic cholecystectomy include gallbladder cancer, congenital absence of the gallbladder, and extrinsic biliary obstruction. Most such problems lead to conversion to open exploration both for diagnosis and treatment, although improvement in techniques may ultimately minimize the need for conversion. Retained instruments within the common duct have occurred and were treated by postoperative ERCP.

Diagnosis

Published series[7,8] and anecdotal reports indicate that biliary injury at the time of laparoscopic cholecystectomy is unlikely to be recognized. In the Duke series of 38 biliary

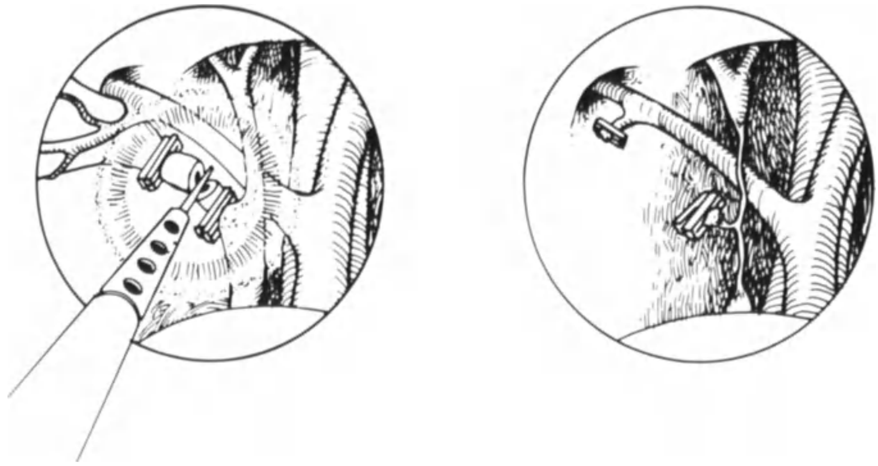


FIGURE 11.8.5. Inappropriate use of the laser to divide the cystic duct resulting in transmission of thermal energy to the common bile duct with subsequent stricture. (From Davidoff AM, Pappas TN, Murray EA, et al,[6] by permission of *Ann Surg.*)

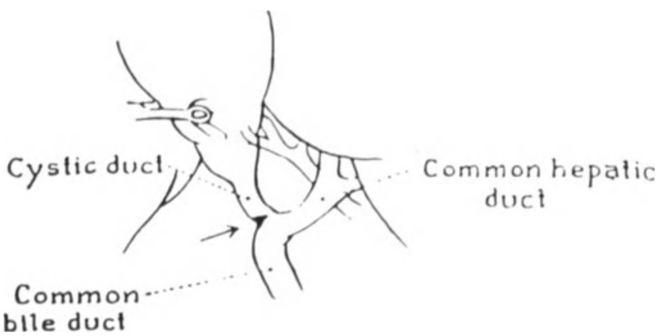


FIGURE 11.8.6. Inappropriate traction on the gallbladder infundibulum leads to traction injury at the cystic duct/common duct junction. (From Gelman R, Alexander MS, Zucker KA, et al,[11] by permission of *Gastrointest Radiol.*)

injuries treated operatively, only 4 were recognized at the time of the initial procedure, while 3 of 11 were recognized at the initial operation in the Lahey Clinic series.[7,14] Videotapes of procedures in which injuries occurred revealed that in many cases the injury should have been suspected at the time of the first procedure. Several intraoperative events alert the surgeon to the suspicion of biliary injury. These include unusual hemorrhage, hemorrhage from sites that are difficult to control, unexplained "accessory" vessels, division of two distinct ductal structures, a cystic duct with a larger diameter than usual, or the presence of unexplained golden hepatic-type bile drainage.

Postoperatively, a majority of patients have pain as their initial primary symptom. Pain out of proportion to what one expects or persistence of pain should lead to ERCP or CT scan. Biliary leakage or biliary obstruction occurs in only about half of patients, as evidence for this generally occurs later.

Radionuclide imaging using Tc99mIDA provides a simple noninvasive test to evaluate whether a leak is ongoing (Figure 11.8.7). Nuclear scans are sensitive and specific and may detect small leaks that pool in the gallbladder fossa or Morrison's pouch. Biliary ascites may yield increased tracer uptake throughout the peritoneal cavity. Early and delayed views are necessary in some cases to demonstrate extrahepatic distribution of the radioisotope.[10,11]

ERCP or percutaneous transhepatic cholangiography (PTC) are the investigational methods necessary to diagnose the level and severity of bile duct injury after laparoscopic cholecystectomy.[6,7,9] In the case of the classic injury, ERCP demonstrates the presence of an injury and does not show its proximal extent. A PTC becomes necessary to demonstrate preoperatively the proximal ductal anatomy, as well as the source of bile leak if present (Figure 11.8.8). In addition, stents placed via PTC are useful intraoperative adjuncts for identification of the ductal structures at surgery and postoperative stenting if necessary (Figure 11.8.9). Because of the absence of biliary dilatation, PTC may be difficult and often requires considerable expertise. Post-PTC CT scanning with injection of contrast through the biliary tubes may show the bile leakage and provide a roadmap for preoperative percutaneous drainage of extrabiliary bile in preoperative stabilization of the patient.

Treatment

Even if the injury is recognized at the time of the initial procedure and consists of division of the common duct, primary repair should consist of hepaticojejunostomy. The vast majority of injuries come to attention from days to weeks after the initial procedure.[7] Thermal injury may initially be recognized even months after the initial procedure. After preoperative study and identification of the exact choledochal anatomy, a Roux-en-Y hepaticojejunostomy should be performed unless there is a compelling reason to do otherwise. Most injuries, even high into

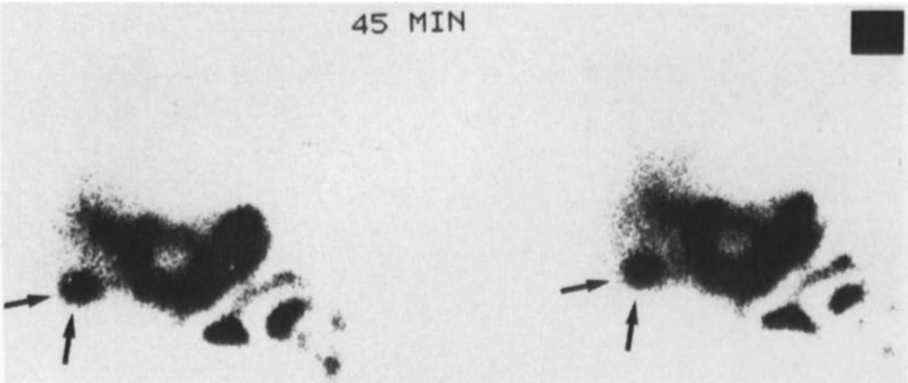


FIGURE 11.8.7. TC-99_m IDA scan of a patient with a bile leak. Tracer collects in the right upper quadrant 45 minutes after injection. (From Rosenberg D, Brugge WR, Alavi A,[10] by permission of *J Nuclear Med.*)

FIGURE 11.8.8. Percutaneous transhepatic cholangiogram revealing obstruction of the common hepatic duct approximately 1.5 cm below the bifurcation. This low injury is the exception and not the rule.

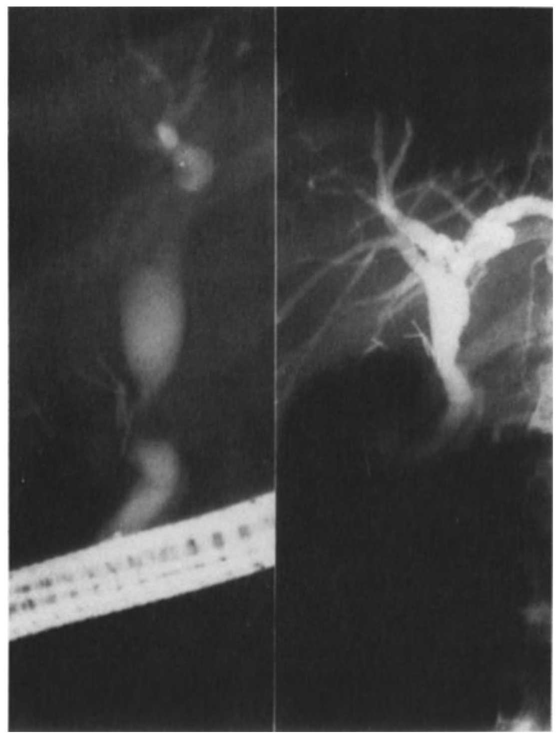
A  B

FIGURE 11.8.9. (A) ERCP revealing mid-common-bile-duct stricture in the region of several clips. (B) postdilatation cholangiogram reveals excellent results following balloon dilatation. (From Davidoff AM, Pappas TN, Murray EA, et al,[6] by permission of *Ann Surg.*)

the tertiary hepatic radicals, can be successfully treated by this approach. The importance of resection of scar tissue and an anastomosis performed to normal ductal tissue above the scar cannot be overemphasized. At the time of corrective surgery, a coronary O ring may be placed on the antimesenteric border of the Roux-en-Y segment and attached to the peritoneal surface of the anterior abdominal wall. This allows subsequent easy access to the biliary system via a percutaneous route. The best chance of long-term success is at the first attempted repair, thus an experienced hepatobiliary surgeon should be closely involved. The long-term success of these procedures should be 80 to 90% in experienced hands, depending on the level of injury and associated burn or vascular injury. However, several patients have been placed on waiting lists for liver transplantation. These patients had severe burn injuries high into the radicals and severe vascular injury in the presence or absence of underlying liver disease.

Thermal injury is particularly devastating in that the dense character of the damaged tissue makes intraoperative identification and repair difficult. The stricture and scarring in many cases is reminiscent of ductal malignancy, especially if the stricture presents months after the initial injury. In this situation the scar tissue should be sent for pathologic diagnosis.

Strictures caused by partial ductal occlusion by clips may be treated by dilatation. Transhepatic, or more commonly, ERCP balloon dilation may be successful in these cases (Figure 11.8.9). Most strictures are not amenable to such therapy, and operation has been necessary in all but two patients who were initially managed in this manner.

Simple cystic duct leakage may be treated initially by transcutaneous drainage alone.[7,9,16,18] Persistent leakage should lead to ERCP with stent placement or papillotomy. A retained stone or a cause for the leakage may be removed at the same time. If these measures fail to correct the leakage or the patient's clinical condition is slow to improve, operative intervention may be required to secure closure of the cystic duct or repair the injury. Sandostatin® (somatostatin analogue) may be a useful adjunct in this situation to decrease the volume of biliary secretion.

Prevention

Several publications[12,13,20] on laparoscopic injury lead to the conclusion that essentially all bile duct injuries are preventable, provided a few technical principles are maintained. Clear and accurate visualization of the operative field is mandatory and dissection should never begin until a clear and unobstructed view of the gallbladder infundibulum and the region of the porta is obtained on the operating monitor. While seemingly intuitive, reviews of videotapes of injuries reveal that inadequate visualization due to mechanical difficulties or inexperience often results in operative misadventure.[6,7]

Hunter[20] emphasizes the importance of maximal cephalic retraction on the fundus of the gallbladder, with lateral retraction on the infundibulum to expose the cystic duct at right angles to the common bile duct (Figures 11.8.10 and 11.8.11). We would modify that recommendation slightly by saying the traction on the infundibulum should also be slightly inferior to see the superior edge of the gallbladder. Dissection should be directed toward exposing the cystic duct infundibular junction, which should be accomplished by dissecting the adventitial fatty tissue *away* from the infundibulum toward the common duct. This principle holds true for the cystic artery as well, and no clips should be placed nor cuts made in a tubular structure until the gallbladder–cystic duct junction is absolutely visualized.

Intraoperative cholangiography may be an important adjunct to the dissection, especially early in one's experience with the procedure. This may be performed via cystic ductotomy or direct puncture of the gallbladder transcutaneously with aspiration of bile and instillation of contrast material. Particularly useful is the technique of fluoroscopic cholangiography. It not only gives an accurate view of the cystic and portal structures but requires less time than traditional cholangiograms.[20] Properly performed and interpreted, cholangiography should prevent

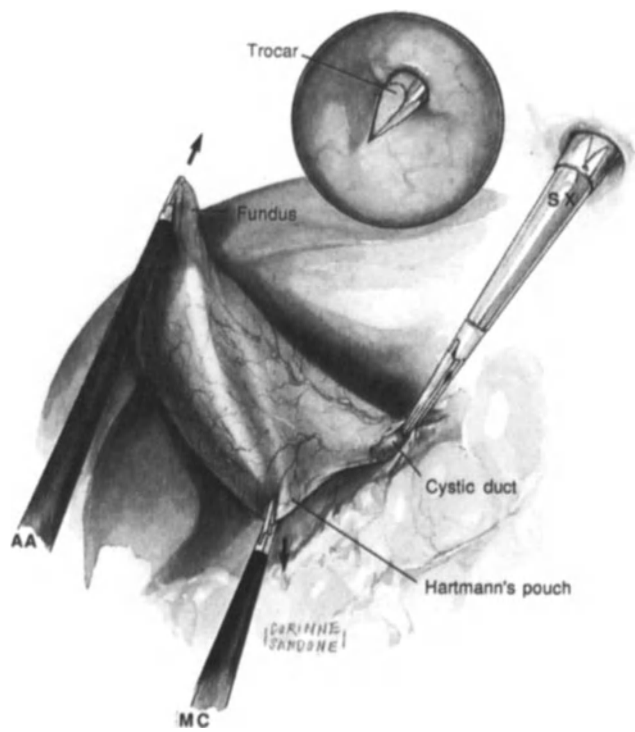


FIGURE 11.8.10. Illustration of the appropriate directions of traction to expose the cystic duct infundibulum junction at right angles. (From Peters JH, Ellison EC, Innes JT, et al,[2] by permission of *Ann Surg.*)

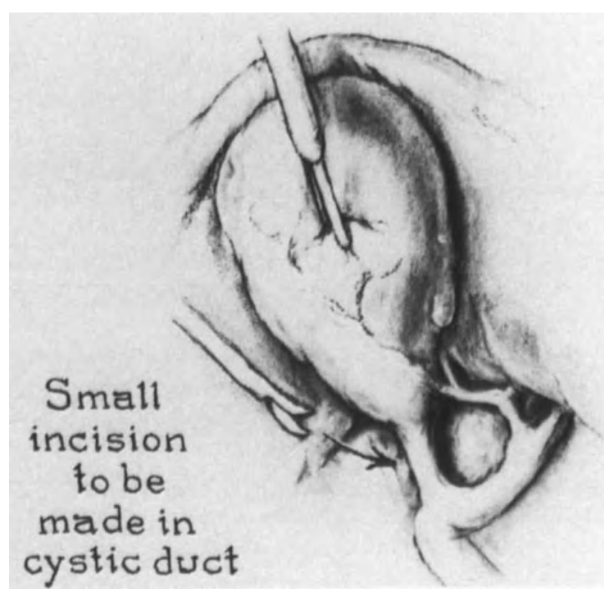


FIGURE 11.8.11. Illustration of the inappropriate direction for traction on the infundibulum with tenting of the common bile duct and removal of any angle from the junction of the cystic and common bile ducts. This illustrates how the common duct might be mistaken for the distal cystic duct. (US Surgical Corporation, Norwalk, CT.)

many injuries. Hunter reported alteration of the operative course based on cholangiographic findings in 9% of 100 cases, 6 of which were due to anatomic findings and 3 of which were due to filling defects.[20] This is not to say that cholangiography is absolutely necessary in every case, but it may clarify a difficult dissection and is important in the early experience of any individual surgeon.

Unrecognized aberrant ductal or arterial anatomy results occasionally in bile duct injury, but this is unusual.[16,20] Most injuries have occurred despite normal anatomy. Acute cholecystitis or severe scarring does increase the risk. Recognition of a very short cystic duct is important in order to avoid clips placed so that they impinge on the common bile duct. The cystic duct occasionally arises from the right hepatic duct, a situation that leads to injury if not recognized. Arterial anomalies that may lead to injury include the "catapillar hump" right hepatic artery, or a right hepatic artery that passes anterior to the common duct. A conservative attitude towards conversion to open cholecystectomy should be maintained despite extensive experience in laparoscopic cholecystectomy. One should consider conversion in the absence of a complication as good judgment rather than a defect in experience.

Summary

Experience and attention to the technical details of laparoscopic cholecystectomy can prevent most intraoperative mishaps. The industry standard of a bile duct injury rate of 0.1 to 0.2% should be the goal of surgeons performing laparoscopic cholecystectomy. Prospective and retrospective analyses show that most complications occur within the initial 15 cases in any surgeon's experience.[1,3] Particular attention to detail should be paid during this period and the assistance of an experienced laparoscopic surgeon should be enlisted. Cooperation of surgeons, endoscopists, and radiologists is necessary to offer state-of-the-art treatment after biliary tract injury has occurred.

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12
Management of Common Bile Duct Stones

12.1 The Evolution of Common Bile Duct (CBD) Stone Removal

George Berci

Courvoisier reported the first successful choledocholithotomy (CL) before the turn of the century.[1] A few years later, in 1912, the father of biliary surgery, Hans Kehr, published his landmark textbook based on 2,000 cases including patients with CBD stones. He invented T-tube drainage after surgical exploration of the CBD.[2] It is ironic that the great American surgeon, William Halstead, a few years after a cholecystectomy, died of complications from a choledocholithotomy for retained stones. There are four major developments that contributed to improved results in common bile duct surgery:

1. The introduction of operative cholangiography;
2. The use of choledochoscopy;
3. Retrograde endoscopic sphincterotomy (RES);
4. Laparoscopic choledocholithotomy.

The discovery of antibiotics was also a milestone in the successful treatment of infected bile cases, but keeping the scope of this book in mind, I will elaborate only on the above-listed developments.

The Introduction of Operative Cholangiography

Operative cholangiography has a rich history. In 1918, Reich injected a petroleum paste mixed with bismuth in a fistula of a woman who underwent pelvic surgery. To his great surprise, the extrahepatic biliary system became opacified. The patient developed a stormy course (spiking temperature, etc.) after this venture, but the infection subsided and the patient survived the first "cholangiography."[3] In 1922, Tenney and Patterson injected bismuth paste into a fistula that developed after cholecystectomy. They found a stricture of the common hepatic duct. Here, also, the patient developed fever and jaundice after this fistulography. They did exploratory surgery, and a bilioenteric bypass was performed. Unfortunately, the anastomosis leaked and the patient died of biliary peritonitis.[4] In 1930, Ginzburg and Benjamin injected Lipiodol into a biliary fistula after cholecystectomy, and the first reported, retained stone in the ampulla was discovered.[5] Then in 1932, Mirizzi introduced operative cholangiography:

> The bile in the peritoneum observed by surgeons who believe its presence is due to slipping of a ligature, in most cases, is a testimony that there is an anatomical functional lesion of the hepatic or common bile ducts that has not been noticed because of the inaccuracy, deceptiveness, and lack of precision in the methods of exploration used . . . (Mirizzi).[6]

In the United States, Hicken introduced cholangiography in 1936.[7] For the next two to three decades, operative cholangiography remained in the hands of a few enthusiasts. The eternal debate started whether we should do it routinely, selectively, or not at all. In 1958, Mallet-Guy, noticing the shortcomings of portable machines, introduced fluoroscopy. At this stage, it was difficult to switch quickly from fluoroscopy to radiography.[8] In 1963, Stefanini built a special operating room where the patient was moved from one tabletop during surgery to an x-ray table in order to perform cine fluoroscopy.[9]

With better understanding of the surgical environment, we introduced modern radiology (fluorocholangiography) into the operating room in 1978, and collected experience before the laparoscopic cholecystectomy (LC) era in approximately 4,000 cases, with an average of eight films per case.[10] The total time required for injection and aimed exposure using a fixed-ceiling C-arm arrangement with image amplification, closed circuit television, and a 100- × 100-mm camera was in the vicinity of three to five minutes. The TV image was also shown in the X-ray Department where a radiologist, at hand through an intercom, could advise the surgeon about his or her opinion of the findings.

The introduction of LC put the use and aim of fluorocholangiography in a completely different perspective. Unfortunately, ductal injuries increased. Hopefully, with further experience, they will decrease to a minimum. Operative cholangiography is not a guarantee of completely eliminating this catastrophic event of ductal injuries, but is of immense help in discovering anomalies or injuries. Anomalies of surgical importance occur in 10% of cases. Injuries can be seen by extravasation or stoppage of contrast material in the extrahepatic ductal system. During an inadvertent ductal injury, it is of enormous advantage to the patient if it is discovered at the first operation, and the injury can be immediately repaired. Unfortunately, the majority of patients are readmitted on the second or third day with biliary peritonitis, and have to be explored under more difficult circumstances. Only 10% of ductal injuries are recovered in the first postoperative week.

The development of mobile, digitized fluoro units, with an improved image and modern software, make it possible to do a cholangiogram, including positioning fluoroscopy with six to eight films to be completed in three to five minutes. This minimal extension of operating time is worth the effort and capital outlay.[11] The introduction of laparoscopic choledocholithotomy makes it mandatory to have modern fluorocholangiography available.

Operative Biliary Endoscopy (Choledochoscopy)

In 1922, Bakes introduced an ear funnel with a 45° mirror and illumination into the distal duct to discover calculi. The proximal ductal system could not be examined.[12] In 1942, McIver designed a right-angled cystoscope with a distal electric globe, but no clinical evaluation followed this announcement.[13] In 1953, Wildegans reported great success with 200 cases (one retained stone after 200 CBD explorations). He designed a choledochoscope that was angulated at a 60° angle, with a distal globe.[14] The introduction of the Hopkins-Rod lens system facilitated the design of a right-angled, rigid choledochoscope with a diameter of only 5 × 3 mm and fiber light illumination.[15]

The general surgeons were not endoscopists, nor was the interest, in those times, targeted toward learning endoscopic procedures. In 1982, a survey conducted of 150 California hospitals showed that in 80% of hospitals, a choledochoscope was available in the operating room, but it was employed in only 8% of choledocholithotomies.[16] It took decades for the surgical community to accept the idea of using an endoscope after the ductal system is cleared to remove overlooked calculi. In experienced hands, the incidence of retained stones could be kept below 3%. The introduction of video choledochoscopy helped the surgeons to obtain an enlarged image that could be seen with both eyes form a convenient distance, instead of looking at a small, dim monocular image. Stone removal from the CBD is team work. Four hands are required, as well as coordinated movements, therefore, video choledochoscopy was also an improvement from the point of assistants and training.

Endoscopic Retrograde Cholangiography and Sphincterotomy (ERC and ES)

Introduced by Oi, McCune, and others, endoscopic retrograde cholangiography (ERC) and endoscopic sphincterotomy (ES) became an "emergency exit" for surgeons.[17,18] It is invaluable in postcholecystectomy patients who develop symptoms or signs of a retained or reformed stone. In the laparoscopic era, the use of ERC increased significantly, despite the fact that in the subgroup of suspected stone cases, the incidence of negative ERCs in the preoperative stage could be as high as 30 to 50%.[19] Despite positive liver function tests, in half of the cases ERCs can be negative or noninformative. And this procedure is not without risk and adds significantly to the cost. But there is no doubt that in the elderly, high-risk patient with jaundice, cholangitis, or septicemia, preoperative ERC, drainage, or sphincterotomy is the method of choice. There are still many gray areas where we need more data to determine which treatment modality is best for which type of patients with CBD stones.

Laparoscopic Choledocholithotomy (LCL)

The incidence of CBD stones varies (10 to 20%), according to the age of the patient and length of time with symptoms. Therefore, LCL is a logical extension of LC. This procedure, whether performed through the cystic duct or through the CBD, is a new adjunct to LC and requires more experience and skill, a trained team, special instruments, and fluoroscopy. We hope that general surgeons who perform LC will acquire the knowledge of this new technique, and the patient's treatment modality can be completed in one session, or the patient cured with one operation. This is, of course, preferable compared to having several different procedures done, thereby increasing the risk, with the added morbidity and mortality of ERC and ES. Time and experience will show which way we have to go in the future.

Since Kehr introduced routine exploration of the CBD with T-tube drainage at the turn of the century, the treatment for this disease has changed significantly. We are entering a new area of laparoscopic CBD stone removal, and more time and some reliable follow-up data are required before one technique or the other will have its proper place in the treatment of CBD stones. In the experienced hands of a well-trained biliary surgeon, an open exploration of the CBD with drainage is still safe and efficient.

Laparoscopic choledocholithotomy is the future. The operator and his or her team need additional training and special instruments to do this procedure well. The advantages to patients are obvious, but we need to advance slowly and safely to establish another "gold standard" for the laparoscopic removal of CBD stones.

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12.2
The Evolving Role of ERCP in the Era of Laparoscopic Cholecystectomy

Jorge Navarrete, Joel C. Hammond, and Maurice E. Arregui

With the advent and remarkable success of laparoscopic cholecystectomy, endoscopic retrograde cholangiopancreatography (ERCP) has been catapulted into a major role in the perioperative management of common bile duct stones. ERCP is also a very useful adjunct to managing difficult cases of choledocholithiasis in conjunction with laparoscopic common bile duct exploration. Moreover, it has assumed a dubious role in the diagnosis and management of laparoscopic cholecystectomy complications, while it continues to maintain a dominant role in the diagnosis and management of postcholecystectomy syndromes. This chapter will attempt to put into perspective the evolving role of ERCP in this era of laparoscopic cholecystectomy.

Rationale for the Perioperative Use of ERCP

Since McCune, an Ohio surgeon, published the first report of ERCP in the *Annals of Surgery* in 1968,[1] it has evolved from a diagnostic tool to a therapeutic instrument. Kawai in 1974[2] and Classen in 1975[3] both independently reported the technique of endoscopic sphincterotomy. In 1981 Siegel reported a 97% success with stone removal accompanied by a 5% morbidity, a 0.8% mortality, and a late stenosis rate of 0.7%.[4] A similar experience was reported by Cotton in 1984 showing a stone removal rate of 87%, morbidity of 11%, mortality of 1.2%, and a 4% stenosis rate.[5] Carr-Locke demonstrated that this can be safely used in acute pancreatitis,[6] and Danilewitz reported its safe and effective use in the early postoperative period.[7]

Others have reported using ERCP for common bile duct stone removal while leaving the gallbladder in situ for high-risk surgical patients. For these patients, Davidson, Rosseland, and Miller separately reported that only 11, 18, and 21%, respectively, would ultimately require the gallbladder to be removed.[8–10] Moreover, prior to the advent of laparoscopic cholecystectomy, several investigators including Neoptolemos in 1987, Heinerman in 1989, Ponchon in 1989, and Stiegemann in 1989 reported on the preoperative clearance of common bile duct stones prior to open cholecystectomy. Heinerman showed a reduced morbidity and mortality associated with this technique, while others did not show any significant difference in morbidity or mortality. They all showed reduced hospitalization, and Stiegmann additionally demonstrated lowering of hospitalization costs.[11–14]

Indeed, the rationale for the use of ERCP with laparoscopic cholecystectomy for perioperative stone removal is quite sound for the following reasons:

1. It is a clinically proven technique used for the management of common bile duct stones in patients with previously removed gallbladders;
2. It has been proven to be safe and effective;
3. There are few long-term side effects;
4. It is widely available;
5. There is previous clinical experience with open cholecystectomy;
6. It does allow the use of minimally invasive surgery.

Moreover, several investigators including Reddick, Peters, Cuschieri, Spaw, Voyles, Martin, and Arregui have successfully demonstrated the safety and efficacy of combining ERCP with laparoscopic cholecystectomy.[15–21] Since the most efficacious use of ERCP is removal of intrabiliary stones, a focus should first be made on diagnosing these stones.

Assessment of Perioperative Choledocholithiasis

Preoperative Assessment

Hepatic or common bile duct stones are encountered in the surgical arena as suspected or unsuspected intruders. Historically, incidental choledocholithiasis is discovered in 10 to 15% of routine intraoperative cholangiograms. More recent reports with laparoscopic cholecystectomy indicate that incidental stones are found in approximately 5% of intraoperative cholangiograms. A detailed preoperative assessment can better discover stones prior to cholecystectomy, thus allowing for more flexibility in addressing the stones before, during, or after gallbladder removal.

A detailed preoperative assessment includes a thorough history and physical examination that focuses on signs and symptoms of jaundice, pancreatitis, and cholangitis. Phlebotomy screening for liver and pancreatic enzyme elevation is an inexpensive adjunct. Transabdominal ultrasound, which is routinely used to diagnose symptomatic cholelithiasis, can diagnose common bile duct stones by echo visualization or raise suspicions by documenting a dilated biliary tree. A hepatobiliary scan can infrequently suggest stones when there is obstruction of flow into the duodenum. Graham and Arregui found visualization of common bile duct (CBD) stones on preoperative ultrasound to be uniformly accurate, while a dilated duct was variably predictive in 71 and 47% of cases, respectively.[21,22] A history of pancreatitis or jaundice was predictive of CBD stones less than half of the time in both series. In fact in Arregui's series, only 8% of patients with preoperative pancreatitis were found to have stones at intraoperative cholangiography. Hawasli grouped patients from his series of 459 consecutive cholecystectomies into three graded categories for suspicion of CBD stones.[23] A high index of suspicion group with a 75% incidence of CBD stones was seen in patients with elevated bilirubin plus one other liver function test (LFT), elevation of all three LFTs, or dilated CBD by ultrasound plus one or more elevated LFT. A low index group, defined by an elevated alkaline phosphatase or two of three LFTs, had CBD stones 6% of the time. Only two patients with totally normal preoperative studies had postoperative abnormalities (elevated LFTs). One required nonoperative intervention while the other was observed.

Intraoperative Assessment

Suspicions for choledocholithiasis may first arise during initial exposure and dissection of the cystic and common ducts. The ducts may appear to be dilated, and stone protrusion can rarely be visualized. Laparoscopic common duct ultrasonography with a 7.5-MHz wand allows screening of most common ducts through the pancreas and into the duodenum. The most critical review of the biliary tree is afforded by fluoroscopic digital cholangiography. Cinematic replays can be viewed in a frame-by-frame fashion to reveal the most subtle of stones and sludge. For irrefutable confirmation, a fiberoptic flexible choledochoscope can be threaded transcystically to view intraluminal stones. One must be careful, however, to avoid creating damage during ductal dilatation required for passage of the choledochoscope.

Postoperative Assessment

Unfortunately, efforts during this phase of diagnosis usually uncover our weaknesses in detecting or dealing with the stones intraoperatively. Small stones (usually less than 3 mm) questionably may be followed from a clinical standpoint. Recurrent biliary pain, pancreatitis, or unsuspected jaundice several days postoperatively may invoke a CT scan, hepatobiliary scan, or transabdominal ultrasound that turns to ERCP for differentiation of retained stones from intraoperative iatrogenesis.

Technique of ERCP

This procedure is usually performed on an ambulatory basis. In preparation, the patient should fast for at least six hours. For interventions that may require a papillotomy, a complete blood count, prothrombin time, and partial thromboplastin time should be obtained. An intravenous line is established, along with placement of a semiautomated blood pressure cuff and pulse oximeter for monitoring awake sedation. Cardiac monitoring can also be employed optionally.

In the fluoroscopy suite, the patient is placed in a prone position to obtain a scout film. The patient may then either stay in that position or get into the left lateral decubitus position for initial passing of the endoscope. The pharynx is anesthetized topically prior to placement of a bite block. Intravenous sedation with midazolam is combined with an analgesic agent, usually meperidine. The analgesic may need to be withheld to prevent interference with sphincter manometric measurements.

While the patient is still awake enough to follow directions, he or she is asked to swallow the endoscope that has been placed over the tongue with the tip bent slightly caudad. The endoscope is then passed as one feels the cricopharyngeus muscle has relaxed. A side view of the esophageal wall will then be seen. Rugae of the stomach will be seen at approximately 50 cm. Air is insufflated to facilitate orientation. Any pooled secretions are aspirated. The patient should now be in a prone position if the decubitus position was used for passing the endoscope.

Advancing the endoscope at this time usually follows the greater curve. The angularis incisura may be encountered for further orientation and to prevent retroflexion. The pylorus should next come into view and should be approached like a setting sun, with its upper arc dropping more and more into the six o'clock position as the side-viewing endoscope looks toward 12 o'clock. With gentle pressure, the endoscope is passed through the pylorus and fine villi of the duodenum are now seen. The small wheel is then turned completely to the right (clockwise) and the tip deflected downward. The descending duodenum will come into view.

This positioning may take 90 to 100 cm of the endoscope and is known as the long position, as it travels along the greater curve. To reach an en face position to the papilla for cannulation, the short position is generally recommended. The small wheel is kept locked in right deflection while slowly pulling the excess endoscope backward while torquing the shaft to the right, and still maintaining the same relative duodenal tip position. Fluoroscopy demonstrates the long and short positions as depicted in Figures 12.2.1 and 12.2.2. With the major papilla and its telltale bilious staining in en face view, glucagon 0.5 to 1 mg is given intravenously to greatly decrease peristalsis and facilitate selective cannulation.

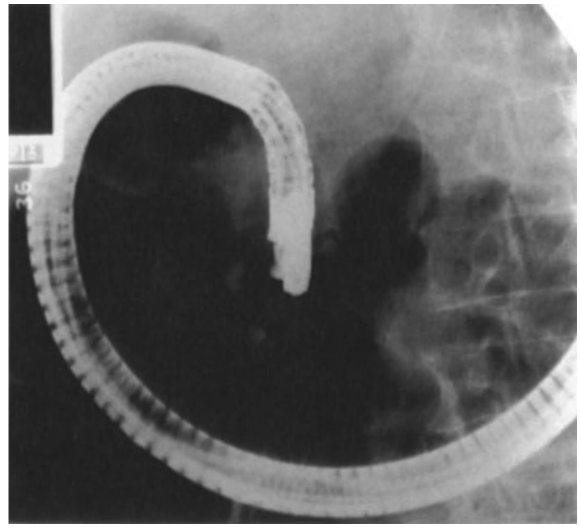

FIGURE 12.2.1. Duodenoscope is in the long scope position.

FIGURE 12.2.2. Duodenoscope is in the short position for cannulation.

Cannulation is best attempted with the papilla in the upper center or upper left of the video screen. With the use of the elevator, this allows the catheter to approach the biliary duct at the 11 o'clock position. Slight adjustment by subtle body torquing enables the catheter to approach the pancreatic duct at its two o'clock position. Fine wriggling motions then allow shallow positioning in the duct, with confirmation by fluoroscopic viewing of dye injection. With practice, cannulation should be successful in 90 to 95% of patients. Precut papillotomies are necessary in only the most difficult and stenotic papillae in order to find the ductal orifices.

Other techniques can be employed for difficult cannulations of the bile duct. The cannula can be angulated upward after impacting the orifice, so the tip assumes a better position for the more anterior CBD orifice. A flexible guidewire tip may enter and be advanced into the CBD more easily than a rigid cannula. A sphincterotome can be used to achieve a more acute angle to access entry. A precut papilla is the last alternative but is associated with more risks. Other alternative techniques for selective cannulation have been described.[60]

Once selective cannulation is verified, further injection should be with diluted contrast to optimize visualization of small CBD stones. After the cholangiogram is performed, and choledocholithiasis is verified, a guidewire is passed through the diagnostic cannula. Over the guidewire, the diagnostic cannula is removed and in its place a sphincterotome is advanced and positioned at the 11 to 12 o'clock position. If a metal guidewire is used, it must be removed prior to performing a papillotomy. A carefully controlled incremental papillotomy is performed to the first transverse duodenal fold (Figure 12.2.3). If a fast or "zipper" cut is made, there is a greater risk of bleeding or perforation. For stone extraction, balloon catheters or wire baskets can be used. We prefer to use balloon catheters. The balloon is inserted into the bile duct, advanced proximal to the stones, inflated, and withdrawn, pulling the CBD stones out. A completion cholangiogram is taken with the balloon occluding the distal CBD to ensure clearance of the duct. When large, impacted, or numerous CBD stones are encountered, baskets, mechanical or electrohydraulic lithotripser, and many sessions may be needed to clear the duct. In these situations, we favor laparoscopic CBD exploration by either transcystic technique, with or without the use of electrohydraulic lithotripsy to fragment the stones, or laparoscopic choledochotomy.

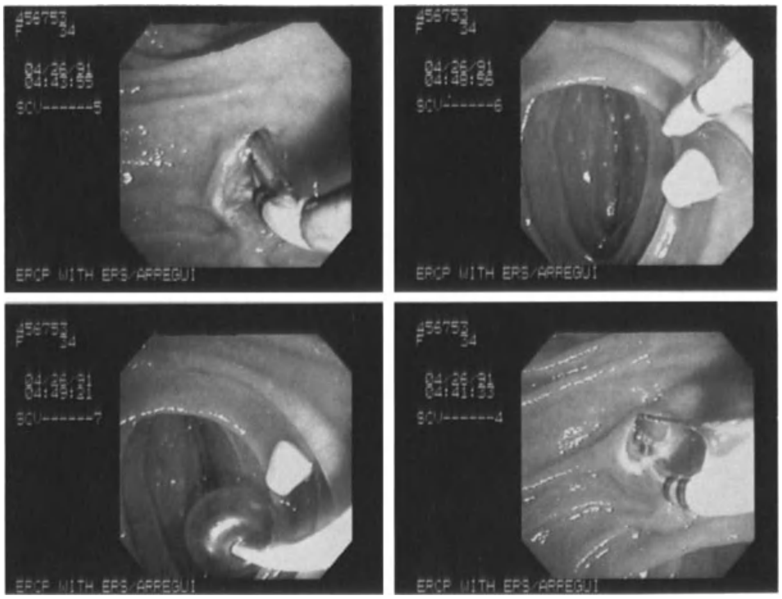

FIGURE 12.2.3. Endoscopic sphincterotomy for stone removal. Removal of the common bile duct stone is accomplished with a balloon catheter.

Clinical Experience

Between November 1989 and March 1993, nine surgeons have performed over 1,500 laparoscopic cholecystectomies at St. Vincent Hospital and Health Care Center in Indianapolis. Seven hundred twenty-seven (727) patients were referred for laparoscopic cholecystectomy to two surgeons (MEA and CJD) who shared the same management philosophy. In these patients, 46 CBD stones were encountered, for a CBD stone incidence of 6.0%. In this group, a total of 67 ERCPs were performed, 43 preoperatively and 24 postoperatively (Table 12.2.1). Successful cannulations were carried out in 65 (97%), and in 28 (42%) patients stones were found on ERCP. Of the three unsuccessful cannulations, two had stones documented by ultrasonography. These two underwent open CBD exploration, as this was early in our series, prior to mastering laparoscopic transcystic CBD exploration or choledochotomy. All in all, 25 of 30 CBD stone patients, or 83%, did not require open surgery. ERCP alone was effective in 22 (73%). The remaining three required adjunctive laparoscopic CBD exploration for complete stone clearance.

TABLE 12.2.1. The use of perioperative ERCP in the management of common bile duct stones—St. Vincent Hospital.

	Preop	Postop	Total
Attempted	43	24	67
Successful cannulation	41	24	65 (97%)
Known stones	20	10	30
Stones found on ERCP	18	10	28/67 (42%)
Open surgery not required	15	10	25/30 (83%)
ERCP clearance	10	10	
ERCP partial clearance*	4	2†	
Failed ERCP clearance*	1	0	
Open surgery required	5	0	5/30 (17%)
ERCP clearance			22/30 (73%)

*Where ERCP clearance was partial, laparoscopic common bile duct exploration was used for complete removal of common bile duct stones.

†ERCP required pre- and postoperatively to completely remove all stones.

In a similar experience by Mandujano in Santiago, Chile, ERCP was attempted preoperatively and postoperatively in 102 of 926 patients referred for laparoscopic cholecystectomy. Cannulation was successful in 101 (99%) and stones were found in 37 of these 102 patients (36%). For these patients, preoperative ERCP combined with laparoscopic cholecystectomy provided 100% stone clearance. Three additional patients were found to have CBD stones on intraoperative cholangiogram. Postoperative ERCP stone removal was successful in two of these patients. Thus, only 1 of 40 known CBD stone patients managed by perioperative endoscopic technique required open surgery.[24]

Likewise, Graham at Maryland and Larson at Louisville had similar experiences.[22,25] Combining the experiences of these four groups, there were 2,496 laparoscopic cholecystectomies performed. Two hundred forty-three (243) ERCPs yielded 106 CBD stones (44%). An additional two stones were ultimately discovered after failed cannulations. A total of 13 patients required open surgery out of 106 CBD stones (12%). The complication rate ranged from 1.7 to 8%. There were no deaths (Table 12.2.2). For open CBD exploration, successful clearance of 98% has been reported by Motson.[26] Morbidity of 5 and 20%, and mortality of 0 and 3% have been reported by Pappas[27] and McSherry,[28] respectively. Thus, perioperative ERCP with laparoscopic cholecystectomy compares quite favorably to conventional open techniques.

TABLE 12.2.2. Combined experience using perioperative ERCP in managing common bile duct stones in the era of laparoscopic cholecystectomy.

	Laparoscopic cholecystectomy	Cannulations successful/attempts	Stones found/known	Successful clearance	Morbidity/mortality	Open surgery
Arregui	720	65/67	28/30	22	6%/0	5
Graham	540	57/63	29	29	6%/0	4
Larson	310	20	9	9	8%/0	3
Mandujano	926	101/102	40	39	1.7%*/0	1
TOTAL	2,496	243/252	106/108	94		13

*This is based on a total series of 1,000 ERCPs.

TABLE 12.2.3. Intraoperative sphincterotomy during laparoscopic cholecystectomy.

	Number	Successful	Technique	Morbidity/mortality
Phillips/Berci	2	1	ERCP	Panc pseudocyst/0
Litwin	7	6	ERCP	0/0
Gagner/Deslander	25	24	ERCP	2 increased amylase/0
DePaula	10	10	Transcystic sphincterotomy	1 increased amylase/0
TOTAL	44	41		2.3%/0

Intraoperative ERCP developed a dubious reputation with the initial experiences of Phillips and Berci.[29] Others, including Litwin, Gagner, and DePaula have shown it to be quite effective with a low complication rate.[30–32] These results are depicted in Table 12.2.3.

Current dependence on endoscopic means for CBD stone manipulation stems from the surgeon's inability to perform laparoscopic CBD explorations. Indeed, it is technically challenging, as well as dependent upon specialized and somewhat difficult to obtain instrumentation. Phillips from Los Angeles compiled the experiences of various surgeons performing 83 laparoscopic CBD explorations.[33] Morbidity was 4% and the mortality 0.9%. There were two deaths in patients over age 60. Transcystic laparoscopic approaches to CBD stone extraction have also been reported by Jacobs, Petelin, and Quattlebaum.[34–36]

Numerous other adjunctive tools are very useful in the management of difficult CBD stones. These include the mother-daughter scope, mechanical lithotripsy, electrohydraulic lithotripsy, laser lithotripsy, extracorporeal shock wave lithotripsy, and chemical stone dissolution. The use of electrohydraulic lithotripsy has been adequately documented in the literature.[37–44] Reported perforations in animal studies have made its use somewhat controversial, but the clinical experience appears to be less morbid. A review of 253 cases from the literature found no perforations or serious complications due to electrohydraulic lithotripsy (see Chapter 12.7 by Yucel and Arregui on Electrohydraulic Lithotripsy of Common Bile Duct Stones). Our experience in managing choledocholithiasis is summarized in Table 12.2.4.

TABLE 12.2.4. Management of common bile duct stones (November 1989 through March 1993).

Preop ERCP with ERS and stone removal and LC	9
LC with IOCG (+) and postop ERCP with ERS for stone removal	10
Preop ERCP with ERS and partial stone removal and LC with IOCG (+) and postop ERCP with stone removal	1
ERCP with ERS with stone removal in gallbladder in situ (cholecystectomy not performed)	1
LC with IOCG (+) and laparoscopic TCDE with stone removal	12
LC with IOCG (+) and laparoscopic CBDE with stone removal	1
Preop ERCP with ERS with partial stone removal and LC with TCDE with stone removal	2
Preop ERCP with ERS and stent placement and LC with laparoscopic CBDE with stone removal	1
Preop ERCP with ERS & partial stone removal & stent placement & LC with TCDE with stone removal & postop ERCP	1
LC with IOCG (+) and attempted laparoscopic TCDE for stone removal and postop ERCP (−)	1
LC with IOCG (+) and attempted laparoscopic TCDE for stone removal and follow-up observation	1
Open surgery with CBDE	7
ERCP with ERS and stone removal of retained or recurrent CBDS in patients with previous OS	6
Percutaneous "T-tube" stone removal	2
TOTAL	55

ERCP = endoscopic retrograde cholangiopancreatography
ERS = endoscopic retrograde sphincterotomy
IOCG = intraoperative cholangiogram
LC = laparoscopic cholecystectomy
TCDE = transcystic duct exploration
CBDE = common bile duct exploration
OS = open surgery

Current Recommendations

There is no doubt that the availability of ERCP, laparoscopic, and open techniques for management of CBD stones allows for many permutations in the timing and mode of eradicating stones. There is no question that a greater degree of treatment modalities is available to the surgeon who is adept at all three: open, laparoscopic, and endoscopic techniques. No good studies are available to evaluate different management schemes in a randomized, prospective fashion. Instead, one must rely on his or her own clinical acumen that has been bent by personal experiences. This, in turn, needs to be fit to the individual patient's acute and chronic medical condition. A Society of American Gastrointestinal Endoscopic Surgeons (SAGES) opinion survey report published by Brodish and Fink[45] compiled an experience of almost 20,000 laparoscopic cholecystectomies and asked surgeons their current management of CBD stones. The majority favored the removal of the suspected stones with preoperative ERCP with endoscopic sphincterotomy, and the unsuspected with laparoscopic CBD exploration.

As more surgeons gain experience with laparoscopic intraoperative cholangiograms and transcystic CBD explorations, ERCP will have a vanishing role in preoperative CBD stone management. The two main disadvantages to preoperative ERCP are that it is a second procedure and that $> 50\%$ of the preoperative ERCPs are negative for stones. Indeed, approximately 10% of patients in our experience and that of others have had preoperative ERCP for possible choledocholithiasis. Sixty percent of these are negative. This is therefore an expensive cholangiogram with significant morbidity and mortality in skilled hands, not to mention the less-skilled endoscopist. Additionally, it is not effective for large stones, and long-term effects of sphincterotomy in young patients are not known. However, preoperative decompressive ERCP is very useful for severe gallstone pancreatitis and ascending cholangitis. (Figures 12.2.4–12.2.6) Of course, for patients deemed unfit for general anesthesia, ERCP may be the only CBD stone eradication modality available.

Intraoperative ERCP has the advantage of not requiring an additional sedation or anesthetic. On the other hand, cannulation is performed in an uncomfortable orientation with the patient in supine or left lateral decubitus position. Moreover, if the surgeon does not perform his own ERCPs, he or she may waste precious anesthetic time awaiting the impromptu arrival of an endoscope and its accompanying endoscopist. We predict that the main role of ERCP will be as a postoperative adjunct to difficult cases of CBD stone management. These will include failed attempt at cholangiogram in patients still suspected of having CBD stones postoperatively, failed laparoscopic or open removal of CBD stones, high-risk patients found to have unsuspected stones, retained stones without T-tubes, and recurrent CBD stones.

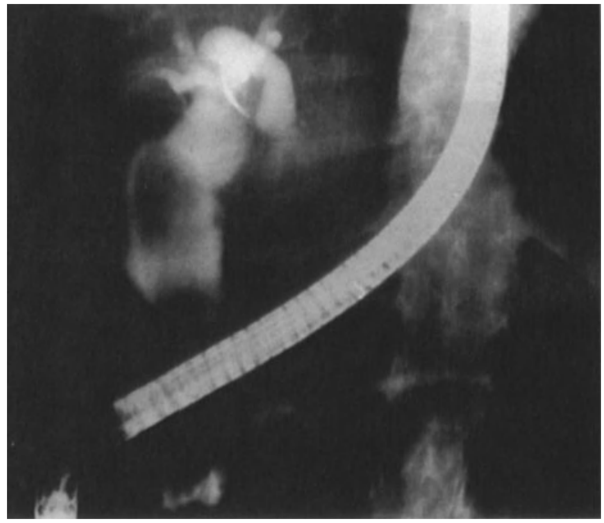

FIGURE 12.2.4. ERCP of large common bile duct stone. (By permission of Yucel O, Arregui ME, Electrohydraulic lithotripsy combined with laparoscopy and endoscopy for managing difficult biliary stones. *Surgical Laparoscopy and Endoscopy.* 3:398–402, 1993.)

Currently, our management scheme for cholelithiasis with suspected cholelithiasis is described as follows. Our patients undergo laparoscopic cholecystectomy with intraoperative laparoscopic ultrasound and cholangiography routinely. If stones are found, a laparoscopic transcystic CBD exploration and stone removal are performed. For too hard and large or impacted stones, electrohydraulic lithotripsy or mechanical lithotripsy can be employed. If this fails, laparoscopic choledochotomy is performed, which we have done in two cases with stones of 2×2 cm and 2.5×5 cm. Open CBD exploration is used when the above methods fail. We have not implemented intraoperative ERCP. Postoperative endoscopic sphincterotomy is sometimes used in a "cleanup" role for retained stones and fragments. Postoperative endoscopic stone extraction is also used if CBD stones are encountered in a high-risk patient in whom a long procedure and general anesthetic is felt to be too risky.

Acute Biliary Pancreatitis

The timing of surgical intervention in acute biliary pancreatitis has been a source of debate for many years.[46–48] With the advent of ERCP and endoscopic papillotomy, more options are available for management. Several prospective randomized trials have compared early endoscopic sphincterotomy with conservative therapy, prior to the advent of laparoscopic cholecystectomy. From Hong

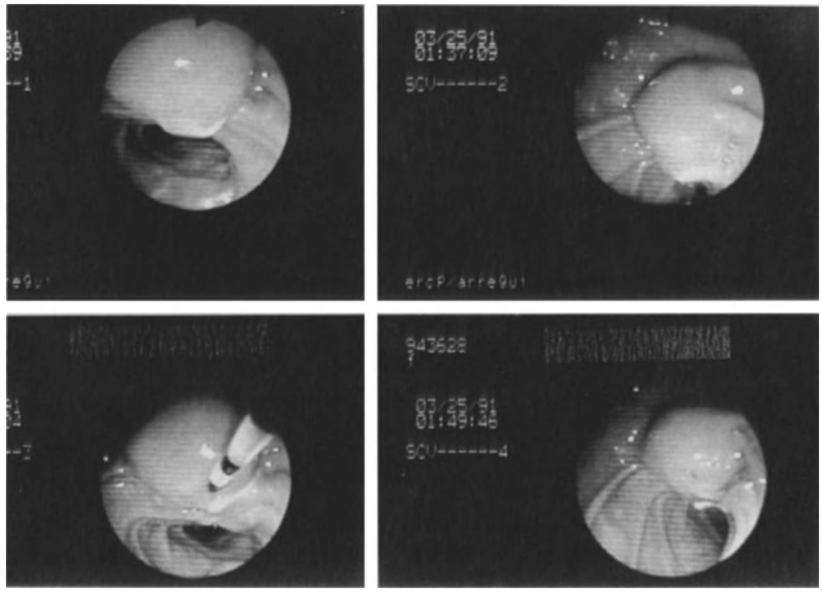

FIGURE 12.2.5. Impacted common bile duct stone with pus oozing from bulging papilla in a patient with ascending cholangitis.

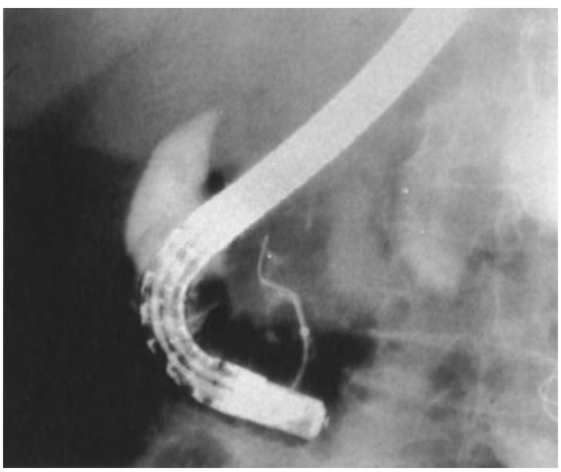

FIGURE 12.2.6. ERCP of impacted common bile duct stone in same patient as Figure 12.2.5. (By permission of Yucel O, Arregui ME, Electrohydraulic lithotripsy combined with laparoscopy and endoscopy for managing difficult biliary stones. *Surgical Laparoscopy and Endoscopy* 3:398–402, 1993.)

Kong, Fan randomized 195 patients with acute pancreatitis to receive early (< 24 hours) ERCP versus initial conservative therapy with selective ERCP.[49] There was a significant reduction in biliary sepsis with early ERCP as compared to conservative treatment. However, there were no other significant differences in morbidity or mortality between the two groups. Furthermore, CBD stones were identified by ERCP in only 37 out of 97 patients in the early ERCP group, for a sensitivity of 38%. Similarly, Neoptolemos randomized 121 patients to receive early ERCP (< 72 hours) versus conservative treatment.[50] Only in those with predicted severe attacks (modified Glasgow > 2) was morbidity significantly lower in the early ERCP group as compared to conservative treatment. Mortality showed a downward trend in the early ERCP group, but was not significantly different (2 versus 8%). CBD stones were found in 19 of the 59 patients randomized to ERCP, for a sensitivity of 32%. Although these data suggest possible better outcomes from early ERCP intervention in severe acute pancreatitis, preoperative ERCP is a poor screening test for CBD stones, as evidenced by stones being present in only one of three cases.

Acosta in 1974 demonstrated that the vast majority of biliary pancreatitis stones will pass if not operated upon in the first 48 hours of disease.[51] Because of this natural history of biliary pancreatitis and the low sensitivity of preoperative ERCP, we favor initial nonoperative management followed by laparoscopic cholecystectomy and intraoperative cholangiogram in one to three days. We feel that this allows stones to pass without any surgical or endoscopic manipulation. For more fulminant courses, however, we have a lower threshold for preoperative endoscopic sphincterotomy.

Other Roles of ERCP

One of the newer roles that has developed during the learning curve of the laparoscopic era is the use of ERCP in the diagnosis and management of complications of laparoscopic cholecystectomy and postcholecystectomy syndromes. (Figures 12.2.7–12.2.10) Early reports revealed bile duct injuries in 0.5 to 2.7% of cases[52–54] versus 0.25 to 0.5% of open cases. Postcholecystectomy syndrome is thought to occur in up to 20% of patients. Indeed, in reviewing 87 ERCPs that we performed in patients with previous laparoscopic cholecystectomy, we evaluated and

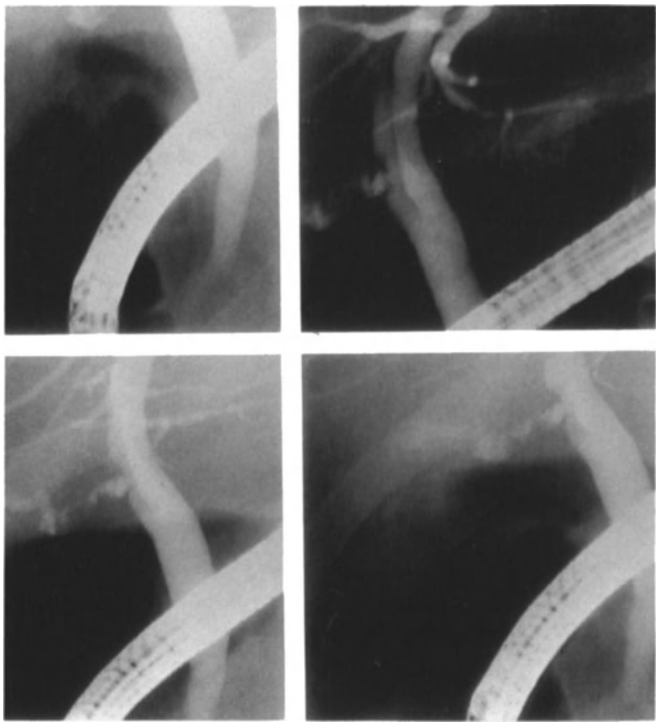

FIGURE 12.2.7. Cystic duct leak seen on ERCP. This patient was managed with a stent placed by ERCP.

FIGURE 12.2.8. Stent place with ERCP for decompression in ascending cholangitis in same patient as in Figure 12.2.5. (By permission of Yucel O, Arregui ME, Electrohydraulic lithotripsy combined with laparoscopy and endoscopy for managing difficult biliary stones. *Surgical Laparoscopy and Endoscopy* 3:398–402, 1993.)

FIGURE 12.2.9. Persistent bile peritonitis in a patient who was treated with endoscopic stent placement for postcholecystectomy bile leak. This laparoscopic view shows the large amount of bile in the right upper quadrant. Note the inflammatory fibrinous exudate coating the liver and hepatic flexure of the colon.

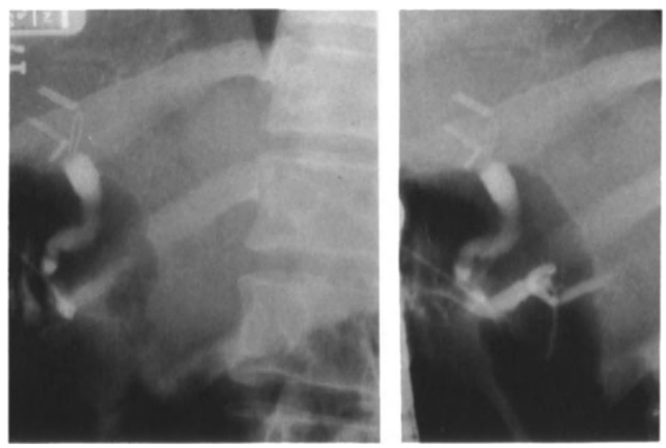

FIGURE 12.2.10. ERCP of transected common bile duct. This patient was managed with a choledochojejunostomy.

treated two bile leaks, five sphincter of Oddi stenoses, and two biliary dyskinesias. Additionally, we found one recurrent CBD stone, one pancreatic lithiasis, and one pancreas divisum. At the 1992 SAGES meeting in Washington, Kozarek and Traverso presented 42 patients who underwent ERCP after laparoscopic cholecystectomy.[55] Their diagnoses included stones, pancreatitis, papillary stenosis cystic duct leaks, and CBD injuries. Thirty-one patients were treated with endoscopic papillotomy, and 15 patients had stents placed for definitive management. Others, likewise, have used ERCP in the diagnosis and management of bile leaks.[56–58] These results are summarized in Table 12.2.5.

Concerning postcholecystectomy syndromes, Geenen in Milwaukee randomized 47 patients with proposed sphincter of Oddi dysfunction to undergo endoscopic

TABLE 12.2.5. The use of ERCP postcholecystectomy for management of bile leaks.

Investigator	Causes	Leaks	ERCP/ Diagnostic	ERCP/ Therapeutic
Kozarek*	Cystic duct	2	2	2
Brooks[43]	Cystic duct	6	4	3
	Duct of Luschka			
Peters[44]	CBD† injury	11	1	?
	Cystic duct		4	
	Duct of Luschka		6	
Wootton[45]	Cystic duct	3	3	2
Arregui	Segmental branch	2	1	0
	Duct of Luschka		1	
TOTAL		26	22	7

*Presented SAGES meeting, April 1992.
†CBD—common bile duct.

sphincterotomy versus sham sphincterotomy.[59] Over 90% of patients with elevated sphincter pressure benefited from sphincterotomy after one year versus only 25% with sham sphincterotomy. After four years of follow-up, 17 of 18 patients with sphincter of Oddi dysfunction, verified by manometry, benefited from sphincterotomy.

With time, the incidence of bile duct injuries should at least approach that of open surgery. Endoscopic transampullary sphincter of Oddi manometry will have an increasing role in diagnosing postcholecystectomy syndromes, as measurement systems become more accurate and reproducible.

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12.3
Intraoperative Endoscopic Retrograde Cholangiopancreatography (ERCP)

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The approach to common bile duct (CBD) stones has gone through important and progressive changes since the introduction of ultrasonography. Formerly restricted to the domain of surgery, their treatment evolved with the introduction of endoscopic papillotomy by Kawai in 1974.[1,2] Primarily indicated for patients with residual or recurrent CBD stones, especially for older and high-risk patients, its application was progressively extended to patients with acute cholangitis, acute biliary pancreatitis, concomitance of choledocholithiasis with other conditions, placement of prostheses in the management of benign and malignant diseases, and in the perioperative approach to CBD stones in patients undergoing cholecystectomy.

Approximately 10% of patients with cholelithiasis have choledocholithiasis. On the other hand, 95% of patients with CBD stones have gallbladder stones.[3] Therefore, some of the patients that will be submitted to cholecystectomy must undergo CBD exploration, which can be done in the pre-, intra-, or postoperative period. However, determining the best moment for approaching the CBD involves a series of difficulties. Because of the low prediction rate for CBD stones through clinical observation, ultrasonography, and laboratory evaluation, the routine use of preoperative endoscopic retrograde cholangiopancreatography (ERCP) results in a high rate of negative findings. Endoscopic CBD exploration in the postoperative period presents the possibility of failure as a major problem that may require yet another procedure. Both pre- and postoperative ERCP have morbidity and mortality rates around 10 and 1%, respectively.

With the advent of laparoscopic cholecystectomy, several authors have reported good results obtained from CBD stone removal using either pre- or postoperative ERCP.[50–52,67–72] The relevance of this issue has resulted from the limitation of the laparoscopic approach to the CBD during early experiences with laparoscopic cholecystectomy. Some authors have suggested the routine preoperative radiologic assessment of the CBD through intravenous cholangiography to select patients for laparoscopic cholecystectomy.

In the beginning of our experience we performed preoperative ERCP for patients with suspected choledocholithiasis, and postoperative ERCP, or conversion to open surgery for those with intraoperative diagnosis of CBD stones. In an attempt to avoid unnecessary ERCPs in the preoperative period, the possibility of postoperative drawback, and to treat cholelithiasis and CBD stones in a single procedure, we changed our management scheme to intraoperative ERCP during laparoscopic cholecystectomy.

With the advent of laparoscopic CBD exploration, we began using this approach for the treatment of choledocholithiasis during cholecystectomy.[4–10] However, some patients required drainage of the CBD, thus determining the development of laparoscopic antegrade sphincterotomy.[7]

Technique

Intraoperative ERCP is performed with the patient in the supine position and head turned to the left. After the confirmation of CBD stones through intraoperative cholangiography, a side-viewing endoscope is introduced and positioned in the duodenum facing the papilla. For proper positioning, it is necessary to have a clockwise rotation of 180° in relation to the patient. Insufflation must be restricted to the minimum necessary. Escape of air usually occurs, especially in deeply relaxed patients. Under fluoroscopic and endoscopic guidance, the surgeon maneuvers a 5F polyethylene catheter through the cystic duct and into the duodenum. With the help of a knife-type papillotome, progressive cuts of the ampulla and of the CBD sphincter are made using a blended current until reaching the first transverse fold of the duodenal mucosa. The use of a guidewire is optional. The catheter and/or guidewire is then removed, followed by closure of the cystic duct. The stones are extracted under fluoroscopic control with a basket or balloon type catheter introduced through the working channel of the duodenoscope. Endoscopic completion cholangiography is performed. The duodenoscope is taken out and the surgeon continues the laparoscopic cholecystectomy.

Laparoscopic antegrade sphincterotomy is performed following intraoperative cholangiography. A standard Classen-Demling or a Billroth II type papillotome is introduced through the cystic duct orifice or through a choledochotomy. A side-viewing duodenoscope is then introduced and placed facing the papilla (Figure 12.3.1). Under both fluoroscopic and endoscopic guidance, the papillotome is advanced through the papilla and into the duodenum. The correct position of the papillotome, as well as of the diathermic wire, is then confirmed endoscopically with the side-viewing duodenoscope. Sphincterotomy is performed in the standard fashion with the diathermic wire placed in the 12 o'clock position. Progressive cuts are made through the superior portion of the ampulla using a blended current until reaching the first transverse fold of the duodenal mucosa. The ampulla is then observed for any evidence of postsphincterotomy bleeding or intestinal perforation (Figure 12.3.2). Following sphincterotomy, a repeated cholangiogram through the cystic duct or choledochotomy is performed in an attempt to demonstrate free flow of the contrast into the duodenum. A flexible choledochoscope can also be used in order to confirm complete removal of stones from the extrahepatic biliary tree. It is important to emphasize that the duodenoscope is used only to check the adequate positioning of the papillotome and to control the extension of the cut.

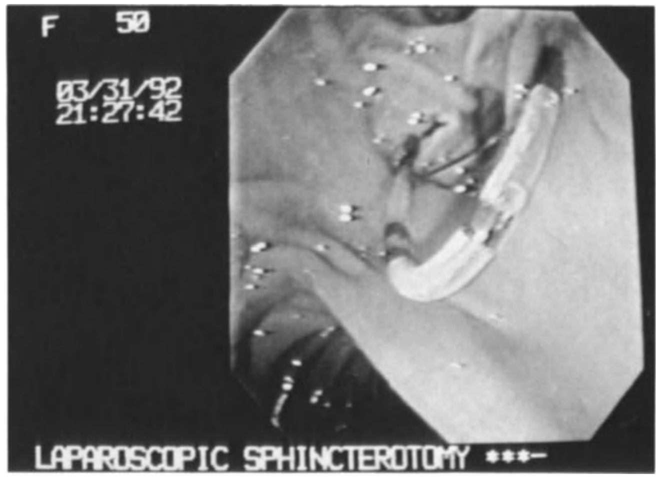

FIGURE 12.3.1. View of laparoscopic transcystic papillotomy.

FIGURE 12.3.2. Duodenoscope view of choledochoscope passing through ampulla.

Clinical Results

In our initial experience, 11 intraoperative ERCPs with sphincterotomy and endoscopic choledocholithotomy were performed in three male and eight female patients, with mean age of 54.4 years, ranging from 44 to 71 years. Four of these patients had cholelithiasis and an intraoperative diagnosis of CBD stones, and the other seven had preoperative suspicion of choledocholithiasis. All of these procedures were successfully carried out, with an additional average time of 28 minutes, ranging from 19 to 44 minutes. One patient developed hyperamilasemia without any clinical evidence of acute pancreatitis. Two patients had bleeding after endoscopic sphincterotomy. No transfusion was required. No deaths occurred. The mean hospital stay was 2.4 days, ranging from 1 to 4 days.

Subsequently, we have performed laparoscopic CBD exploration and laparoscopic antegrade sphincterotomy in 23 patients. Seven were male and 16 female, with mean age of 53.5 years, ranging from 32 to 81 years. The indications for performing laparoscopic antegrade sphincterotomy included: inability to completely clear the CBD in five patients with multiple stones and stones in the common hepatic duct found during laparoscopic CBD exploration; a drainage procedure in six patients with large (> 2.0-cm) stones in the CBD; three patients with large and multiple fragments after laparoscopic mechanical and electrohydraulic lithotripsy; and nine patients with suspected papillary stenosis. The procedure was successfully carried out in all of the patients. The transcystic approach was used in 22 patients and done through a choledochotomy in 1 patient. Laparoscopic antegrade sphincterotomy added an average of 18 minutes to the laparoscopic cholecystectomy and CBD exploration, ranging from 10 to 30 minutes. The mean hospital stay was 1.5 days. Two patients had hyperamylasemia without any evidence of acute pancreatitis, and one patient had postsphincterotomy bleeding but no transfusion was required.

Discussion

The management of choledocholithiasis continues to challenge surgeons and gastroenterologists. Due to the effectiveness of the ERCP approach as evidenced by decreased morbidity and mortality rates, and less trauma to the patients, the surgical management of CBD stones has significantly declined.[15–18]

The success rate of ERCP is about 90%, morbidity between 5 and 10%, and mortality of approximately 0.8%.[19] The most frequent early complications are hemorrhage, pancreatitis, cholangitis, and duodenal perforation. Hemorrhage is the most frequent complication, accounting for approximately 2.5% of cases, and is the major cause of death from cholangiography with endoscopic sphincterotomy. In a series of 11,572 sphincterotomies, surgery was required in 17% of the patients who bled, accounting for 8.9% of the deaths in this series.[12–14] Hyperamylasemia often occurs after ERCP, though it is not associated with symptoms in most cases. Approximately 2% of the patients who underwent ERCP and papillotomy developed acute pancreatitis. The etiology of this complication is multifactorial and includes mechanical, hydrostatic, chemical, enzymatic, thermal, microbiologic, and hypersensitivity factors.[40–49] Although infrequent, cholangitis constitutes a severe complication of ERCP and sphincterotomy. Approximately 1.3% of the sphincterotomy procedures are complicated by cholangitis, 34% of these patients will have to undergo surgery, and 9% will die.[19,22–24] Retroduodenal perforation is a rare complication. It has been observed in 1.1% of the patients who undergo ERCP and sphincterotomy, and accounts for a mortality rate of approximately 12%. Late complications occur in approximately 10% of patients who undergo sphincterotomy.[25–36] These include papillary stenosis, recurrent stones, and cholangitis.[53–59]

ERCP has been used in the treatment of choledocholithiasis with the gallbladder *in situ,* and is associated with cholecystitis and biliary colic in 4.1 to 20.6% after a two-month to nine-year follow-up. Cholecystectomy was required in 5 to 18% of cases.[18,22,37–40,53,60,61]

The use of perioperative endoscopic sphincterotomy has been assessed by several authors. Heinermann (1987) in his comparative study between preoperative ERCP, followed by open cholecystectomy and cholecystectomy with CBD exploration, demonstrated morbidity rates of 2.1 versus 21.8%, mortality of 1.0 versus 3.8%, and residual stones of 0.5 versus 2.2%. However, Neoptolemos (1987), Ponchon (1989), and others did not observe a statistically significant decrease in morbidity and mortality rates, except for a shortened hospital stay when the preoperative ERCP was used.[62–65]

Laparoscopic surgery, especially laparoscopic cholecystectomy, came into being at the end of the 1980s. The good results obtained were associated with minimal trauma, short hospital stay, fast return to previous activities, and better aesthetic results. Because of the initial limitations of the method for patients with concomitant choledocholithiasis, in whom the procedure was contraindicated, there was an increased interest in perioperative ERCP. Arregui (1992), in his study of 553 patients who had undergone laparoscopic cholecystectomy, performed preoperative ERCP in 41, and postoperative ERCP in 14 patients, obtaining a morbidity rate of 6%, and no mortality. Catheterization was possible in 52 (94%) patients. Neuhaus (1992) performed preoperative ERCP and laparoscopic cholecystectomy in 288 patients, having reached a success rate of 91.7%, morbidity rate of 2.8%, and no mortality. Graham (1992) used the perioperative ERCP in 51 patients, 29 in preoperative, and 22 in postoperative patients. No mortality was observed and the morbidity rate was 4%. Other studies, like those conducted by Larson, Boulay, and Barkum, confirmed the results obtained with pre- and postoperative ERCP in conjunction with laparoscopic cholecystectomy.[50–52,67–72] However, due to the necessity for a second procedure, the low prediction rates related to clinical, laboratory, and ultrasonographic evaluation, which led to a high negative rate of preoperative ERCP, its associated risks, and the possibility of failure of the postoperative ERCP which would require yet a third procedure, the authors decided to evaluate the role of intraoperative ERCP during laparoscopic cholecystectomy.[66] According to Phillips and Berci, intraoperative ERCP was associated with tactile and technical difficulties as well as with high morbidity, in spite of the limited number of cases. Litwin and Gagner performed intraoperative ERCP in 35 patients, having reached a success rate of 94.3%, without complications or mortality. The majority of these patients had an intraoperative diagnosis of CBD stones. Taking into consideration our own experience and that of the authors mentioned above, the main advantages would be the management of gallbladder and CBD stones in a single surgical and anesthetic procedure; ERCP only in patients with a confirmed diagnosis of choledocholithiasis; decreased possibility of failure, as papillotomy is performed over a catheter introduced through the cystic duct; and also a possible decrease in the incidence of acute pancreatitis, as there is no catheter maneuver or use of contrast in the pancreatic duct. However, the procedure is laborious due to the extensive amounts of staff and equipment in the operating room; a morbidity rate of approximately 9% in this small series; position of the patient during surgery requiring readaptation of the endoscopist to the new position of the duodenal papilla; gastric and intestinal distension that make the subsequent laparoscopic procedure more difficult; and easy loss of air. It is important to emphasize that the majority of complications related to the endoscopic management of CBD stones comes from papillotomy. Therefore, its selective indication, as in the cases that required a drainage procedure, would be advantageous.

With the advent of laparoscopic CBD exploration in conjunction with laparoscopic cholecystectomy, a new treatment choice was available.[4–10] The advantages observed are: treatment in a single procedure, a minimally invasive technique, use of papillotomy limited to special situations, short hospital stay, and fast return to previous activities. There was a success rate around 90%, morbidity of 4%, and mortality around 1%. The transcystic approach was chosen as the first and principal way of access by the majority of authors, while choledochotomy was reserved for cases in which removal of stones was not possible through the cystic duct or when the cystic duct catheterization was not possible. However, a drainage procedure was required in some patients with multiple stones, as well as those with stones proximal to the cystic duct, in some cases after fragmentation with mechanical or electrohydraulic lithotripsy, in patients with a large CBD, and in suspected cases of papillary stenosis. Laparoscopic antegrade sphincterotomy was successfully performed in all of the patients. The transcystic approach was used in 96% of the patients, through a choledochotomy in 4% of them. Insertion of the duodenoscope was carried out by the surgeon himself, with the first assistant keeping the papillotome in place, and it was used only for monitoring the papillotomy. Since selective catheterization of the CBD is not required as in the retrograde approach, the antegrade cannulation is technically easier, especially when the patient is in the supine position. So, it is reasonable to believe that a high success rate can be achieved with a possibly lower incidence of pancreatitis. Of the 23 patients who underwent this procedure, 2 of them had hyperamylasemia without clinical evidence of pancreatitis, and there was one case of hemorrhage with a subsequent drop in the hematocrit, but transfusion was not required. The additional time spent on surgery averaged 18 minutes, and the hospital stay was very much like that of patients who had undergone laparoscopic cholecystectomy with CBD exploration.

So, we now advocate the laparoscopic approach to patients with an intraoperative diagnosis of choledocholithiasis; in those with suspected preoperative diagnosis of CBD stones; and in patients with residual CBD stones after unsuccessful endoscopic therapy. Contraindications include: patients with acute cholangitis, acute biliary pancreatitis, intrahepatic lithiasis, and patients with residual or recurrent CBD stones. It appears that laparoscopic antegrade sphincterotomy is necessary for some patients. Thus, with selective indications, it was successfully used in all of the cases, being associated with a low incidence of complications. Intraoperative ERCP has been performed in some patients. Recently there was a case of a patient with an 8-mm CBD stone, a cystic duct entering adjacent to the papilla, in whom the transcystic approach was not possible. In conclusion, intraoperative ERCP, laparoscopic CBD exploration, and laparoscopic antegrade sphincterotomy provide new alternatives for the management of CBD stones, and might provide, when selectively used, lower morbidity and mortality rates.

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12.4 Laparoscopic Management of Common Bile Duct Calculi

Edward H. Phillips

The treatment of common bile duct calculi was relatively straight forward, prior to the adoption of laparoscopic cholecystectomy as the standard treatment for patients with symptomatic cholelithiasis. Prior to the laparoscopic era, patients suspected of harboring common bile duct stones underwent intraoperative cholangiography. If common bile duct calculi were discovered, the bile duct was opened and the stones retrieved. Only elderly, critically ill patients were considered candidates for preoperative endoscopic sphincterotomy. The only difficult clinical decision involved deciding which patients were elderly or sick enough to benefit from preoperative sphincterotomy.

The introduction of therapeutic laparoscopy altered the surgical approach to patients undergoing cholecystectomy. In order to avoid opening patients, preoperative diagnostic endoscopic retrograde cholangiopancreatography became the standard for patients suspected of having choledocholithiasis. Postoperative endoscopic sphincterotomy became the preferred approach to treating common duct stones encountered at surgery or discovered afterwards. Unfortunately, the step forward in the treatment of symptomatic cholelithiasis was accompanied by a step backwards in the treatment of choledocholithiasis.

In an effort to treat patients with common duct stones in one session and avoid the potential complications of endoscopic sphincterotomy, especially in younger patients with small common bile ducts, several laparoscopic techniques of transcystic duct common bile duct exploration were developed. With the development of laparoscopic suturing skills, laparoscopic choledochotomy also became feasible. These techniques and when to apply them will be the subject of this chapter.

Routine Versus Selective Cholangiography

Since Mirizzi recommended routine intraoperative cholangiography in 1934,[1] the controversy of selective versus routine intraoperative cholangiography has continued. Lacking prospective randomized trials, this controversial issue remains unresolved. Most surgeons fortunate enough to have fluoroscopic cholangiographic units in their operating rooms perform routine cholangiography. Therefore, one must conclude that despite all the arguments[2] regarding the severity, incidence, and immediate recognition of common bile duct injuries, and the diagnosis of unsuspected common bile duct calculi, surgeon convenience is a major factor in its use. Nearly all surgeons agree that intraoperative cholangiography significantly decreases the incidence of negative common bile duct exploration. However, most surgeons do not appreciate the inaccuracy of the preoperative prediction of common bile duct calculi.

Most surgeons agree that retained common bile duct calculi postcholecystectomy are most safely treated with endoscopic sphincterotomy. What is not universally appreciated is that intraoperative cholangiography can obviate not only the need for postcholecystectomy endoscopic sphincterotomy, but also diagnostic endoscopic cholangiography in patients with abdominal pain (1 to 3.4% of patients). With the development of transcystic duct endoscopy and calculi retrieval, it is more important than ever to identify patients with common bile duct calculi at the time of laparoscopic cholecystectomy. Patients with unsuspected choledocholithiasis (4% of patients undergoing laparoscopic cholecystectomy)[3,4] are the easiest patients in which to learn the technique of transcystic duct biliary endoscopy. In fact, performing transcystic duct endoscopy and wire basket stone retrieval is recommended during "open" common bile duct exploration first, before applying the technique laparoscopically.

Transcystic Duct Common Bile Duct Exploration

Most techniques involve the dilation of the cystic duct with balloon dilators or sequential graduated bougies to access the common bile duct. Biliary flexible endoscopy, balloon trolling of the common bile duct, fluoroscopically guided wire basket stone retrieval, ampullary balloon dilation with lavage and transcystic endoscopically assisted sphincterotomy are all techniques that can be laparoscopically employed via the cystic duct.

The most commonly employed is flexible biliary endoscopy with wire basket retrieval of calculi. This technique appears to be the safest technique because stone capture and manipulation is performed under direct vision without manipulation of the ampullae. This technique is feasible in 80 to 90% of cases.[5] One limitation is that the endoscope can only be passed into the proximal bile ducts in approximately 10% of cases.[6] Multiple stones, small fragile cystic ducts, and stones proximal to the cystic duct–common duct junction usually must be dealt with by choledochotomy.

Technique of Laparoscopic Transcystic Duct Common Duct Exploration

After review of the intraoperative cholangiogram, a strategy for treatment of choledocholithiasis should take into account the patient's age and medical condition. If the location of the stones and the patient's condition permits, the cystic duct should be bluntly and carefully dissected down close to the common duct. It is often necessary to make an incision in the larger portion of the cystic duct closer to the common duct so that less duct requires dilation. The location of the incision should allow an adequate stump for closure with an Endoloop (Ethicon, Cincinnati) at the end of the procedure. This maneuver increases the success of the procedure. A #5 Phantom balloon dilating catheter (Microvasive, Boston), which has a balloon that is 4-cm long and 6 mm in diameter, is preloaded with a 0.35-in., 150-cm long hydrophilic guidewire. The assemblage is inserted via a 5-mm trocar in the anterior axillary line just under the costal margin. Depending on the laparoscopic cholecystectomy technique employed, it may be necessary to add an additional 5-mm trocar in a better location to intubate the cystic duct. After x-ray or fluoroscopic confirmation of the guide wire location, the balloon dilating catheters or sequential bougies are inserted over the guidewire. Two-thirds of the balloon should be inserted. The balloon is then slowly inflated with a LeVeen syringe attached to a pressure gauge. The balloon and cystic duct are observed laparoscopically as the assistant or nurse slowly inflates the balloon as the pressures are read aloud. The balloon should be inflated to the insufflation pressure recommended by the manufacturer (usually 12 atm) (Figure 12.4.1). If the cystic duct begins to tear, stop inflation and wait three minutes before attempting further inflation. With patience, most cystic ducts can be dilated to 7 mm, but they should never be dilated larger than the inner diameter of the common bile duct. When exploring a small common duct, care must be taken to choose the proper diameter-dilating balloon based on the intraoperative cholangiogram.

The cystic duct should be dilated to the size of the largest stone so the stone entrapped in the wire basket does not get impacted on removal. Stones larger than 1 cm have to be fragmented with a dye pulse laser or electrohydraulic lithotripsy, or they have to be removed via choledochotomy. After the duct is dilated, the balloon catheter is deflated and withdrawn. The endoscope can be inserted over the guidewire if it is 150 cm long, or the endoscope can be inserted freehand or gently guided with an atraumatic instrument. The working channel of some endoscopes is eccentric to its cross section, making insertion over the guidewire difficult.

The endoscope should have bidirectional deflection and a working channel of at least 1.2 mm. An outer diameter of 2.7 to 3.2 mm is ideal. Smaller scopes compro-

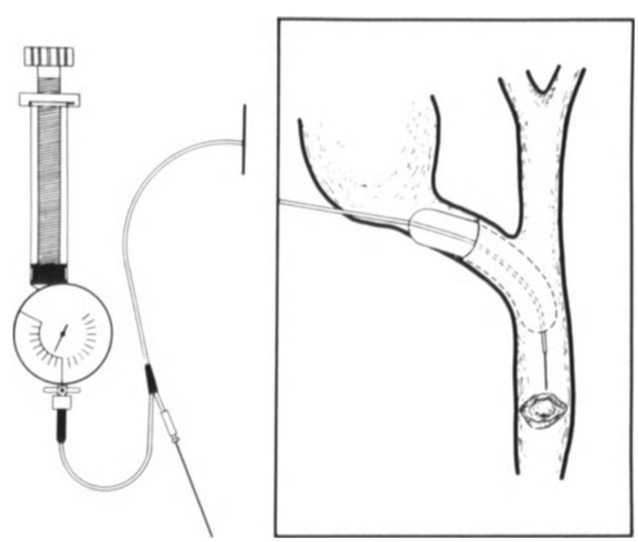

FIGURE 12.4.1. Balloon catheter in place in the cystic duct, inflated to 12 atm. One-third of the balloon is visible outside the incision in the cystic duct. (Illustration by Gino J. Hasler.)

mise the working channel and larger scopes are more difficult to pass. A camera should be attached and the image should be projected on the monitor with an A-V mixer (picture in picture), or it should be projected on its own monitor. It is convenient to set up a mobile cart with a monitor, light source, camera box, video recorder, endoscopes, wire baskets, balloon dilating catheters, and other instruments needed for a laparoscopic common bile duct exploration. This cart can function as an emergency cart and a backup cart for other laparoscopic procedures. Having all the required instruments in one place decreases the frustration and delays when common duct calculi are encountered.

Once the endoscope is in the cystic duct, irrigation with warm saline should be initiated. Attention must be paid to the temperature of the irrigation, as it is not uncommon to have 3 to 6 L instilled by the end of the procedure. The operating surgeon manipulates the scope, inserting and torquing with his or her left hand and deflecting the end of the scope with his or her right hand on the deflecting lever. Grasping the scope with a grasper can damage it.

Once a stone is seen it should be removed. Always entrap the stone closest to the scope, and do not bypass any, as they may irrigate up into the liver. A straight four-wire basket (2.4F) is preferable. The closed basket should be advanced beyond the stone, opened, and then pulled back to entrap it. The basket should be closed gently, and the basket and stone should be pulled up against the end of the endoscope so that they can be withdrawn in unison (Figure 12.4.2). This process is repeated until all the stones are removed. A completion cholangiogram is essential.

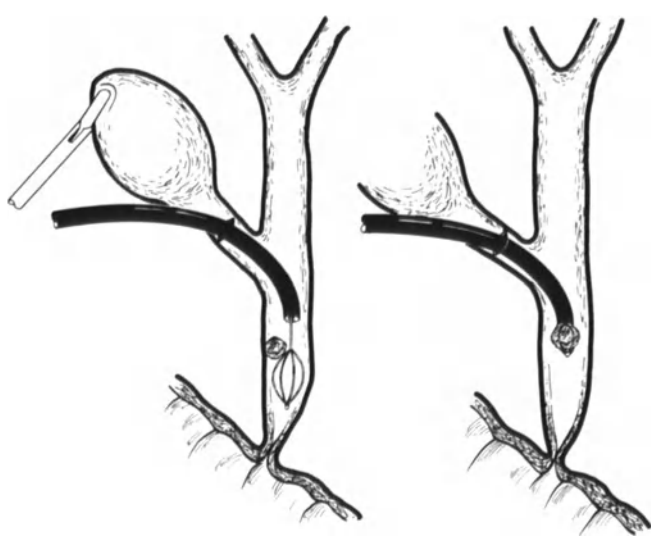

FIGURE 12.4.2. Endoloop closure of cystic duct, and rubber drainage tube in cystic duct sump, held in place with two Endoloops. (Illustration by Gino J. Hasler.)

At this point a decision regarding cystic duct tube drainage must be made. Elderly or immunosuppressed patients with cholangitis should have a latex tube placed for postoperative decompression of their biliary system. Patients with a likelihood of harboring a retained stone should have one placed for postoperative cholangiography and, if necessary, percutaneous tube tract stone extraction. If the pre-exploration, intraoperative cholangiogram shows a different number of common duct stones than found on endoscopy, a tube should be placed.[7]

Fluoroscopic Wire Basket Stone Retrieval

Fluoroscopic wire basket stone retrieval is feasible if fluoroscopy is available. Special spiral wire baskets with flexible leaders must be used to avoid injuring the common bile duct. The basket is placed into the common duct via the cystic duct. It is advanced under x-ray guidance into the lower common duct or duodenum and opened.[8] Then it is pulled back until the stone is captured. The advantage of not having to dilate the cystic duct is offset by the problem of extracting the wire basket and stone through the nondilated cystic duct. In our experience, this technique is not as successful as other transcystic duct techniques, but it can occasionally be of help (Figure 12.4.3).

Biliary Balloon Catheter Stone Retrieval

This technique is occasionally helpful, especially in cases of a dilated cystic duct. A biliary balloon catheter can be passed blindly or under fluoroscopic control via the cystic duct into the duodenum. The balloon is inflated and then the catheter is gently withdrawn, modulating the pressure on the balloon. The drawback to this technique is the risk of pulling the stone into the common hepatic duct, out of reach of an endoscope.

Ampullary Balloon Dilation

This controversial technique can be employed when the cystic duct is extremely small and an endoscope cannot be inserted. 1 mg glucagon is administered intravenously. A specific size balloon dilating catheter, appropriate for the inner diameter of the common duct is chosen. A hydrophilic guidewire is inserted in its lumen. The assemblage is inserted via the subcostal trocar and the guidewire is advanced into the duodenum via the cystic duct. The balloon catheter is advanced under fluoroscopic

FIGURE 12.4.3. Fluoroscopic transcystic basket retrieval of common bile duct stone. (Illustration by Gino J. Hasler.)

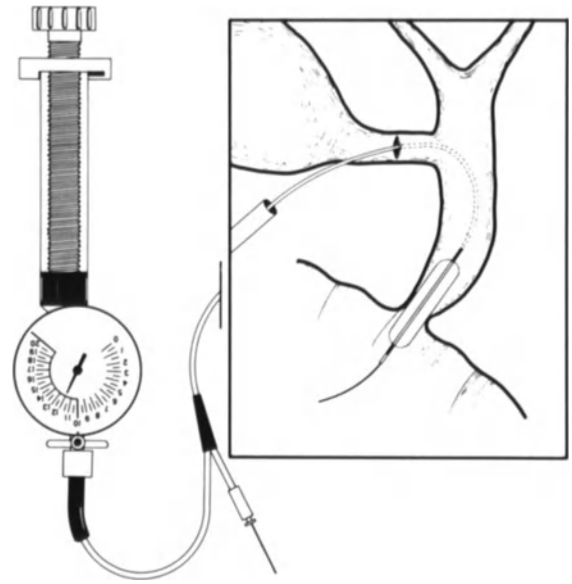

FIGURE 12.4.4. Technique of fluoroscopically guided transcystic duct ampullary balloon dilation. (Illustration by Gino J. Hasler.)

guidance so that the balloon x-ray markers span the sphincter. The balloon is inflated to the manufacturer's recommended pressure with a LeVeen syringe attached to a pressure gauge (Figure 12.4.4). Hypaque 25% is used to inflate the balloon so that the balloon is visible on fluoroscopy. The balloon is left inflated for three minutes, and then deflated and withdrawn. A large bore catheter or the dilating balloon catheter is placed in the cystic duct, and warmed saline is used to forcibly flush the common duct, using a pump or high-flow irrigators. A completion cholangiogram is mandatory.

Phillips and Carroll reported on 20 cases. Small common duct stones and stone debris have been successfully lavaged into the duodenum in 17 of 20 cases (85%) by this method. Postoperative hyperamylasemia was noted in four patients. Mild clinical pancreatitis was observed in three patients (15%). Appel presented 16 cases without complications.[9] Still, this technique should be attempted only when the alternative is endoscopic sphincterotomy or choledochotomy (in a small common duct).

Laparoscopic Choledochotomy

Laparoscopic choledochotomy is an excellent approach to patients with stones 1 cm or larger, multiple stones, or in patients that require lithotripsy for impacted stones. It is contraindicated in small ducts because of the risk of stricture. The advantage of choledochotomy is that stones can easily be irrigated out of the common duct and an endoscope can be inserted up into the intrahepatic ducts. A larger diameter (8 mm) choledochoscope can be used with better optics and a larger working channel that accommodates larger and less delicate wire baskets. Another advantage of the technique is that a T-tube is placed, which decompresses the duct, and provides access for cholangiography and stone retrieval. The disadvantage of choledochotomy is that a T-tube is required, and considerable laparoscopic suturing skill is needed to close the choledochotomy.

Some surgeons perform laparoscopic choledochotomy as their primary approach to common duct calculi. Cuschieri[10] has performed 40 cases, and Franklin[11] has performed 53 cases. Their morbidity has been 10 and 5%, respectively. Their mortality has been 0 and 2%, respectively. They have not experienced retained stones to date. The procedure is performed before the gallbladder is removed, so that it can be used to elevate the liver and apply tension to the cystic duct. The anterior wall of the common duct is bluntly dissected. Occasionally it is necessary to aspirate bile to confirm the identity of the structure suspected to be the common duct. Two stay sutures should be placed in the common duct, and its anterior wall tented before an incision is made with a micro-scissor. The choledochotomy should only be made as long as the circumference of the largest stone, so as to minimize the suturing required for closure. The most efficient technique is to insert a choledochoscope into the duct and irrigate with warm saline. A biliary balloon catheter or wire baskets can be used to remove the calculi in most cases. Occasionally a three-prong grasper or biliary lithotripsy is necessary to remove an impacted stone.

Dye pulse laser energy is the safest technique of lithotripsy, but electrohydraulic lithotripsy can be used safely if it is performed carefully under direct vision.[12] If a larger endoscope is used, baskets with a central lumen for the probe can be employed with increased safety, but usually the basket cannot encircle the stone, as lithotripsy is usually performed when the stone is impacted. After the common bile duct is cleared, a decision must be made regarding the necessity of a drainage procedure. This can be done laparoscopically by performing a choledochoduodenostomy, Roux-en-Y choledochojejunostomy, or a postoperative or intraoperative facilitated endoscopic sphincterotomy. If a drainage procedure is not needed, a latex T-tube must be inserted entirely intracorporeally to avoid CO_2 loss and allow easier manipulation of the tube. The "T" end should be inserted into the common bile duct as close to the duodenum as possible, and a suture placed there to keep it in place. The next suture should be placed in the most proximal end of the choledochotomy, and the two sutures lifted to facilitate the closure of the choledochotomy. The author's preference is to close the choledochotomy with interrupted sutures of Vicryl (Ethicon, Summerville). The long end of the T-tube is then brought through the abdominal wall, and a completion cholangiogram is performed.

Intraoperative Laparoscopically Facilitated Endoscopic Sphincterotomy

There are two major drawbacks to intraoperative endoscopic sphincterotomy. One is the logistical problem of marshalling all the equipment and personnel necessary to perform the procedure, and the other is that the patient is in the supine position on the operating table when most surgeons and gastroenterologists are familiar with performing the procedure in the prone position, with instruments designed for that angle. The intraoperative technique that seems most feasible is to place the papillotome through the cystic duct into the common duct, and then position it with visual guidance from a video duodenoscope inserted through the patient's mouth.[13] This technique should not replace transcystic biliary endoscopy in the majority of cases, because the risks of sphincterotomy are greater than those associated with biliary endoscopy and stone retrieval (they do not require manipulation of the sphincter). Nevertheless, laparoscopically guided sphincterotomy may be indicated when a drainage procedure should be performed. Randomized studies on the comparative safety of laparoscopic drainage procedures, open drainage procedures, laparoscopically facilitated ampullary balloon dilation of the sphincter, and perioperative endoscopic sphincterotomy need to be carried out.

Preoperative Endoscopic Sphincterotomy

Many reports, including the NIH consensus conference on laparoscopic cholecystectomy,[14] advocate preoperative endoscopic retrograde cholangiopancreatography. Unfortunately, the two largest randomized prospective studies performed in the prelaparoscopic era found no benefit to preceding cholecystectomy with endoscopic sphincterotomy.[15,16] In fact, Donovan and Stain found preoperative endoscopic sphincterotomy to significantly increase morbidity and cost in those who require cholecystectomy. One of the major drawbacks to preoperative diagnostic endoscopic retrograde cholangiopancreatography is that the prediction of common bile duct calculi is so imprecise (Table 12.4.1). The cost and morbidity of performing unnecessary studies on 40 to 70% of patients undergoing laparoscopic cholecystectomy is enough to overcome the morbidity of even "open" common bile duct exploration.

Intravenous cholangiography on more modern tomographic x-ray equipment has been advocated in Europe and by Salky in New York.[17] However, this is a costly preoperative test for all patients undergoing laparoscopic cholecystectomy. If it is performed on only those suspected of harboring common bile duct calculi and scheduled for preoperative endoscopic cholangiography, it might be of benefit. However, allergic reactions and the morbidity of diagnostic and therapeutic endoscopic sphincterotomy should be studied and compared to routine and selective intraoperative cholangiography.

The morbidity and mortality of diagnostic endoscopic retrograde cholangiography is relatively low—morbidity 5 to 10%, and mortality is 0. Still, patients do not respond well to complications when the study is negative and, therefore, in their mind unnecessary. Therapeutic endoscopic sphincterotomy, on the other hand, has a 10% morbidity and a 1% mortality, which is not age-related. Failure rates vary based on expertise, but range from 5 to 10%. Postprocedure stricture also can occur in a moderate number of patients, about 5%.[18]

TABLE 12.4.1. Incidence of specific liver function test abnormalities and prediction of common bile duct stones (CBDS) (n = 727).

Abnormality	Number	%	CBDS	%
Alk.ptase	35	5	12	34
SGOT/PT	32	4	5	16
Alk + SGOT/PT	31	4	13	42
Alk + SGOT/PT + bili	22	3	12	55
Bilirubin	19	3	4	21
Bili + SGOT/PT	13	2	5	38

These results have to be compared with the results of "open" common bile duct exploration and laparoscopic bile duct exploration. Morgenstern reported on 220 common bile duct explorations in the immediate pre-laparoscopic era. There was no mortality under age 60, and 4.1% over age 60. In the author's combined experience of 104 laparoscopic common bile duct explorations, there has been no mortality under age 65 and one death in 45 patients over 65 (2%). These statistics include the added mortality of laparoscopic cholecystectomy, and suggest laparoscopic common bile duct exploration is safer than "open" common duct exploration in patients over 60. This suggests that endoscopic sphincterotomy should not be performed in patients under age 60 to 65, even if it means performing "open" common bile duct exploration. In patients over age 60, the results of laparoscopic common bile duct exploration and endoscopic sphincterotomy are probably equivalent. The decision to perform postoperative endoscopic sphincterotomy or laparoscopic common duct exploration must be individualized, based on local expertise.

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12.5 Laparoscopic Choledochotomy for Management of Common Bile Duct Stones and Other Common Bile Duct Diseases

Morris E. Franklin, Jr.

With the advent of laparoscopic cholecystectomy and its wide acceptance by many surgeons, the problem of managing choledocholithiasis has taken on a new perspective.[1–5] After the first open cholecystectomy was performed in 1862, the necessity for tailoring a surgical approach to stones in the common bile duct became apparent. The standard treatment of common bile duct stones has been an open choledochotomy, followed by the placement of a T-tube and drainage for postoperative decompression of the common bile duct while healing occurs.[6–9] Laparoscopic cholecystectomy has compromised this technique to some extent because many surgeons cannot perform laparoscopic suturing. Other approaches to choledocholithiasis and diseases of the common bile duct include routine endoscopic retrograde cholangiopancreatography (ERCP) and a transcystic approach to common bile duct exploration.[10–17,19–25] While these methods certainly have merit, sometimes opening the common bile duct for diagnosis or definitive treatment of a given common bile duct disease is necessary.[26]

With our experience in laparoscopic cholecystectomy, and the favorable results obtained with open cholecystectomy, a laparoscopic approach to common bile duct disease has been to first obtain a cholangiogram on most of our patients. This is followed by a laparoscopic choledochotomy, with formal common bile duct exploration or bypass, if necessary. This is extremely effective, and is an acceptable technique in most of our patients with benign common bile duct disease. This method is also invaluable in evaluating other causes of common bile duct obstructions, as well as the first step in a bypass procedure.

Historical Review

The efficacy and safety of open common bile duct exploration with or without T-tube placement, and with or without a bypass procedure has been understood for many years. The overall low mortality rate of this approach has remained at 0.03% for uncomplicated common bile duct explorations.[27,28] The open technique has been well accepted for many years by both surgeons and internists. However, in the last four years, with the tremendous advances in laparoscopic surgery this has been challenged.[29] Because of inadequate skills in suturing and lack of experience, most surgeons have chosen to avoid a laparoscopic approach to common bile duct disease. Rather they have chosen to rely on pre- or postoperative ERCP, depending on the situation.[30,31] Extreme cases, where ERCP cannot be done, have been approached almost universally (with the exception of a few investigators worldwide) by an open procedure. Experience and innovative laparoscopic techniques have demonstrated that perhaps there is an alternative to routinely opening the patient for known, suspected, or even unsuspected common bile duct stones.[32]

Since mid-1990, our standard approach to common bile duct stones has been that of a laparoscopic choledochotomy. It closely mimics the open procedure. This has resulted in an extremely high rate of successful completion of the procedure, with placement of a T-tube and no evidence of retained stones or later sequelae. The laparoscopic approach as a compliment to laparoscopic cholecystectomy has been acceptable to both patients and gastroenterologists. Gastroenterologists now refer difficult cases to us, particularly those cases with difficult ERCP or very large impacted stones.[26] The investigators in our series feel that laparoscopic choledochotomy accomplishes the same thing as open procedures, although technically more difficult, more demanding, and certainly mandating laparoscopic suturing skills. With patience, this approach can be mastered by any laparoscopic surgeon willing to invest the time, energy, and effort. The technique is based primarily upon well-established open techniques, and merely transfers these to closed procedures. The result is improved patient well-being.[33,34]

Laparoscopic Techniques

While there are definite indications for preoperative ERCP, we have avoided it in most patients.[31,32,35,36] Patients suspected of having common bile duct disease that is probably choledocholithiasis are no longer subjected to the high incidence of complications (15 to 20%) and the established mortality rate (1%) associated with ERCP/endoscopic spincterotomy (ES). Instead, they routinely undergo laparoscopic cholecystectomy and intraoperative cholangiography, followed by a laparoscopic common bile duct exploration, if needed.[31,32,35–39] In this way, we have totally avoided the very high incidence of negative ERCP for suspected but unproven choledocholithiasis. We have also treated many patients who have undergone ERCP and were referred to us when stones were demonstrated but could not be removed by sphincterotomy and basket extraction. These patients, as well as those patients with a difficult approach to the sphincter (patients with prior gastric surgery, a difficult sphincter-cannulation, or a sphincter sitting high in a duodenum diverticulum), have all undergone successful laparoscopic choledochotomy for removal of their stones, or a bypass procedure.

One advantage of a laparoscopic choledochotomy for exploration of the common bile duct is that it can easily be converted to choledochoduodenotomy or another bypass procedure, if necessary. A choledochoduodenostomy should be performed laparoscopically as in an open procedure, using an internal layer of 4–0 Vicryl on the mucosal layer, and having an outer layer of 3–0 silk seromuscular sutures. We utilize the existing vertical incision in the common bile duct, make a longitudinal incision in the duodenum, and begin the suturing process near the distal portion of the choledochotomy and the medial portion of the duodenostomy. With the open procedure, we begin distally and laterally, and work proximally, tying a knot at the apex of the choledochostomy. We then complete the anastomosis medially, suturing from distal to proximal, on the medial side of the choledochotomy. It is helpful in these procedures to insert an additional port in the left upper quadrant, and place the 0° camera in the subxiphoid port, using the umbilical port, as well as the left upper quadrant ports, for suturing. Using needle holders in both hands is extremely helpful and greatly speeds the procedure.[26,39]

Laparoscopic choledochotomy for treatment of benign common bile duct disease, in particular common bile duct stones, very closely parallels, and is a continuation of, laparoscopic cholecystectomy.[1,5,23] Four ports are used and the patient is in the supine position. Ready access to a C-arm and a fluoroscopy table is very helpful for this type of procedure, although it can be performed with standard x-ray equipment and still film technology. However, the C-arm and intraoperative fluoroscopy are invaluable aids for expediting the procedure and allowing more rapid completion of a successful common bile duct exploration. The standard trocars are used, and the laparoscope is inserted through the umbilicus using either a 0 or a 30° scope. We routinely use a 0° scope but have a 30° scope available for difficult angles or patients with a large omentum. The standard subxiphoid port is also used, although we try hard to stay completely to the right of the falciform ligament during placement of this trocar. This facilitates manipulation of the choledochoscope. Standard working subcostal midclavicular anterior axillary line, and lateral umbilical ports are used for retraction.[3,6] In the case of extremely obese patients, or very severely inflamed tissue, an additional port is often placed in the left upper quadrant at approximately the midclavicular line, just above the level of the umbilicus. This is done purely for retraction.

An operative cholangiogram is attempted in all of our patients, utilizing a guidewire and catheter technique. A small incision is made in the cystic duct after the cystic duct has been very clearly isolated and identified, followed by placement of a guidewire. The guidewire usually falls directly into the common bile duct. The surgeon then slips a cholangiogram catheter over the guidewire. Access to the common bile duct is obtained most of the time. No clips are applied, as the catheter is frequently inserted in the duodenum. Pulling the catheter back while injecting contrast material results in instant visualization, with the entire common bile duct becoming immediately visible. We have been successful with this method 99% of the time and continue to use it.[39] We are aware of several other techniques for cholangiography and endorse utilization of other techniques that will deliver the needed information. We feel very strongly that a road map to the biliary duct system is mandatory for successful completion of laparoscopic common bile duct exploration and improves the margin of safety for laparoscopic cholecystectomy.

After completion of the cholangiogram, the cystic duct is doubly clipped, and the common bile duct is exposed by incising the peritoneum which overlies the common bile duct.[26,39] In extremely obese patients, this can be a somewhat tedious procedure and there can be a moderate amount of bleeding. Slow dissection with meticulous use of smaller clips and pinpoint low-voltage coagulation can adequately control any bleeding. A 1- to 2-cm margin on the anterior surface of the common bile duct is exposed and a vertical incision is made in the common bile duct. We have chosen not to use stay sutures, although this is certainly an acceptable method of securing the common bile duct for a given patient. We have found, however, that merely grasping the cystic duct and elevating it results in adequate visualization of the anterior surface of the common bile duct and allows ready access to a vertically placed incision. The location of the incision is dependent on the patient's anatomy and the exact junction of the cystic duct into the common duct system. We do not routinely try to avoid going above or below this junction, although in most cases going below the junction is advantageous since the common bile duct is larger in this location. This dissection may be extremely difficult laparoscopically, however, and is not always undertaken. If a choledochoduodenostomy is anticipated, then a lower incision is preferable. The operating surgeon should use the instrument he or she is most familiar with to make the incision. We have used several techniques including KTP (potassium titanyl phosphate) laser, standard scissors, and laparoscopic knives, but routinely use micro-scissors for the initial incision into the common bile duct, followed by expansion of this incision. We initially make the incision no larger than 3.5 to 4.5 mm to afford a tight fit around a 10.5F (3.3 mm) flexible choledochoscope. Obviously, larger or smaller choledochoscopes can be used, depending on the availability in a given operating room and hospital and the pathology involved.

After completion of a choledochotomy where numerous stones are present, direct visualization is possible, and stones can be removed from the common duct on an individual basis, or by irrigation, using an irrigating catheter. We have used this highly successful technique when patients have 10 or more stones. If a solitary stone is present, or common bile duct visualization is needed prior to removal of stones, the choledochoscope is introduced from the subxiphoid port through an endoloop guide for protection of the flexible choledochoscope. This guide is brought down within approximately 3 cm of the common bile duct, and the scope is protruded through the end of the endoloop guide. A scope that will flex in two directions is much better than a unidirectional flexing scope because greater maneuverability inside the abdominal cavity as well as in the duct is possible. We routinely explore the proximal portion of the common bile duct initially, and feel that irrigation during the exploration is mandatory to successful exploration. This can be done with normal saline infused under pressure with a blood administration pack or through a pump device such as a Uromat (Storz, Los Angeles, CA). Irrigation devices with pressure greater than gravity seem to be advantageous and can result in better visualization of the ductal system. The scope is passed proximally, and the bifurcation can be visualized.

In several instances, stones impacted in this area have been easily removed using standard basket or irrigation techniques. After clearance of the proximal ductal system, the scope is passed distally, where at least 70% of the stones are located. The stones are individually identified and removed with a basket or a grasper-type device. Frequently a Fogarty catheter (American Edwards Labs, Anasco, PR) has been used as well to mobilize stones that are impacted. If the surgeon is particularly familiar with this technique, it can be used in lieu of a choledochoscope. The baskets used for passage through the choledochoscope are primarily those of 1 mm or less (3 to 4F), and require some degree of practice by the operating surgeon. Both three- and four-wire or grasper-type baskets have been used and each has its own individual characteristics and usefulness in removing certain stones. Impacted stones present a particularly difficult problem and can be removed by using a Fogarty catheter, or utilization of a pulsed dye laser to fracture stones or loosen them from an impacted state. Extremely large, impacted stones can be very readily removed with the use of a Candela-type pulsed dye laser (Candela Inc, Boston, MA) if available. The high cost of these lasers prohibits their routine use in every operating room.

After all stones have been removed, the sphincter can be readily visualized in 90% of cases and in approximately 20 to 25% of the cases, the choledochoscope can be passed directly into the duodenum in order to perform duodenoscopy. If a given sphincter shows up on the cholangiogram as extremely tight, and does not allow passage of the dye, a wire guide can be passed through the sphincter. This can be followed by an angioplasty-type balloon that is then insufflated for gentle dilation. A laparoscopic antegrade sphincterotomy can also be performed.[40] Clearance of the common bile duct with the choledochoscope may require numerous passages of the choledochoscope and the basket. Individual stones can be placed in a secure location in the abdominal cavity utilizing a bag, or placed on a convenient portion of the omentum for subsequent removal. A second intraoperative cholangiogram is taken through the choledochoscope to ensure that the distal portion of the common bile duct is clear. If the duct is clear and dye flows into the duodenum, the scope is withdrawn and preparations are made for placement of a T-tube. We use smaller T-tubes as they are much easier to manipulate within the closed peritoneal cavity. The size most commonly used is an 8 to 10F, although we have placed a 12 or 14F in the case of an extremely large bile duct, where there was concern for retained stones. The T-tube is shown in Figure 12.5.1. It is tailored for easy placement into the common bile duct. The long limb can be introduced distally or proximally, depending on the preference of the surgeon. The rest of the choledochotomy is then closed with individual sutures. We prefer to close the choledochotomy with interrupted 4–0 Vicryl sutures, although a running suture can also be used. To suture the T-tube into the common bile duct, we have developed a special knot that allows initial slippage and rapid subsequent placement of a second throw. The use of this knot is outlined in Figures 12.5.2–12.5.5. Unless a very large choledochotomy has been used, two or three sutures are usually all that are needed for closure of the duct. Time required for tying

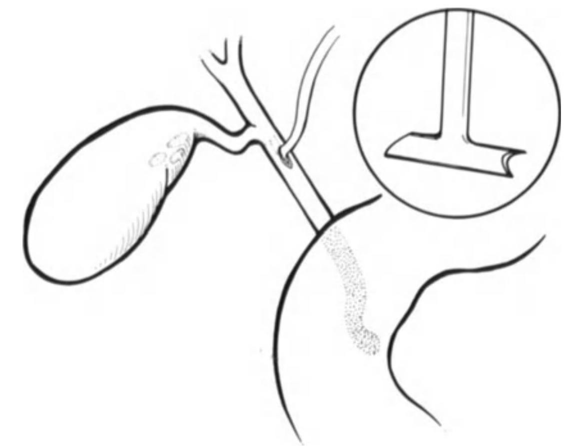

FIGURE 12.5.1. Location of choledochotomy and placement of T-tube. Inset—technique of tailoring T-tube for ease of inserting.

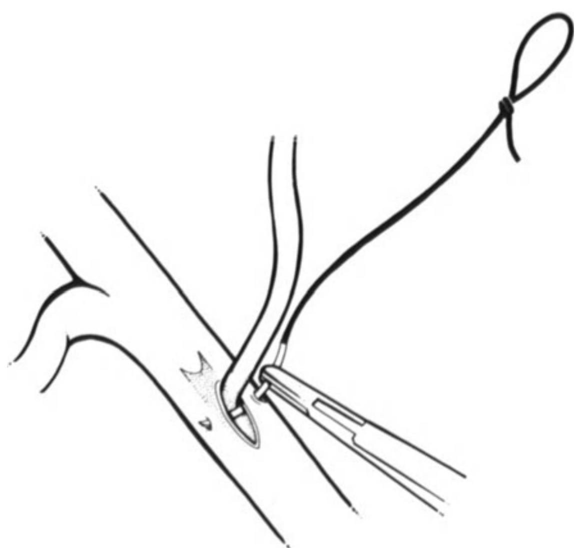

FIGURE 12.5.2. Initial suture through choledochotomy site using pretied slip knot in shortened sutures.

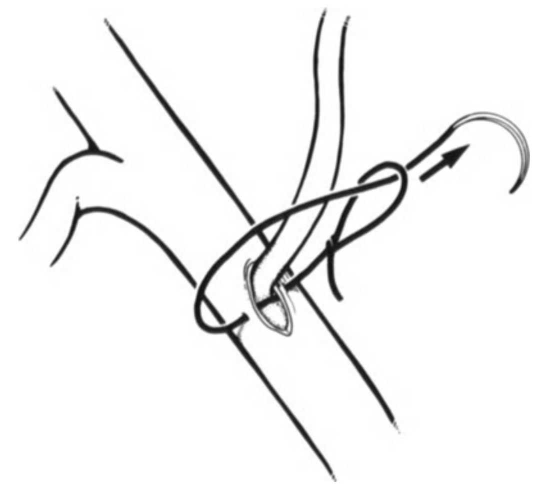

FIGURE 12.5.3. Suture passed back through pretied slip loop.

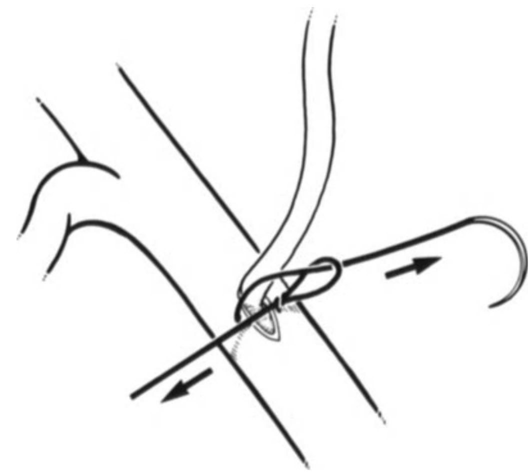

FIGURE 12.5.4. Suture being tightened by traction in opposite directions.

the suture, removal of the excess suture material, and the needle, is about two to three minutes per suture.

After placement of the T-tube, the free portion is brought out through the subcostal trocar and a T-tube cholangiogram is taken. The reason for the cholangiogram is to be sure closure of the choledochotomy is adequate, as well as to find possible residual stones and ensure proper drainage through the sphincter. Upon completion of this portion of the procedure, the T-tube is replaced in the abdominal cavity, the cystic duct is divided, the cystic artery is clipped and divided, and the remainder of the laparoscopic cholecystectomy is performed. If a bag has been used for placement of the common bile duct stones, the gallbladder is placed in the same bag and all are brought out through the umbilical port at the conclusion of the procedure. After bleeding has been controlled in the gallbladder bed, the T-tube is brought out through the subcostal port, sutured into place with 3-0 nylon, and a #10 Jackson-Pratt drain (American Hospital Supply, Chicago, IL) is placed in the gallbladder bed, very near the choledochotomy site. The drain is brought out through the lateral umbilical port and the remainder of the trocar sites are closed.

The primary alternative technique for laparoscopic common bile duct exploration is a transcystic common bile duct exploration. This technique has been well described by other authors including Arregui, Phillips, de Paula, Hunter, and Petelin.[22,40–43] The common duct is approached through the cystic duct with a variety of devices including a Fogarty catheter, wire basket, laser, and choledochoscopy, all with varying degrees of success. The cystic duct is dissected completely to the CBD junction

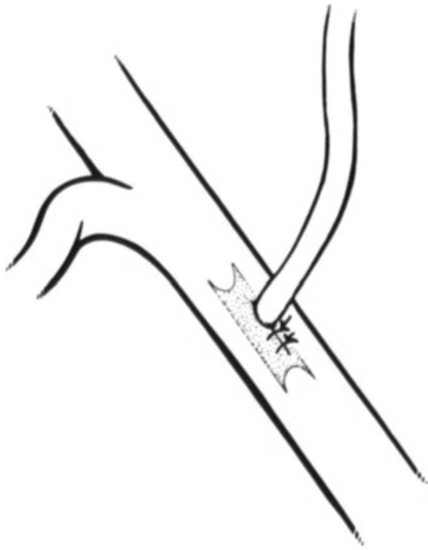

FIGURE 12.5.5. Sutures tied and choledochotomy closed around T-tube.

and then often dilated with a balloon system or with progressive solid dilators until the duct is larger than the largest stone in the common bile duct. Often an incision must be made very near the cystic duct/CBD junction to bypass cystic bile duct valves. The common bile duct exploration is then carried out via the cystic duct, utilizing the above devices in a manner similar to that previously outlined. Frequently, the proximal common bile duct cannot be reached, due to individual variation in the relationship of the cystic duct to the common bile duct. Additionally, large stones and multiple stones are somewhat difficult to handle with this technique. A drainage tube may be left inside the cystic duct. It is secured in place with an endoloop or suture tied intracorporeally. If no drainage tube is utilized, the cystic duct must be ligated but no clips should be used.

Very little specialized equipment is needed for a laparoscopic choledochotomy. However, an operating table that allows fluoroscopy from several different locations on the table is necessary. Fluoroscopy is best accomplished with a C-arm, although dedicated fluoroscopy units can be used. We have found the C-arm to be quite adequate for our purposes. A flexible choledochoscope is mandatory. We feel the choledochoscope should be one that will flex in two directions, as well as have an adequate working channel. The choledochoscope should have a readily adaptable eyepiece for auxiliary monitor viewing. We routinely use a third monitor setup, along with its light source, for common bile duct procedures. A reliable source of irrigation fluid is advantageous. The Uromat is beneficial and convenient for supplying greater than gravity pressure to the irrigation system. Other types of irrigation systems can be used, including the blood-pressure pump-type irrigation system, as well as several other commercially available systems. The choice of baskets for this technique is essentially the same as baskets used by urologists. They have been effective in the majority of our cases. Surgeons must become familiar with the use of these baskets before attempting to use them, as they are fragile as well as expensive. A #4 and 5 Fogarty catheter can also be used for moving stones, and the initial exploration of the duct. Standard T-tubes are available in every operating room as are needle drivers and sutures.

Clinical Results

Since mid-1990, we have approached all of our patients who have common bile duct disease with laparoscopic techniques. During this period of time we have operated on 104 patients with common bile duct stones and have been successful in completing all but two of these procedures laparoscopically. The age range and weights of the patients are outlined in Table 12.5.1. The technique is acceptable for the thin, as well as the morbidly obese, patient. We have utilized the technique in patients with acute cholecystitis as well as in nonacute situations. We have performed intraoperative cholangiography on all of our patients. Our success rate has been extremely high. These results are outlined in Table 12.5.2.

Our patients have presented a variety of clinical problems. As gastroenterologists refer more and more difficult patients, we are finding that this technique has enabled a successful clearance of the common bile duct in every case. The range and size of stones that have been successfully removed with laparoscopic choledochotomy are outlined in Table 12.5.3. Our standard routine for removal of the T-tube is to leave the T-tube in place for 10 days, followed by an operative cholangiogram, and subsequent removal of the T-tube. There have been no

TABLE 12.5.1. Patient profile—choledocholithiasis.

		Average	Range
Age:		53	21–84 years
Weight:		179	110–310 lbs
Sex:	Male:	43 (40.5%)	
	Female:	61 (59.5%)	

TABLE 12.5.2. Laparoscopic intraoperative cholangiography.

Technique	Number	Successful cholangiogram	Satisfactory image
Standard method (Taut catheter)	30	14 (47%)	10 (33%)
Guide wire with C-arm technique	827	823 (99.5%)	823 (99.5%)

TABLE 12.5.3. CBD stone size in relation to method of removal.

Stone size	Number of patients	Method of removal
0.1–0.5 cm	11	Removed with basket or flushed through sphincter
0.51–0.75 cm	19	Removed with basket
0.76–1.0 cm	43*	Removed with basket
1.1–2.0 cm	30	Removed with basket and Fogarty
> 2.0	4	Cholecystocholedocho fistula with impacted stones (removed with aid of pulsed dye laser)

*One patient early in series with impacted stone converted to open procedure.

complications with this technique, save the death of one patient who had a myocardial infarction 24 hours postoperatively. This patient had had jaundice for approximately two months and had refused treatment. Finally, he had a preoperative ERCP where 10 stones were identified and removed with ES. At the time of choledochotomy, 12 remaining stones were removed and the patient did extremely well for 24 hours. It took approximately two hours for the cholecystectomy and common bile duct exploration. Postoperatively, he had a reduction in bilirubin level from 22 to 8 within a short period of time. He had no pre-existing history of cardiac disease, but was being monitored carefully. He was sitting up, eating, and talking with his family approximately 24 hours postoperatively, when he had an onset of chest pain and died instantly from a massive myocardial infarction.

We have had two markedly obese patients who developed postoperative umbilical wound infections, which were successfully treated with local drainage and oral antibiotics. These patients weighed more than 325 lb and had extremely deep umbilicus clefts, as well as severe, acute cholecystitis.

The postoperative hospital course has been remarkably benign on virtually all of our patients, although one patient did pull out the T-tube in the first 30 hours after surgery, after having a grand mal seizure. In this patient the T-tube was left out and an ERCP with stenting of the sphincter was performed. She had successful resolution of the problem without further surgical intervention. To this date, there have been no retained stones, and minimal morbidity, with only transient hyperamalysemia (150 IU units) in 2 out of 104 patients. We have performed a choledochoduodenostomy on 11 patients, and they have all been dismissed from the hospital within 48 to 60 hours of their surgery, depending upon their clinical condition and concurrent medical problems. We have performed no subsequent surgical procedures on any patient, and have had no evidence of stricture or retained common bile duct stones. There have been no incidences of new stones forming. We carefully follow our patients at three-month intervals with liver function tests and have found no evidence of abnormality. Review of the literature reveals that several other physicians are performing this type of surgery and are having similar results.

Comparison to Open Techniques

We have obtained the same results with laparoscopic choledochotomy as with open choledochotomy for treatment of choledocholithiasis and benign common bile duct disease. As mentioned previously, we have had one mortality which was probably not directly related to the surgical procedure, but rather to the patient's pre-existing heart disease and delay in accepting medical treatment. While our mortality rate is less than 1%, we feel that with further experience and with more patients in the series, the mortality rate will drop, as no significant insult, other than laparoscopic cholecystectomy, is being placed on the patient. The most significant difference from the open procedure is a marked reduction in the amount of pain. Other benefits include: improved patient comfort level, marked reduction in analgesic demands, more rapid ambulation with prevention of pulmonary and deep vein thrombosis, lack of wound problems, more rapid discharge from the hospital, more rapid return to full function, and patients prefer minimally invasive surgery over the open techniques because of these benefits.

The disadvantages of laparoscopic choledochotomy compared to the transcystic approach are that:

1. It mandates laparoscopic suturing;
2. It mandates laparoscopic placement of a T-tube or sphincterotomy, or closing of the choledochotomy, both of which are technically demanding;
3. The potential for longer hospitalization is definitely present, although this has not been the case in our series;
4. It requires laparoscopic dissection of the common bile duct;
5. Additional equipment including a flexible choledochoscope, additional monitors, and additional light source with an irrigation system is needed. (However, these are sometimes needed with transcystic exploration.)

The advantages of laparoscopic choledochotomy are:

1. One hundred percent of the time access to the proximal common bile duct as well as the distal common bile duct is possible;
2. No danger of tear or of creating bleeding with dilatation of the cystic duct;
3. All sizes of stones can be approached and successfully removed;
4. Access to the common bile duct is readily available in the postoperative stage should jaundice develop;

5. Retained stones can be readily accessed through a T-tube access port;
6. Conversion to a bypass procedure can be readily accomplished.

Choledocholithiasis and other common bile duct procedures have always been the responsibility of the general surgeon. Laparoscopic surgery has not changed this. Difficulties with advanced technical procedures have for the most part certainly shifted the emphasis for care of patients with common duct stones to the gastroenterologist (or, rarely, surgeon endoscopist) and the modality of ERCP with or without sphincterotomy. However, the complex problems involved in handling common bile duct stones should again be the responsibility of the general surgeon. Equipment and materials are now at hand for the general surgeon who is willing to invest the time, energy, and effort in learning additional laparoscopic skills in order to perform nearly any procedure on the common bile duct that is currently being done open. Certainly, handling of common bile duct stones is no exception to this and training general surgeons in this area should improve care for patients with a multitude of biliary tract diseases.

The efficacy of the open approach to common bile duct stones and to most benign common bile duct disease processes has been well documented. The extension of these principles to laparoscopic surgery is a natural transition. It will be followed by a multitude of new procedures as well as new techniques that will enable the general surgeon to handle these problems with minimally invasive surgical approaches. The low morbidity and mortality associated with laparoscopic cholecystectomy, despite a tremendous learning curve, will, in all likelihood, spill over to procedures involving the common bile duct. Surgeons who are willing to invest the additional time needed to acquire the skills to perform these procedures will benefit their patients. These new procedures are cost effective and safe. Now the task is to improve the skills of a sufficient number of general surgeons so they can perform these procedures in a safe and efficacious manner.

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12.6 Fluoroscopic Transcystic Common Bile Duct Exploration in Laparoscopic Cholecystectomy

Brock M. Bordelon and John G. Hunter

Introduction

Intraoperative cholangiography is an expedient and highly accurate method of detecting common bile duct pathology. Many surgeons feel routine cholangiography is a vital part of laparoscopic cholecystectomy, needed to identify relevant biliary anatomy and prevent bile duct injury.[1,2] When one performs routine cholangiography, common bile duct stones are found in 5 to 10% of patients, depending on whether the surgeon performs preoperative endoscopic retrograde cholangiopancreatography (ERCP) on patients with clinical indicators of choledocholithiasis.[3,4] Even if the most narrow selection criteria are used, *unsuspected* stones will be found in approximately 5% of patients.[5,6] These unsuspected stones are usually quite small, and their passage into the biliary tree generally produces no ductal dilatation. These are the ideal stones to remove using fluoroscopic techniques.

The experience of the senior author (Hunter) with retrograde retrieval of common bile duct stones during ERCP provided the impetus to attempt stone retrieval through the cystic duct at the time of laparoscopic cholecystectomy. Transcystic common bile duct exploration (CBDE) is not a new technique; in fact, it has been advocated for some time as a means of removing small stones from the nondilated common bile duct. Because most surgeons were unfamiliar with guidewire and basketing techniques, transcystic approaches to bile duct stones did not flourish until the advent of laparoscopic cholecystectomy. Fluoroscopic and endoscopic transcystic common duct clearance has since been popularized by surgeons attempting to maintain a minimally invasive approach to choledocholithiasis.[7,8] As compared to endoscopic transcystic bile-duct explorations, which requires a large variety of expensive instruments,[8,9] fluoroscopic exploration requires no more than the C-arm that has been used to perform the cholangiogram, a lead apron, and a stone basket.

Instruments

Digital Fluoroscopic Imaging

Static cholangiography has long been the "gold standard" for intraoperative biliary tree visualization.[10] This technique was immediately adopted for laparoscopic cholecystectomy, because surgeons were familiar with it and every operating room had the necessary equipment.[11,12] However, in the laparoscopic setting, static cholangiography often provides poor-quality images or is impractically slow. The amount of contrast that renders the biliary tree opaque but does not obscure small stones cannot be accurately determined with static films, and trocars, light cables, and graspers may overlie the common duct and obscure the cholangiogram. Intrahepatic duct opacification with the patient in the reverse Trendelenburg position may be inadequate to distinguish stones. Air bubbles and defects of duodenal filling may falsely indicate common duct stones and lead to unnecessary CBDE or ERCP. Static cholangiograms that are suboptimal for any of these reasons may result in missed common duct stones or unwarranted CBDE or ERCP.

Static cholangiography is also time-consuming, with a built-in delay of 5 to 15 minutes between performing and viewing the cholangiograms. If the operation proceeds without the benefit of the cholangiogram, errors in common duct identification may result in common duct injury. If the surgeon divides the cystic duct while waiting to inspect the cholangiograms, the transcystic route for laparoscopic CBDE is lost. Finally, each technical difficulty in obtaining a good-quality static cholangiogram necessitates a further wait while new films are obtained and developed.

A superior alternative is digital fluoroscopic cholangiography, which provides surgeons with immediate, high-quality dynamic images of the biliary tree.[13,14] While any C-arm is generally adequate for the job, the digital processor permits noise elimination, edge enhancement, and image magnification, which together lead to improved stone detection. The images can also be relayed electronically to the radiology suite and simultaneously reviewed by the surgeon and radiologist.

Stone Retrieval Baskets

Another consideration is the design of the fluoroscopic retrieval basket. It is impractical to stock several types of fluoroscopic baskets. In general, the more wires, the better the basket will hold its shape and ensnare the stone. Unfortunately, a large number of wires also prevents large stones from entering the basket. Baskets with fewer than four wires are impractical, and baskets with more than eight wires are simply too bulky.

We have found it best to stock a six-wire helical stone basket, which is appropriate for most small stones. This basket was developed by urologists for removal of ureteral stones at the time of cystoscopy and retrograde ureterograms. The basket has a soft tapered (filiform) tip to avoid perforating the ureter. The soft tapered tip is absolutely essential for performing fluoroscopic basket retrieval because the rather sharp junction of cystic and common bile ducts makes attempts to pass a rigid basket very dangerous. The basket we have had the most success with is a 4F, six-wire helical basket that opens to 11 mm (Figure 12.6.1) (Baxter, V. Meuller, McGaw Park, IL). The advantage of this basket is that the filiform leader is stiff enough to pass through the valves of Heister but not so stiff as to damage the common bile duct. Alternatively, a back-loading helical stone basket (Cook Inc., Bloomington, IN) can be utilized; the basket is passed through a Teflon sheath after the sheath has been passed into the distal bile duct over a guidewire. It is also wise to stock a three- or four-wire Segura-type stone basket (2 to 4F) in case transcystic choledochoscopy is required.

Technique

The first and most important step in successful transcystic CBDE is proper trocar positioning. Common duct access through the cystic duct is facilitated by positioning the mid-subcostal trocar *laterally*—in the anterior axillary line just below the costal margin (Figure 12.6.2).

If cholangiography identifies a filling defect, the surgeon's first job is to convince himself that the filling defect is not an air bubble, polyp, or tumor. A decision must also be made about the adequacy of the cystic duct for stone removal. A narrow, spiralling cystic duct that enters the common duct medially and distally may prevent successful transcystic exploration (Figure 12.6.3).

If the filling defect has the appearance of a stone, the anesthesiologist administers glucagon, 1 mg intravenously, before stone manipulation to decrease the likelihood of sphincter of Oddi spasm with resultant injury or cholangitis. If the stones are small (< 3 mm), an attempt to flush the stones into the duodenum after the glucagon has circulated (1 to 2 minutes) will occasionally dislodge a few of the smaller ones. Caution should be used when contrast is used for irrigation, because the con-

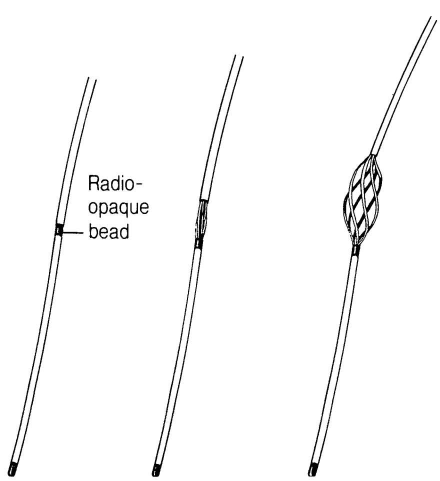


FIGURE 12.6.1. Six-wire helical stone baskets for fluoroscopic transcystic bile duct exploration. The filiform tip is soft enough to avoid common duct perforation and simplifies basket positioning under fluoroscopic guidance.

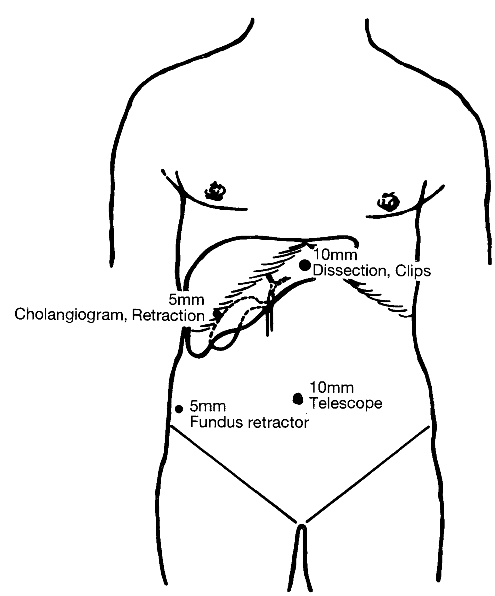


FIGURE 12.6.2. Proper trocar positioning for laparoscopic transcystic bile-duct exploration. Cholangiography and transcystic duct access is facilitated by placing the subcostal trocar in the anterior axillary line immediately below the costal margin. (Adapted from Hunter JG and Soper NJ,[16] by permission of *Surg Clin North Am* 1992; 72(5):1077–1097.)

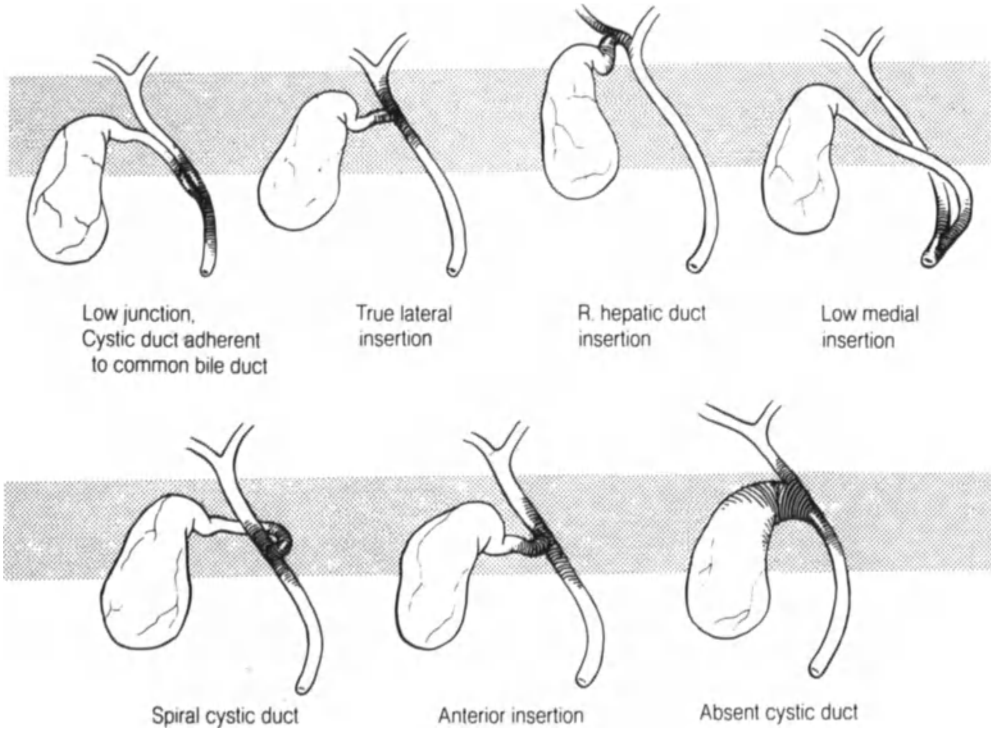


FIGURE 12.6.3. Variations in cystic duct anatomy. (By permission of Hunter J. and Sackier J., eds. *Minimally Invasive Surgery*. New York: McGraw-Hill, 1993, p. 219.)

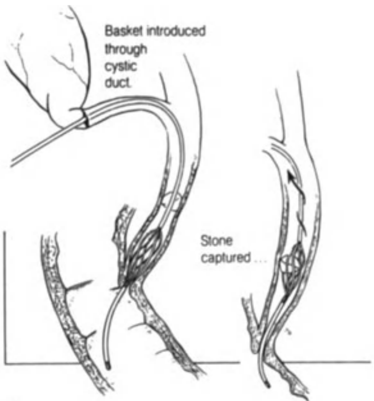
centrated x-ray dye often fails to dislodge all stones and obscures remaining ones. For this reason, irrigation attempts are made with saline, followed by more contrast, which usually demonstrates the stones continuing to reside in the distal common bile duct.

The next step is a direct attempt at stone retrieval. Some surgeons prefer to use a Fogarty balloon catheter as their initial retrieval device.[15] While this is occasionally helpful, the possibility that we might propel a common bile duct stone into the common hepatic duct rather than pull it out the cystic duct has made us dissatisfied with this technique. If the Fogarty retrieval system is used, a 4 or 5F *vascular* Fogarty catheter (biliary Fogarty catheters are too short) is advanced through the cholangiocatheter guide and into the duodenum. The balloon is inflated and brought back up to the papilla, where it is deflated. Once inside the bile duct, the balloon is reinflated and extracted, with luck with the stone in tow.

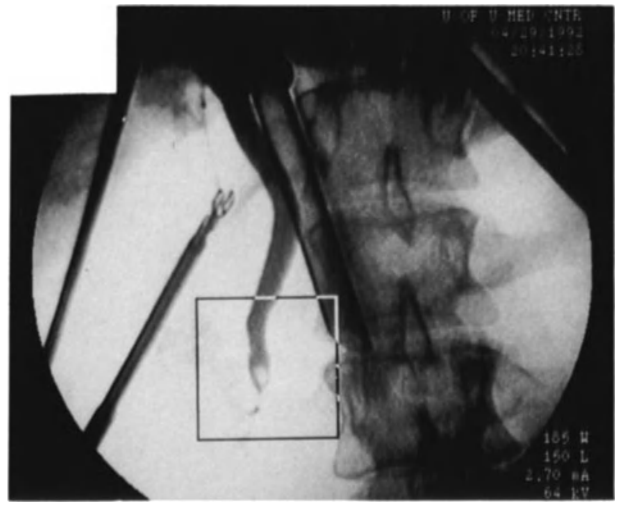
The most successful technique in our experience has been the use of helical stone baskets.[16] As previously stated, a 4F six-wire basket is passed through the cholangiocatheter guide and into the cystic duct as if a cholangiogram were being performed. The filiform leader is generally stiff enough to pass through tenacious valves of Heister but soft enough to avoid common duct perforation. Nevertheless, if the basket does not pass easily, it should not be forced or the common bile duct will indeed be perforated. If the basket passes easily, it is advanced 20 cm into the biliary tree, ensuring that it has entered the duodenum. The first assistant then backs away from the left side of the table and the fluoroscopic C-arm is returned to cholangiography position to confirm the basket's position in the duodenum. The *unopened* basket is then pulled back under fluoroscopic guidance until the marker between the filiform tip and the basket is at the inner contour of the duodenal sweep. If the surgeon cannot be sure of the basket's position, a cholangiography catheter may be passed along it, and contrast injected into the bile duct to confirm its position and that of the stone. This is a slightly more difficult technique, and we have so far not found it to be necessary.

It is vital that the basket be opened only in the common bile duct. *If the basket is opened in the duodenum, it is likely that the major papilla will be entrapped as the basket is pulled back into the common bile duct.* If the papilla become entrapped, the only way to avoid conversion to an open procedure and open duodenotomy is to divide the basket wire, insert a side-viewing duodenoscope, snare the basket, and pull it out through the stomach. Occasionally an entrapped basket can be jiggled free of the papilla; however, edema resulting from papillary injury may cause cholangitis or pancreatitis.

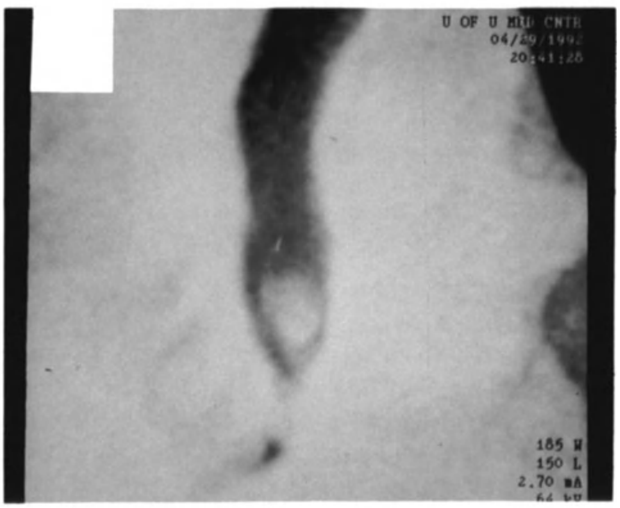
When the surgeon is comfortable that the basket is entirely within the bile duct, it is slowly opened and gently withdrawn as it is rotated clockwise to entangle the stones (Figure 12.6.4). Ideally, once the junction of the cystic



A



B



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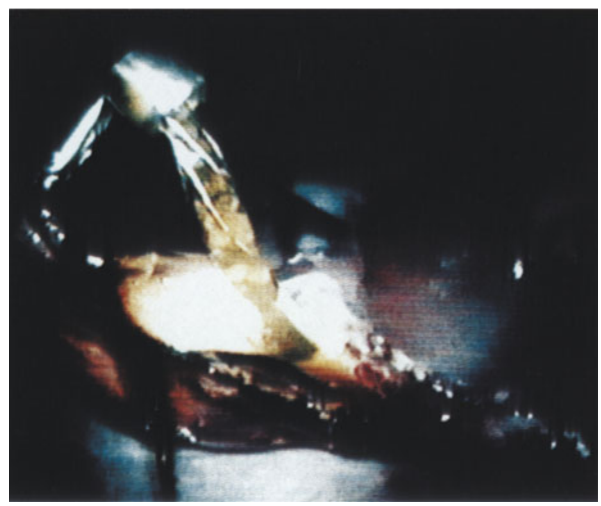
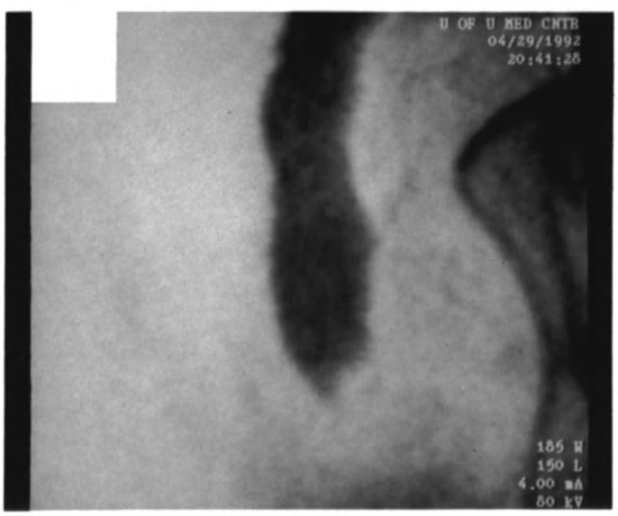


D



E

FIGURE 12.6.4. *A,* Once properly positioned using fluoroscopic guidance, the basket is opened in the distal common bile duct and gently withdrawn as it is rotated clockwise to entrap the stones. *B, C,* Digital cholangiogram demonstrating a distal common bile duct filling defect. *D,* Stone removal via the cystic duct. *E,* A completion cholangiogram following transcystic basket retrieval demonstrates common duct clearance. (Adapted from Hunter JG and Soper NJ,[16] by permission of *Surg Clin North Am* 1992; 72(5):1077–1097.)

and common ducts is reached, a cholangiogram is performed to document stone entrapment. Unfortunately, a helical stone basket with cholangiogram capabilities has not yet been developed. When the open basket with the entrapped stone reaches the cystic-duct junction, the basket is closed and pulled out the cystic duct. If the effort has failed, a second pass down the duct is a simple procedure. If several passes fail, the surgeon should perform cholangiography during attempted stone capture. This can be a difficult feat.

Occasionally an entrapped stone will meet with some resistance at the valves of Heister in the cystic duct. Since excessive force could damage the bile duct, the appropriate response is to resist the urge to pull harder and instead to snug the basket down harder, which will usually fracture the stone. If a larger stone is entrapped and cannot be fractured, it is sometimes necessary to disengage the stone from the basket with counterclockwise rotation. After the surgeon has made several passes retrieving no stones, a follow-up cholangiogram should be performed (Figure 12.6.4E). Occasionally, it is necessary to repeat the intravenous glucagon injection to relax the sphincter of Oddi and document flow into the duodenum.

Problems Associated with Basket Retrieval

The first decision the surgeon must make is whether the clinical situation warrants an attempt at fluoroscopic basket stone retrieval. In most situations, we attempt basket retrieval of stones while a choledochoscope is being readied. However, fluoroscopic retrieval is destined to fail if the stone is large (> 1 cm) or impacted, which makes it virtually impossible to pass the basket beyond it. The ideal anatomy for the laparoscopic transcystic approach is a short, wide, laterally inserting cystic duct, but this is seen in less than 20% of cases; a spiraling cystic duct entering the common duct distally precludes endoscopic transcystic exploration but often allows fluoroscopic stone basketing (Figure 12.6.3).[17] If the stone is above the confluence of the cystic and common hepatic ducts ($\sim$6% of the time) most transcystic techniques will fail.

Results of Fluoroscopic Stone Extraction

At the University of Utah and subsequently at Emory University, we performed 32 laparoscopic transcystic CBDEs. In half of these patients (16 cases) the stones were not suspected preoperatively. Bile duct clearance was successful in all cases. In two of these 16 cases, the patient subsequently became jaundiced or developed biliary colic. In neither case was an ERCP performed because the patients' symptoms and laboratory abnormalities quickly resolved. We suspect that in both instances a stone was left behind and subsequently passed. In the other 16 transcystic bile duct explorations, choledocholithiasis was suspected preoperatively. Basket retrieval was completely successful in about a third of these cases. Failure in these more difficult cases was due to impacted stones, stones too large to enter the basket, or an inability to entrap stones despite numerous basket passes. Laparoscopic transcystic CBDE will achieve success rates comparable to that of ERCP with endoscopic sphincterotomy (80 to 95%)[18] only if *endoscopic* bile duct exploration, the occasional use of lithotripters, and laparoscopic choledochotomy are added for the more difficult cases.

A few authors have utilized fluoroscopic stone-extraction techniques with some success. Petelin recently reported a series of 92 laparoscopic bile duct explorations, in about a third of which fluoroscopic techniques were used exclusively.[19] It is unclear how often fluoroscopic techniques were used as an adjunct to endoscopic bile-duct clearance. Relatively few authors, however, have reported their experience with fluoroscopic common duct clearance.[20]

Complications

A major complication of fluoroscopic transcystic CBDE, occurring in 15% of our cases, is retained stones. Although we have not experienced basket impaction, we are aware of two occasions on which an impacted basket necessitated conversion to open cholecystectomy. Postoperative hyperamylasemia is not uncommon, occurring in approximately 10% of our patients. Elevated transaminase levels, often seen with open common duct exploration, are not unusual. Hyperbilirubinemia associated with fever and pain (cholangitis) occurred following transcystic common duct exploration in 2 of our 32 patients but resolved rapidly with antibiotic therapy alone. Although perforation of the common bile duct would be an expected complication of this technique, we have yet to see or hear of instances of this problem.

Goal of Fluoroscopic Exploration in the Management of the Common Bile Duct Stone

Transcystic fluoroscopic bile duct exploration is widely used in some centers and has been abandoned by others. When endoscopic retrograde cholangiography and endoscopic sphincterotomy are routinely utilized for clinically apparent stones in the preoperative setting, most operative cholangiograms will demonstrate only unsuspected stones. Because small, unsuspected stones are easily dealt with with fluoroscopic techniques, many surgeons have found it unnecessary to purchase expensive minicholedochoscopes and extra video equipment. Moreover, because fluoroscopic extraction requires neither bile duct dilation nor specialized skills, it is an excellent way to get comfortable with laparoscopic bile duct exploration.

It is currently the authors' practice to combine fluoroscopic and endoscopic techniques. If a single stone is seen on an operative cholangiogram and a single stone is retrieved with a basket, we feel it unnecessary to perform choledochoscopy, which simply makes the procedure more lengthy and expensive and requires the dilatation of the cystic duct. If the fluoroscopic basket technique fails or the situation appears hopeless, we prefer to proceed directly with endoscopic bile-duct exploration. When the cystic duct is already quite dilated, there is generally little advantage to the fluoroscopic technique, and we proceed directly to transcystic choledochoscopy.

Summary

Fluoroscopic transcystic bile duct exploration is a relatively simple and inexpensive technique requiring equipment already available in most operating suites. The fluoroscopic C-arm is often available because these machines are heavily utilized by orthopedic and spine surgeons. The Fogarty catheters are generally available on the vascular surgery cart, and the requisite ureteral stone baskets are available in the urology room. Merely by combing through the supply area of most operating rooms a surgeon can pull together the necessary materials for dealing with the majority of unsuspected bile duct stones.

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12.7
Electrohydraulic Lithotripsy of Common Bile Duct Stones

Osman Yucel and Maurice E. Arregui

Electrohydraulic lithotripsy was first devised in the Soviet Union as an industrial technique for fragmenting rocks. It was first used for medical purposes in 1968 by Reuter.[1] The electrohydraulic lithotripter is an electronic device that is capable of cracking urinary and biliary stones of any size and composition. It shatters stones by means of shock waves, which are generated by a rapid series of capacitor discharges that produce sparks between two coaxial bipolar lithotripter electrodes. In a liquid medium, these sparks produce a train of sharp high-amplitude hydraulic shock waves that crack the inelastic stones. The objective of lithotripsy is to reduce the size of the stones so that they can be removed with ease.

The entire electrohydraulic lithotripsy sequence, from the initiation of the electrical discharge to the formation and collapse of the cavitation bubble with its resultant hydraulic shock wave, occurs in 1/800th of a second.[2] The instrument produces a high-voltage shock impulse (1,000 to 2,000 V) of 2 to 4 μs duration between two electrodes at the tip of the catheter immersed in a liquid. The sparkover is triggered and controlled by a surge current generator. The voltage can be set at four levels and the frequency of discharge adjusted to 10, 20, 40, or 80 per second (Lithotron, Walz Elektronik Gmbh, Rohrdorf, Germany).[3] Many medical companies have their own devices with comparable physical properties.

The patient receives no electric shock because the spark discharge occurs only across the tips of the lithotripter electrodes. Normal or 1/6-N physiologic saline is used for the cracking of stones. No heat is built up because of the high specific heat of the saline. During the procedure the stone tends to rebound away from the electrode tip and it may be necessary to reposition the electrode relative to the stone between bursts. Since the force of shock waves diminishes with the square of the distance, the probe tip must be in contact with the stone.[4,5] However, one study found that the most-pronounced effect was achieved when the electrode was close to (1 to 2 mm) rather than in contact with the stone because the maximum fluid wave energy is produced at 1 to 2 mm from the probe tip.[6]

The selection of a short or long pulse and input voltage level depends on the size and composition of the stone and is a matter of experience. It is necessary to flush the bile duct periodically because the stone particles suspended in the saline will limit visibility.

Continuous operation of the unit will shorten the electrode life. The electrode has a lifetime of 30 seconds if operated intermittently but only 10 seconds if operated continuously. The tip of the probe should be checked before it is inserted into the endoscope. The tip should be smooth and the outer and inner layers of insulation should be intact. The tip should extend at least 5 mm beyond the end of the scope to preclude damage to the lens. The presence of a guidewire during electrohydraulic lithotripsy is safe as long as the probe is not fixed directly to the guidewire. Electrohydraulic lithotripsy probes have been refined during recent years. The original probes were 9F, but the probe size was then decreased to 7F, 5F, 3F, and, most recently, to 1.3F.[7]

In Vitro Studies

In an experimental study, *in vitro* fragmentation of gallstones was performed by means of contact electrohydraulic lithotripsy. Significantly more pulses were required to fragment gallstones at least 15 mm in diameter than stones less than 15 mm in diameter ($p < .01$). Stones 15 mm or smaller had a greater tendency to fragment into gravel whereas stones larger than 15 mm produced larger fragments of approximately equal size ($p < .05$). Electrohydraulic lithotripsy of heavily calcified gallstones required significantly more pulses than electrohydraulic lithotripsy of less-calcified or noncalcified stones ($p < .002$).[8] In another experimental *in vitro* study, however, fragmentation was not found to be related to the composition of the gallstone. The differences between the times and rates of fragmentation of cholesterol stones and pigment stones were not statistically significant. The time of fragmentation appeared to depend instead on the weight of the stone.[4]

Animal Experiments

Tanaka and colleagues investigated the safety and efficacy of this method with dogs. In their *in vivo* experimental study, the lithotripsy probe easily perforated the bile duct, even at the minimal energy setting, if it was activated when it was perpendicular to and in contact with the bile duct. A triangular mucosal defect tapering away from the probe was created when the probe was activated while it was in tangential contact with the wall. When the probe was 2 mm from the wall, if it was at right angles to the wall, discharge produced a round mucosal defect 5 mm in diameter.[3]

In another experimental study, Lear and colleagues showed that bile duct perforation and fibrosis occurred when the tip of the electrode was placed perpendicular to the common bile duct wall. No damage was seen when the tip was parallel to or grazing the wall.[9]

There is a shielding device consisting of a hollow spring and a metal end cap that can be used with laser or electrohydraulic lithotripsy devices to minimize tissue damage and which does not adversely affect stone fragmentation. In an experimental study, unshielded electrohydraulic lithotripsy caused perforation of a rabbit bladder (in the presence of blood) after only 2 pulses, whereas shielded electrohydraulic lithotripsy required a mean of 35 pulses. The lateral escape of the spark caused mucosal injury with the shielded device, which was modified to completely shield the lateral spark leakage. No significant mucosal injury was noted when the modified device was discharged in a pig ureter for over 300 pulses.[10]

Clinical Applications

Reuter, in 1968, reported the successful use of electrohydraulic lithotripsy to fragment urinary bladder stones.[1] Burhenne, in 1975, used the device through a T-tube tract to fragment a 2-cm retained common duct stone.[11] Since then intracorporeal electrohydraulic lithotripsy has been used to fragment biliary calculi approached by percutaneous and endoscopic routes and those found during intraoperative common bile duct exploration[3,12,9] (Tables 12.7.1 and 12.7.2). Most recently, with the advances in laparoscopic biliary surgery, laparoscopic transcystic common bile duct exploration with electrohydraulic lithotripsy of the bile duct stones has been reported.[13]

The size and location of the calculi determines whether they are best retrieved by operative or nonoperative means. Electrohydraulic lithotripsy offers a safe and effective way to remove difficult stones, those that are large, fill the entire lumen of the duct, are impacted, are located high in the hepatic ducts, or are located behind a stricture or an angulation, if several precautions are taken. This technique can be employed under fluoroscopic, endoscopic, or combined endoscopic and fluoroscopic vision. Entrapment of a stone within a basket combined with a lithotripsy probe is a prerequisite for fluoroscopic lithotripsy. However, this technique frequently fails if the stone is large or the bile duct is filled with multiple stones, as can happen in cases of hepatolithiasis. In those situations, lithotripsy under direct vision control is extremely useful.[14] Choledochoscopic electrohydraulic lithotripsy allows direct ductal visualization before, during, and after stone clearance. Under direct vision, preliminary trapping of the stone is not absolutely necessary. Continuous irrigation of the bile duct during the procedure with Normal or 1/6-N saline is essential to allow clear visualization. Dilatation of biliary strictures may be required to make it possible for the endoscope to reach impacted stones and to maneuver in the biliary tract. The probe is easy to manipulate within the narrow biliary ducts, however, because of its flexibility.

TABLE 12.7.1. Routes for electrohydraulic lithotripsy of gallbladder, common bile duct, and intrahepatic duct stones.

Nonoperative
Endoscopic retrograde cholangiopancreatography + endoscopic sphincterotomy + choledochoscopy + fluoroscopy
Percutaneous transhepatic
T-tube tract
Cholecystostomy
Jejunal limb of hepaticojejunostomy
Operative
Via choledochotomy
Via cystic duct (open or laparoscopic)

Endoscopic Electrohydraulic Lithotripsy

After previous endoscopic retrograde sphincterotomy and retrograde cholangiography the lithotripsy probe passes above the calculus under fluoroscopic control. A Dormia basket carefully captures the stone and closes, with the calculus lodged firmly in front of the opening in the tip of the lithotripsy probe. Spark discharges fragment the stone. It is not always possible to catch calculi inside the basket. It is difficult to capture huge stones of the common bile duct or intrahepatic stones because of the lack of space in which to maneuver the basket.[15] An alternative is the use of a balloon-tipped over-catheter to prevent the contact of the probe with the bile duct wall.[16]

Peroral choledochoscopy using mother/daughter scope systems has been available for several years but interest

TABLE 12.7.2. The use of electrohydraulic lithotripsy in biliary lithiasis; human clinical experience.

	T-tube	Percutaneous	ERCP	Open CBDE	Laparoscopic CBDE	Success	Failure	Complications
Burhenne (1975)	1					1		
Koch (1980)			14			12	2	None
Lear (1984)		1				1		None
Tanaka (1985)		2	1			3		None
Ebbs (1986)	1					1		None
Matsumoto (1987)		2				2		None
Ponchon (1987)		1				1		1 bleed
Mo (1988)		10				10		1 bleed
Yip (1988)				11		11		1 tear (mucosa)
Juliani (1988)		4				2	2	1 hemobilia
Fan (1989)	3	3		4		10		1 bleed
Yasuda (1989)		26	11			35	2	None
Leung (1989)			5			5		None
Yoshimoto (1989)	9	31				38	2	4 bleeds 3 fever
Yamada (1989)		20				20		None
Picus (1990)	4	7				11		None
Wakayama (1990)	4	5				7	2	4 bleeds
Callans (1990)	1					1		None
Josephs (1990)	12					11	1	None
Siegel (1990)			21			18	3	
Vladimirov (1990)			12			8	4	1 pancreatitis
Bonnel (1991)		50				46	4	11 hemobilia Bile-duct perforation Pulmonary edema Hemothorax (4 fatal)
Lo (1991)		4				3	1	None
Schmitt (1991)		6	17			23		None
Hixson (1992)			5			5		1 bleed
Arregui (1992)	1			1	6	7	1	None
Total	36	172	86	16	6	292	24	29 (4 fatal)

ERCP—endoscopic retrograde cholangiopancreatography
CBDE—common bile duct exploration

in this procedure was limited until recently by the absence or the small diameter of the operating channel in the ultra-thin endoscope (the "daughter"). By bending the scope, the probe can be placed close to the stone. This increases the fragmentation success rate and avoids bile-duct damage.[17]

Percutaneous Transhepatic Electrohydraulic Lithotripsy

It is possible to fragment common bile duct or intrahepatic stones by percutaneous, transhepatic intracorporeal electrohydraulic shock wave lithotripsy if endoscopic treatment has failed. After establishing a transhepatic biliocutaneous fistula and a wide communication between the bile duct and the gut, lithotripsy can be done under endoscopic vision (using a choledochoscope or ureteroscope). In order to avoid complications such as hemobilia and bile duct perforations the surgeon should wait until the dilated percutaneous transhepatic route has matured before continuing and then perform the procedure under clear direct vision.[18]

Electrohydraulic Lithotripsy Using a T-Tube Tract

Although many small retained stones can be successfully managed through a T-tube tract, the difficult stones mentioned above necessitate some form of lithotripsy or dissolution therapy. Electrohydraulic lithotripsy of stones prior to their removal is also advisable because tract disruptions mainly due to the jagged edges of a hard stone slightly wider than the T-tube tract have been reported in the literature.[19,20] Stone fragments can either be delivered through the tract in a Dormia basket or pushed into the duodenum through a previously made papillotomy. If there is no papillotomy, balloon dilatation of the papilla to 5 mm can safely be done under fluoroscopic guidance to facilitate the passage of stones into the duodenum.

Laparoscopic Transcystic Common Bile Duct Exploration with Electrohydraulic Lithotripsy as an Adjunct to Laparoscopic Cholecystectomy

The introduction of choledochoscopy has facilitated the management of common bile duct stones, which are found in 5 to 9% of patients undergoing cholecystectomy. The recent introduction of video choledochoscopy has made it easier for the surgeons to learn this technique (Figure 12.7.1).

For proper stone extraction, the surgeon and an assistant work together under visual control. Combined endoscopic and fluoroscopic stone retrieval is more accurate than fluoroscopic technique alone, because the stone and instrument maneuvers can be followed on the video monitor. The procedure is faster, and the radiation dosage is lower.

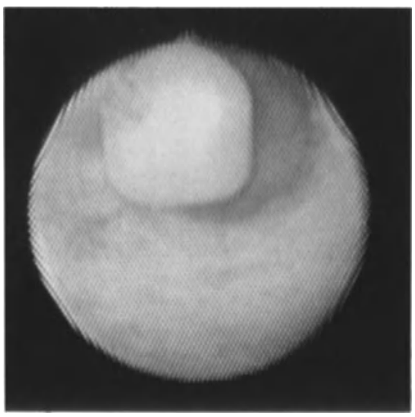

FIGURE 12.7.1*A*. Choledochoscopic view of a 1-cm common bile duct, stone during laparoscopic transcystic common bile duct exploration. Note the 1.3F electrohydraulic lithotripsy probe touching the stone. (By permission of ME Arregui and O Yucel, *Surg Laparos & Endos* 3(5):398–402, 1993.)

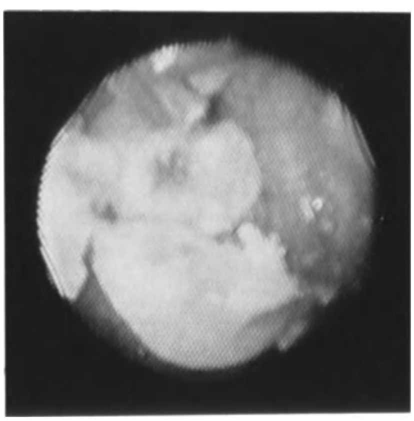

FIGURE 12.7.1*B*. Partial fragmentation of a common bile duct stone using electrohydraulic lithotripsy. (By permission of ME Arregui and O Yucel, *Surg Laparos & Endos* 3(5):398–402, 1993.)

With advances in laparoscopic surgery it is now possible to explore the common bile duct either through the cystic duct or by means of a choledochotomy during laparoscopic cholecystectomy. The techniques used to explore the common bile duct have been clearly described in recent reports.[21,22] Once a stone is discovered on the intraoperative cholangiogram the options are to perform laparoscopic common bile duct exploration, to convert to open common bile duct exploration, or to subject the patient to postoperative endoscopic papillotomy and stone extraction. The latter technique has a failure rate of 10 to 15% and an associated mortality of 1%.[21] The use of a choledochoscope or ureteroscope greatly facilitates the management of common bile duct stones during laparoscopic cholecystectomy. To accommodate the choledochoscope, the cystic duct must be dilated in most cases. Dilatation of the cystic duct with serial ureteral dilators or with ureteral balloons usually achieves this goal. Once the common bile duct is entered and stones are visualized they can be fragmented by electrohydraulic lithotripsy under direct vision. The relatively small stone fragments can either be pushed into the duodenum or extracted through the cystic duct. If there is no previous papillotomy, balloon dilatation of the papilla to 5 mm under fluoroscopic vision can safely be done. This maneuver greatly facilitates the passage of fragments into the duodenum.

We recently used electrohydraulic lithotripsy for the management of six patients with common bile duct stones. We performed laparoscopic cholecystectomy and transcystic exploration of the common bile duct using either a 5-mm flexible choledochoscope or a 3.2-mm ureteroscope. Stone fragmentation and common bile duct clearance was successful in five patients. One patient with a huge stone (2.5 × 5 cm) was managed by laparoscopic choledochotomy and stone extraction followed by T-tube insertion. Although this stone fragmented, it filled the duct and the probe could not be safely positioned. We also managed two other patients using intracorporeal electrohydraulic lithotripsy of bile duct stones. One patient with retained common bile duct stones and a T-tube was managed by dilating the tract to 5 mm using serial ureteral dilators followed by choledochoscopic electrohydraulic lithotripsy of the stones. Another patient, who had had a Billroth II gastric resection with a large ventral hernia that required an open hernia repair was managed with open cholecystectomy, choledocholithotomy, and electrohydraulic lithotripsy of an impacted left hepatic-duct stone with the aid of choledochoscope.

Laparoscopic cholecystectomy has become the standard procedure for the treatment of patients with symptomatic calculous gallbladder disease. Due to advances in laparoscopic technique and instruments, management of the common bile duct is now within the scope of laparoscopic surgery. Transcystic exploration of the common bile duct and fragmentation of stones using electrohydraulic lithotripsy is an attractive alternative to other treatment modalities. Nevertheless, further clinical studies are needed to evaluate the efficacy and safety of this procedure.

Complications

The procedure carries the risks inherent to cannulation of the bile duct: damage to the duct causing bleeding or perforation in the short term and biliary strictures due to fibrotic changes in the long term. Bonnel and colleagues reported a 22% complication rate. Complications included hemobilia, bile-duct perforation, and acute pulmonary edema. The overall mortality was 8% in 50 patients treated by percutaneous transhepatic electrohydraulic lithotripsy, but none of the deaths were due to electrohydraulic lithotripsy. Those complications that occurred early in their study were related to the rapid-access technique that they used (tract dilation to 20F during the same session). The complications diminished when they modified their technique, dilating the biliary tract and waiting for the tract to mature before advancing the endoscope.[18]

It is very important to avoid direct contact of the lithotripsy probe with the duct wall, since perforations are reported in animal studies. Contact between the probe tip and the bile duct wall at the time of pulse discharge can result in perforation even at the lowest energy level.[23] It is essential that the procedure be performed under direct endoscopic vision in order to avoid bile duct perforations. This also reduces the risk of bile duct stricture, which may be a late sequela. Hemobilia, which may be due to the shock wave or the stone particles, usually resolves spontaneously and rarely causes a problem. Fever, rigors, diarrhea, and transient elevation of serum bilirubin levels can also be due to the cholangioscopy itself. We previously reviewed the literature and reported on a series of 256 cases in which there were no instances of bile-duct perforation.[13]

Electrohydraulic Lithotripsy versus Other Lithotripsy Methods

Percutaneous and endoscopic methods for the nonsurgical removal of biliary tract calculi are well established. Direct percutaneous access to either the gallbladder or the bile ducts may be used to remove stones from patients who are too ill for surgery or when endoscopic methods fail. Endoscopic sphincterotomy and stone retrieval is the method of choice for common bile duct stones when there is no T-tube or percutaneous tract in place. These methods usually fail in cases of huge stones, intrahepatic stones, and stones located behind a strictured bile duct. A variety of methods have been used to treat these difficult biliary tract calculi, including dissolution therapy, mechanical, ultrasonic, laser, or electrohydraulic lithotripsy, and extracorporeal shock wave lithotripsy. Each of these techniques has its advantages and disadvantages.

Conservative treatment of gallbladder, common bile duct, and intrahepatic stones with extracorporeal shock wave lithotripsy is not uniformly effective. The number, size, and composition of the stones plays an important role in patient selection. It is also associated with significant morbidity from biliary colic, hematuria, and hemobilia. Treatment not infrequently necessitates some form of adjuvant therapy, such as oral dissolution agents or endoscopic sphincterotomy for stone clearance. Moreover, the equipment is expensive. Laser-induced shock wave lithotripsy of gallstones, although effective for both large and pigmented stones, requires expensive technology and special precautions in the operating room. Ultrasonic lithotripsy has success rates similar to electrohydraulic lithotripsy in fragmenting stones of various size and composition and appears to be a safe technique. However, a rigid probe is needed to transmit the ultrasonic energy to the stone. It requires a large scope (24F) that limits access to the bile ducts.[24,25] Mechanical lithotripsy is not uniformly effective and is cumbersome in cases of multiple stones. It can be difficult to entrap a stone when the stone is large or located behind a stricture or angulation. Chemical dissolution is an unpleasant, lengthy inpatient procedure limited to cholesterol stones.[26]

Conclusion

Laparoscopic cholecystectomy has recently become the procedure of choice in the management of patients with symptomatic cholelithiasis. More recently the extension of laparoscopic techniques to the treatment of patients with common bile duct stones has gained popularity among surgeons. Percutaneous, T-tube tract, and endoscopic methods for the nonsurgical removal of the biliary stones are well documented. Although laparoscopic choledochoscopy and stone extraction is useful, large or impacted common bile duct and hepatic stones are difficult to extract. Various methods are available to fragment difficult biliary stones, including mechanical lithotripsy, ultrasonic lithotripsy, laser-induced shock wave lithotripsy, extracorporeal shock wave lithotripsy, electrohydraulic lithotripsy, and chemical dissolution. Among these, electrohydraulic lithotripsy has proved to be a safe and effective means of fragmenting biliary stones. The method is rapid, relatively inexpensive, and not dependent on stone composition. The small and flexible probes can easily be introduced through the operating channels of fiberoptic scopes. For safety, the probe tip must be in close proximity to the stone and well away from the duct wall because bile duct perforation and fibrotic changes may occur if the tip of the probe comes in contact with the wall during discharge. In previous studies the procedure was done by means of peroral duodenoscopy after sphincterotomy, fluoroscopically through a T-tube tract, or percutaneously through a transhepatic tract. Choledochoscopic- or ureteroscopic-guided electrohydraulic lithotripsy has the advantage of direct visualization prior to, during, and after stone clearance. Some serious complications that have been reported, such as hemobilia, bile duct perforation, acute pulmonary edema, and hemothorax—including four mortalities out of 50 patients—were associated with the technique used to create a percutaneous transhepatic tract, not with electrohydraulic lithotripsy itself.

The use of electrohydraulic lithotripsy through a flexible ureteroscope or choledochoscope is a safe and effective means of fragmenting impacted and large stones during laparoscopic common bile duct exploration, or hepatic duct or retained stones through a T-tube tract when endoscopic retrograde cholangiopancreatography and endoscopic sphincterotomy has failed.

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12.8
Biliary Laser Lithotripsy

Desmond H. Birkett

Introduction

The management of bile duct stones, both intra- and extrahepatic, has changed significantly over the past 10 years. They were once treated by open operative removal, whether the treatment was for the initial stone removal at the time of cholecystectomy or for the removal of retained stones. This required time in the hospital, time away from work, and time away from the family and carried a significant morbidity and mortality.

The introduction of endoscopic retrograde cholangiopancreatography (ERCP) and papillotomy by Classen and Demling demonstrated the advantages of a minimal-access procedure.[1] ERCP and papillotomy have a 10% morbidity and a 1% mortality, lower than the morbidity and mortality associated with open operative removal of a recurrent stone. The use of minimal-access techniques has since increased as endoscopes were improved and miniaturized. With the introduction of percutaneous access to the biliary tree, either via the T-tube tract, a percutaneous transhepatic tract, or laparoscopic common duct exploration, therapeutic procedures began to be performed through small tracts. If a stone is to be removed whole, the access tract must be larger than the stone to be extracted. Otherwise the stone must be fragmented by a safe and effective method. Four methods of stone fragmentation are in clinical use: mechanical fragmentation using a strong but large wire basket; ultrasonic lithotripsy, which uses an oscillating rigid bar; electrohydraulic lithotripsy; and laser lithotripsy. Only the latter two, electrohydraulic lithotripsy and laser lithotripsy, employ probes small enough and flexible enough to be passed through the current generation of small endoscopes.

Evolution of Laser Lithotripsy

The first description of laser lithotripsy was by Orii and colleagues, who described the fragmentation of bile duct stones in two patients using a continuous-wave Nd:YAG laser,[2] and later went on to describe their results in nine patients.[3] Chen and Jan reported the successful use of a transhepatic continuous-wave Nd:YAG laser to fragment biliary stones.[4] Orii and colleagues pointed out that the continuous-wave Nd:YAG laser was only satisfactory for pigment stones and that it was not effective against the more common cholesterol stones.[3] Others found the same and reported that the continuous-wave Nd:YAG laser tended to drill holes in cholesterol stones without fragmenting them.[5] There were also concerns about the safety of the Nd:YAG laser because of the large amount of heat it generates. Indeed the heat the laser generates can be used to necrose and vaporize gastrointestinal tumors to restore intestinal continuity. In the thin biliary tree, however, this heat production is likely to result in duct perforation. Dayton and colleagues showed that the Nd:YAG laser produced more heat than lasers that had other emission wavelengths and showed that pulsed lasers produced significantly less heat than continuous-wave lasers.[6]

In an attempt to improve gallstone fragmentation, particularly that of cholesterol stones, Ell and colleagues investigated the effect of a pulsed Nd:YAG laser in an animal model. They employed an energy of 2 J and a pulse duration of 10 ms.[7] They showed that fragmentation occurred in a matter of seconds and that the rate of fragmentation depended on the volume of the stone. They found that the stones fragmented into large fragments, and they measured significant temperature elevation and ductal perforation in one animal, which led them to question whether Nd:YAG was the best laser for clinical use.

The flashlamp-pulsed Nd:YAG laser, which has a pulse length in the nanosecond range, was shown to fragment renal stones without damage to the ureter.[8] The urothelium was damaged only by multiple pulses with an energy four times that needed for stone fragmentation. This laser does convert light energy to heat, but because of the short pulse length there is only minor heating.

The Q-switched Nd:YAG laser has been shown to convert light energy to mechanical energy and to break gallstones into small fragments without tissue damage in an animal model.[9] Because of its high energy levels this laser is hard to couple to fine quartz delivery fibers and is therefore a difficult laser to use clinically.

Nishioka and colleagues looked at a variety of wavelengths between 450 and 700 nm and found that 504 nm was the most effective wavelength for gallstone fragmentation.[10] At this wavelength, light energy is converted to acoustic energy, resulting in the production of an expanding plasma at the surface of the stone. The plasma, on contraction, produces a shock wave audible as a snap. This theory of its mode of action is supported by the work of Teng.[11]

Murray and colleagues investigated multiple wavelengths and found that at the shorter wavelengths, less energy was needed for stone fragmentation. At the higher wavelengths, more pulses were needed.[12] They also found that the median energy level required to fragment pigment stones was 2.2 J, whereas the median energy required to fragment cholesterol stones was 24.2 J—an elevenfold difference attributable to the higher energy absorption of the pigment stones in the green spectrum.

Other wavelengths have also been investigated in an effort to fine one that would better fragment all biliary stones. Remine and colleagues examined the holmium laser, which has a wavelength of 2.1 μm. They found that 250 mJ was the optimum energy level.[13] Lower energy levels of around 100 mJ drilled holes in stones, and higher energy levels in the range of 800 mJ had a shattering and blast effect on the stones and resulted in ductal perforation. At the optimal energy level for fragmentation, there was no mucosal injury.

The 308-nm excimer laser has been used in an experimental setting by Shi and colleagues, who showed that it effectively fragmented gallstones. Pigment stones were easier to fragment than cholesterol stones, a phenomenon thought to be due to higher energy absorption by the pigment stones.[14] The effect of the excimer laser on tissue has yet to be investigated.

The pulsed alexandrite laser, emitting at 507 nm, shows promise in the fragmentation of biliary stones. It has the advantage of achieving satisfactory stone fragmentation when the fiber tip is in the vicinity of the stone rather than in direct contact. However, fiber-tip disintegration is a problem.[15]

A laser for biliary-stone fragmentation must be safe and effective, and this means it must convert light energy to mechanical energy, efficiently fragmenting stones without injuring ducts. Currently the most effective wavelength by these criteria is the 504-nm coumarin pulsed dye laser with a pulse duration of 1.5 to 2 μs. We have shown this wavelength to be relatively safe in an *in vitro* porcine model. The laser was discharged at pulse energies between 60 and 120 mJ.[16] With the fiber held at right angles to the tissue, perforation occurred after 50 consecutive pulses in 11.1% of ducts at 60 mJ and in 44.4% at 120 mJ. The only other laser, at the moment, that seems to show promise is the alexandrite laser.

Method

There are three percutaneous access routes to the biliary tree. The first is via an established T-tube tract; the second is via a transhepatic tract, which may be acutely established or chronically matured; and the third is via the cystic duct at the time of laparoscopic cholecystectomy.

Via the T-Tube Tract

When a retained stone is found on the T-tube cholangiogram in a patient who has had a common duct exploration and T-tube placement, the stone can be removed using a flexible fiberoptic choledochoscope and, if necessary, laser lithotripsy. This procedure is performed with the patient under IV. sedation and in sterile conditions no sooner than four weeks from the time of common duct exploration. The delay allows the T-tube tract to mature. The T-tube is removed from the tract, and the fiberoptic choledochoscope is steered down the tract under direct vision until the stone is in view. Meanwhile the instrument channel of the endoscope is flushed with saline to distend the biliary tree, aiding visualization. If the stones are small, they are removed by a basket passed through the instrument channel.

If the stone is too large to be extracted through the T-tube tract or to be engaged in the basket, it is fragmented using the laser. A 200-μm quartz fiber attached to a 504-nm coumarin pulsed dye laser is passed down the instrument channel of the choledochoscope and, under direct vision, is placed in contact with the stone. The laser is then discharged in bursts at a power of 80 to 100 mJ and a frequency of 5 Hz under direct vision until the stone is broken into fragments of a size that will pass through the sphincter of Oddi into the duodenum or can be removed by basket extraction through the T-tube tract. It is usually not the size of the stone that determines the feasibility of this approach but rather the size of the endoscope that can be passed down the T-tube tract. T-tube access is rarely a significant problem with the small choledochoscopes, which are 3.2 mm in diameter, since they will pass down a tract made by a T-tube as small as 12F.

Via a Transhepatic Tract

The transhepatic route is useful in those patients without T-tube access and in whom ERCP and papillotomy cannot be used for technical or anatomical reasons. In this group of patients, the transhepatic route is the ideal minimal-access route to the biliary tree. The biliary tree is accessed by a radiologist, who performs a transhepatic cholangiogram followed by the placement of an 8.3F catheter into the right hepatic duct. The procedure can be staged by leaving the catheter in place for 10 days to permit the tract to mature. During this time it is necessary to dilate the tract so that the mature tract will accept either a 3.2-mm flexible choledochoscope or, if preferred, the larger 4.9-mm choledochoscope. Alternatively the tract can be dilated acutely and a 12F Cordis introducer placed into the biliary tree. A 3.2-mm choledochoscope is then passed through the introducer.

Through the mature tract in the staged procedure or through the Cordis introducer in the acute procedure, an endoscope is passed into the biliary tree with the patient under IV sedation, under sterile conditions, and with the means at hand to do fluoroscopy, if needed. The endoscope is steered to the site of the stone. Fluoroscopy can be helpful in guiding the choledochoscope through the biliary tree, particularly when one is trying to intubate the left ductal system from the right side of the liver. Once the stone is visualized, a 200-μm quartz fiber attached to a 504-nm coumarin pulsed dye laser is passed down the instrument channel of the choledochoscope. Under direct vision it is placed in direct contact with the stone. The laser is then discharged in bursts at a power of 80 to 100 mJ and a frequency of 5 Hz under direct vision until the stone fragments are of the size that will pass through the sphincter of Oddi into the duodenum or can be removed by basket through the transhepatic tract. We find it preferable to fragment the stone into pieces that will wash easily into the duodenum because it can be difficult to remove a large stone through the transhepatic tract. At the end of the procedure the biliary tree is visually examined to ensure that it is free of stones. This examination can be confirmed with radiologic studies. If the biliary tree is free of stones, the transhepatic catheter is removed and the tract is permitted to close. If there is a need to re-examine the biliary tree or remove more stones, a catheter is placed in the transhepatic tract to maintain its patency.

Via the Cystic Duct at the Time of Laparoscopic Cholecystectomy

The most common management of bile duct stones found at the time of laparoscopic cholecystectomy is conversion to an open operation, or ERCP and papillotomy before or after the cholecystectomy. However, the most expeditious management would be removal of common duct stones at the time of laparoscopic cholecystectomy, a procedure that is increasingly popular.

After the cystic duct cholangiogram is performed, the catheter is removed from the cystic duct, and a fine flexible choledochoscope, such as the Olympus 3.2-mm ureteroscope (Olympus Corporation, Inc., Lake Success, NY), is passed through a port into the cystic-duct opening and on into the common bile duct using a pair of laparoscopic forceps. A second video camera is mounted on the endoscope, and the picture is viewed either on another video screen or, using a mixer, on the same video screen.

Another method is to pass a Cordis-type introducer and sheath through a separate skin incision over a guidewire into the cystic duct and on into the common duct. The Olympus flexible choledochoscope can then be fed through the sheath down into common duct without the use of laparoscopic forceps. The forceps are difficult to use and may damage the choledochoscope.[17]

Once the stone is visualized, a 200-μm quartz fiber attached to a 504-nm coumarin pulsed dye laser is passed down the instrument channel of the choledochoscope, placed in contact with the stone, and discharged. As the stone is fragmented, the small fragments are washed through the ampulla of Vater into the duodenum by saline running through the instrument channel. Large pieces are fragmented into pieces small enough to wash into the duodenum or to be basket-extracted through the cystic duct. After all the fragments have been removed and the common duct is seen to be clean, the choledochoscope is removed, and the cystic duct stump clipped in the usual manner.

Clinical Use

Although the use of a variety of lasers has been reported in the literature, most clinical procedures are done with the 504-nm coumarin pulsed dye laser.

Laser lithotripsy via the T-tube tract is an effective method of treating retained common duct stones and is the simplest recourse in patients who have a T-tube in place. In report, 9 of 12 patients required only one session, 1 patient required a second session, and for 2 patients the treatment was unsuccessful because the laser failed.[18] We have found laser lithotripsy, using energy levels of 80 to 100 mJ, highly successful. All stone fragments were small enough to wash through the sphincter of Oddi into the duodenum.[19] However, in some patients two endoscopy sessions were needed to empty the biliary tree completely. Ponchon and colleagues also found T-tube access under direct vision to be a satisfactory method of treating large common duct stones.[20]

The first retrograde endoscopic laser lithotripsy was performed by Lux and colleagues, who successfully cleared a common duct of multiple stones using a flashlamp-pulsed Nd:YAG laser to fragment stones.[21] Since then there have been several reports of successful use of this procedure. Cotton and colleagues cleared 25 patients of stones using choledochoscopy and a mother/daughter retrograde duodenoscope.[22] Ponchon and colleagues showed that direct visualization of the calculi with the mother/daughter retrograde endoscope made fragmentation more efficient. They fragmented all of the stones in 11 patients, whereas when the procedure was performed under fluoroscopy, fragmentation occurred in only 5 of 14 patients.[20]

In those patients who are not candidates for T-tube-tract laser lithotripsy or for retrograde endoscopic lithotripsy, the transhepatic route has been shown to be successful. Sullivan and colleagues found that laser lithotripsy performed via a transhepatic tract with the pulsed dye laser was effective at fragmenting stones in three patients who were not good candidates for retrograde endoscopic removal, open operations, or extracorporeal shock wave lithotripsy.[23] Brambs and colleagues reported a similar success rate with the transhepatic approach in seven patients who were not candidates for the more standard techniques.[24] Birkett also found transhepatic laser lithotripsy to be an effective method of treating common duct stones and was able to clear all patients of calculi by fragmenting the stones and washing the fragments into the duodenum. However, in several patients more than one endoscopic treatment session was needed to clear the biliary tree completely.

Laser lithotripsy has also been used to fragment common duct stones at the time of laparoscopic cholecystectomy.[26] Birkett used choledochoscopic laser lithotripsy via the cystic duct at the time of laparoscopic cholecystectomy to fragment common duct stones in two patients, washing the fragments through the sphincter of Oddi into the duodenum.[17]

In none of these reports is there any mention of complications related to laser lithotripsy.

Conclusion

Laser lithotripsy is a very effective way of fragmenting and clearing the biliary tree of stones. It should be performed under direct visualization to maximize the rate of fragmentation and reduce the chance of bile duct perforation. As a technology, it is more expensive than electrohydraulic lithotripsy, but it is safer.[16] It permits minimal-access removal of large stones and reduces the need to dilate percutaneous tracts to sizes that permit extraction of large stones. Laser lithotripsy at the time of laparoscopic cholecystectomy and common duct exploration, particularly exploration via the cystic duct, removes the need for an extraction route large enough to permit removal of the whole stone. Choledochotomy and T-tube placement are avoided, thus reducing the morbidity of common duct exploration. If the exploration can be performed through the cystic duct, with or without dilatation, a stone of any size can be fragmented by laser lithotripsy and the common duct cleared without T-tube or drain placement.

Laser lithotripsy is in keeping with the principles of minimal-access therapy: it permits the treatment of bile duct stones of varying sizes using small endoscopes introduced through small access routes.

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12.9 Extracorporeal Shock Wave Lithotripsy in the Management of Common Bile Duct Stones

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Since Carl Langenbuch performed the first successful cholecystectomy more than 100 years ago, surgery has been considered a mainstay of therapy for most benign biliary tract diseases.[1] Although cholecystectomy was and remains to this day a safe operation, mortality rates approaching 5% after common bile duct exploration were common in the mid-1960s.[2] It is therefore not surprising that lithotripsy and other minimally invasive therapeutic alternatives were developed in an effort to reduce the morbidity and mortality associated with biliary tract surgery for recurrent or retained common bile duct stones.

Over the past 15 years endoscopic retrograde cholangiography and endoscopic sphincterotomy (ES) with retrograde stone extraction have become the most widely used and important nonsurgical techniques for the diagnosis and management of biliary lithiasis, especially in elderly and frail patients judged to be poor candidates for operation.[3] However, failure rates of 10 to 15% are reported for patients with intrahepatic stones, large stones (> 2 cm), and stones located proximal to a biliary stricture.[4] Transendoscopic access to the biliary tree may be impeded by difficulties in cannulating the papilla of Vater, especially in patients with papillary stenosis or impacted stones. Anatomical problems, such as the presence of a juxtapapillary duodenal diverticulum, a prior gastrectomy with Billroth II anastomosis, or a Roux-en-Y enterostomy, increase the risk of ES and are generally associated with reduced stone clearance rates. In addition, ES is accompanied by complication and mortality rates of 10 and 1%, respectively, even when performed by experienced endoscopists under optimal conditions.[5]

Several comorbid factors appear to increase the risk of ES, including cardiorespiratory disease, impaired renal function, sepsis, malnutrition, and liver failure. Advanced age *per se* does not correlate with a negative outcome for ES. The indication for the procedure also influences the risk. Retroduodenal perforation occurs following ES in nearly 1% of patients and is more common in patients with papillary stenosis than in those with stones. Surgical management is required in 30% of patients with perforation and the attendant mortality rate approaches 15%.[5] Pancreatitis of varying severity occurs following ES in 2% of patients. Mild forms of pancreatitis usually resolve spontaneously, but 10% of patients require surgical intervention for severe complications. This complication of ES is attributed to a variety of factors, including overly vigorous introduction of instruments into the papilla of Vater, excessive use of diathermy for coagulation, and possibly the use of hyperosmolar ionic contrast media.[5] Bleeding occurs in approximately 2.5% of patients following ES and is more common in patients with papillary tumors than in those with stones. Associated risk factors include drugs, such as aspirin and nonsteroidal anti-inflammatory agents that adversely affect platelet function, and the coexistence of portal hypertension. Other complications, such as drug reactions, aspiration pneumonia, and cardiac arrythmias, have been reported with ES, but are equally common after other upper-gastrointestinal endoscopic procedures. Late biliary complications of ES have recently been confirmed in 6 to 13% of patients, most notably sphincterotomy stenosis with recurrent stone formation or cholangitis.[6,7]

Adjunctive techniques such as mechanical, electrohydraulic, and laser lithotripsy were developed to enhance stone clearance following ES. However, to be successful, all of these techniques require access to the biliary stones. In the absence of a T-tube tract, percutaneous or transendoscopic placement of a biliary catheter is required. Both laser and electrohydraulic forms of lithotripsy require stone visualization and direct contact or close proximity to be effective and to avoid barotrauma.[8] The efficacy of laser lithotripsy is further limited by the expense of the technology and safety concerns for both the patient and endoscopy personnel.

Despite its limitations, intracorporeal electrohydraulic lithotripsy (IEL) may be useful following failed endoscopic treatment in patients with large or impacted stones, intrahepatic stones, and extrahepatic stones proximal to a biliary structure. In one recent series from the Clinique Radiologique in Paris, France, Bonnel and colleagues reported a stone clearance rate of 92% among 50 patients treated with percutaneous, transhepatic IEL.[9] In all cases contact lithotripsy was performed under endoscopic guidance. Severe complications, including hemobilia requiring blood transfusion and bile duct perforation, were observed in 11 patients (22%), and resulted in four deaths (36%). In another series, Chen and Jan-Y of Taiwan used transhepatic cholangioscopic IEL to treat 14 patients with intrahepatic and common bile duct stones that were too large for conventional extraction techniques.[10] Complete fragmentation was achieved in only 50% of patients, primarily because of intrahepatic duct angulation or strictures. Transient, nonfatal complications, including hemobilia and postprocedure fever, were observed in three patients but resolved without medical or surgical intervention.

Extracorporeal shock wave lithotripsy (ESWL) has been used since 1980 for the treatment of renal calculi. The first successful treatment of bile duct stones using this technology was reported by Sauerbruch and colleagues in 1986.[11] Although several forms of ESWL are currently available, early trials from Germany and the United States utilized the Dornier HM3 lithotripter. The general principles of ESWL have recently been summarized by Moody and colleagues.[12] Briefly, the water-bath lithotripter contains a spark-gap electrode that generates an electrical discharge. The discharge produces an acoustic wave secondary to the expansion of gases at the electrode tip. The acoustic wave propagates toward a metallic ellipsoidal reflector, which directs it toward a target. The shape of the reflector and the energy of the discharge determine the characteristics of the shock wave that reaches the focal point, or target. Water is used as a transmission medium because its acoustic impedance is similar to that of body tissue. The shock waves do not cause the stone to explode but rather create shear forces that fracture and eventually fragment the stone. The Dornier system uses a biaxial roentgenographic imaging system to localize stones and has a relatively wide focal zone that can encompass multiple stones. A nasobiliary tube or similar catheter placed in the bile duct is required for accurate stone localization. Because the shock waves impart significant energy to high-impedance structures, careful targeting is required to minimize inadvertent injury to bone or air-filled viscera, such as the lungs. This form of lithotripsy is contraindicated in patients with renal cysts, calcified vessels, or vascular aneurysms adjacent to or in the shock wave path.

Two large studies have been reported of the use of the Dornier lithotripter for treatment of problematic common bile duct stones.[12,13] A German series consisted of 103 elderly patients (the mean age was 70 years) treated over a period of five years.[13] Disintegration of stones was achieved in 92% of patients after an average of 1.4 sessions. Nearly 75% of patients required adjunctive endoscopic extraction of stone fragments from the biliary tree, but ultimately complete stone clearance was achieved in 88% of patients. Of the 12 patients in whom stone clearance was incomplete, 5 underwent surgery, 4 underwent stent placement, and 3 underwent mechanical lithotripsy. There was no procedure-related mortality, but one patient died from multiorgan failure associated with pancreatitis following endoscopic sphincterotomy. Most adverse effects were mild, except for postprocedure septic fevers in four patients and cardiac arrythmias that necessitated discontinuation of therapy in one patient. Other side effects were transient hemobilia, microhematuria, and cutaneous ecchymoses. Patients were followed for a mean of 26 ± 14 months after ESWL. Fifteen patients (14.5%) died, mainly of causes unrelated to biliary disease, and two of the patients initially rendered stone free (2.1%) were readmitted and treated for recurrent stone disease. All remaining patients were free of symptoms.

A multihospital United States series of 56 patients treated with ESWL was published in 1989.[12] Stone fragmentation occurred in 91% of patients and 79% were ultimately rendered stone free, but 54% required adjunctive procedures such as dissolution therapy or endoscopic extraction. Seven patients (12.5%) underwent surgery after failed ESWL. There was no procedure-related mortality, and complications were mild and relatively uncommon.

The German and United States trials were similar with regard to selection criteria and ESWL technology but differed in terms of the number of shocks administered and the length of follow-up. Both trials reported a low incidence of complications during ESWL therapy. Surgical intervention following failed ESWL was required in a total of 12 patients, or 7.5% of the combined study population. In the German trial, seven additional patients required either mechanical lithotripsy or stent placement because complete duct clearance could not be achieved with ESWL or endoscopic extraction. The number of shocks administered was higher in the German study, which may account for the higher biliary clearance rate achieved (88 versus 79%).

Review of other major clinical trials shows that there are significant differences in the rate of successful stone fragmentation. Many of these differences can be attributed to variations in lithotripsy technology (Figure 12.9.1). In a recent study from the Netherlands, den Toom and colleagues reviewed the results achieved with two different ESWL technologies in 62 patients with retained common bile duct stones.[14] Thirteen patients were treated with a Dornier HM3 lithotripter (electrohydraulic technology), and 49 patients were treated with a Siemens

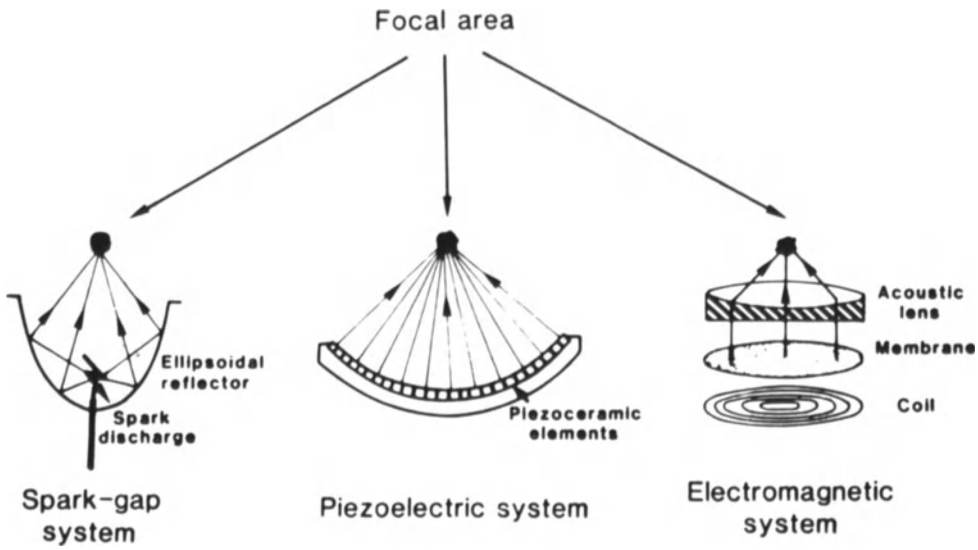

FIGURE 12.9.1. A variety of shock wave lithotripters are currently available, including spark-gap, piezoelectric, and electromagnetic systems. These systems have different x-ray imaging systems, and some require immersion whereas others do not.

Lithostar (electromagnetic technology). Fragmentation rates using the two lithotripters were 100 and 86%, respectively. The majority of patients treated with the Lithostar required only analgesia and sedation, whereas all of the patients treated with the HM3 required general anesthesia. Patients treated with the Lithostar also required more sessions and a greater number of shock waves than those treated with the HM3. Ten patients treated with the Lithostar (20%) ultimately required common bile duct exploration because of incomplete stone clearance.

In another recent study, Weber and colleagues reported the results of extracorporeal piezoelectric lithotripsy in 19 patients with complicated bile-duct stones.[15] With this lithotripter, stones are visualized by ultrasound and shock waves are produced by a piezoelectric acoustic generator. Fragmentation was achieved in 84% of patients, and complete stone clearance was achieved in 79% of patients. No general anesthesia was necessary, and only 25% of patients required analgesia and sedation, making this technology attractive for elderly and frail patients.

Failure rates for a single session of ESWL vary from 14 to 28%. The most important factor determining outcome is stone size or volume. Other factors, such as the absolute number of stones, chemical composition, radiolucency, and computed tomographic density, are probably of less importance. The number of shocks that can be safely administered is limited by the risk of shock wave damage to adjacent viscera. Impacted stones are also more refractory than free-floating stones for unknown reasons (Figure 12.9.2).[16] Most of the reported variations in fragmentation rates are small and reflect intergroup differences in generator voltage, total number of shocks administered, and lithotripter technology, as well as in the definition of "successful" fragmentation.

FIGURE 12.9.2. Percutaneous cholangiogram showing a large impacted stone in the distal common bile duct after previous biliary-tract surgery.

Regardless of the technology, ESWL is an effective method for fragmenting intraductal biliary calculi. One must always keep in mind that successful stone fragmentation does not ensure complete biliary-stone clearance. Spontaneous passage of residual stone fragments can be anticipated in approximately 40% of patients. The probability of passage depends on the number and size of stone fragments as well as on anatomic factors, such as papillary stenosis, a biliary stricture, or a juxtapapillary duodenal diverticulum. In the majority of patients, complete biliary stone clearance will require the use of one or more adjunctive techniques, such as mechanical, electrohydraulic, or laser lithotripsy, endoscopic extraction, and chemical dissolution. Extraction of residual stone fragments requires direct access to the biliary tree. This is most easily accomplished if there is an established T-tube tract. Transendoscopic extraction is highly successful but may be complicated by variant anatomy or an impacted stone. In such situations, percutaneous transhepatic catheterization of the biliary tree may be necessary for stone dissolution or extraction. Variations in overall biliary clearance may reflect differences in the aggressiveness with which individual centers pursue residual stone fragments transendoscopically or percutaneously (Figure 12.9.3).

ESWL has proved to be safe and effective therapy for selected patients with residual or retained common bile duct stones. At this point there is no consensus about the role it should play in the management of complicated biliary stone disease. At least one recent comparative trial of surgical and endoscopic management of common bile duct stones has documented that they have similar outcomes, judged by technical success and complication rates.[17] In another recent study from Innsbruck, Austria, Schwab and colleagues prospectively evaluated a series of 306 patients with choledocholithiasis treated by surgical exploration or endoscopic sphincterotomy.[18] There was no significant difference between the mortality rates. Among the 199 patients treated surgically, 11% developed complications, 1 patient died from postoperative aspiration pneumonia (0.5%), and 1 patient required a secondary choledochotomy to remove a retained stone that could not be cleared by endoscopic means. Of the 107 patients treated by endoscopic sphincterotomy, successful and uneventful stone extraction was achieved in 87%. Complete stone clearance could not be achieved in 12 patients (9%), and 11 ultimately required choledochotomy.

FIGURE 12.9.3. T-tube cholangiogram following extracorporeal shock wave lithotripsy and surgical extraction of an impacted common bile duct stone. Stone fragmentation was achieved using a water-bath lithotripter containing a spark-gap electrode, but the fragments could not be extracted by either the percutaneous or the endoscopic approaches.

Over the past 15 to 20 years, the mean age of patients undergoing treatment for common bile duct stones has increased considerably. Physicians may be reluctant to recommend a primary surgical approach for these patients because the mortality rate for choledochotomy once approached 5%. However, this rate was computed in the 1960s, before the development of invasive cardiovascular monitoring and improvements in cardiac anesthesia and ICU care. Furthermore, the technique for open choledochotomy has since been standardized.[19] The procedure consists of mobilizing the duodenum and performing a short, longitudinal choledochotomy. Rigid instruments for irrigation and stone retrieval have largely been abandoned in favor of flexible catheters. The combined use of choledochoscopy and completion T-tube cholangiography has reduced the incidence of retained stones in most series to approximately 3%.[20] Advanced age *per se* is not longer viewed as a major determinant of mortality after choledochotomy. Several authors have reported mortality rates of less than 1% and stone clearance rates approaching 100% for patients undergoing choledochotomy for retained or recurrent biliary stones, even in patients older than 60 years.[21]

ESWL should be viewed as an important adjunctive therapy for bile duct stones that are difficult to reach or extract. This includes intrahepatic stones, choledochal stones located proximal to a biliary stricture or in a cystic-duct remnant, and large impacted stones. ESWL may be particularly beneficial in the case of large stones, which are usually resistant to other forms of therapy. In general, transendoscopic extraction should be attempted before considering ESWL. Even if this approach fails, the sphincterotomy facilitates placement of a nasobiliary catheter for possible dissolution therapy and radiographic stone localization during ESWL. Currently, the most effective lithotripters employ water immersion and biaxial x-ray imaging systems. Further refinements in ultrasound and dry-table lithotripters may expand the indications for ESWL, especially in elderly or frail patients, by eliminating the need for general anesthesia and reducing procedure-related complications.

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12.10 Radiologic Management of Biliary Stone Disease

Eric vanSonnenberg, Gerhard R. Wittich, Oliver Esch, Eric M. Walser, and Robert Morgan

Radiology can be used in many ways in the diagnosis and treatment of biliary stone disease.[1–7] How it is actually used is quite operator-dependent. Diagnostic roles for radiology include display of common duct and intrahepatic stones and gallstones, and the diagnosis of related disorders including strictures, inflammation, and tumors. Therapeutic roles for radiology include its use in the removal of common duct and intrahepatic stones, the dissolution or removal of gallbladder stones, the treatment of associated problems such as benign strictures and tumors, and the management of complications, including both spontaneous and iatrogenic ones. Although these radiologic techniques are well established, as is true of surgery, the radiologist's expertise often determines the integration of these procedures in patient management at any given institution.

Diagnosis of Biliary Stone Disease

Diagnosis of biliary stone disease may be accomplished radiologically by imaging or by direct cholangiography. Noninvasive detection of stones is accomplished by ultrasound or CT scan. Diagnosis of stone disease with these sectional imaging modalities is accurate in 80 to 90% of cases at best (and many studies suggest the percentage is much lower). Even if stone disease is detected, all of the stones or related strictures may not be visualized. If the clinical question is whether or not there is a stone and the study reveals a stone, however, that information may be sufficient to justify proceeding to operation or other therapeutic intervention.

CT scan and ultrasound usually accurately reveal the anatomic level of obstruction. However, the nature of the obstruction may not always be apparent. For example, a stone that is isodense with bile and is not causing high-grade obstruction may not be visualized, or a short stricture may not be appreciated. In 15% of cases, biliary stones occur in association with another disorder, occasionally a tumor. Imaging by sonography may also yield a false-positive result because of gas, metal clips, or stents.

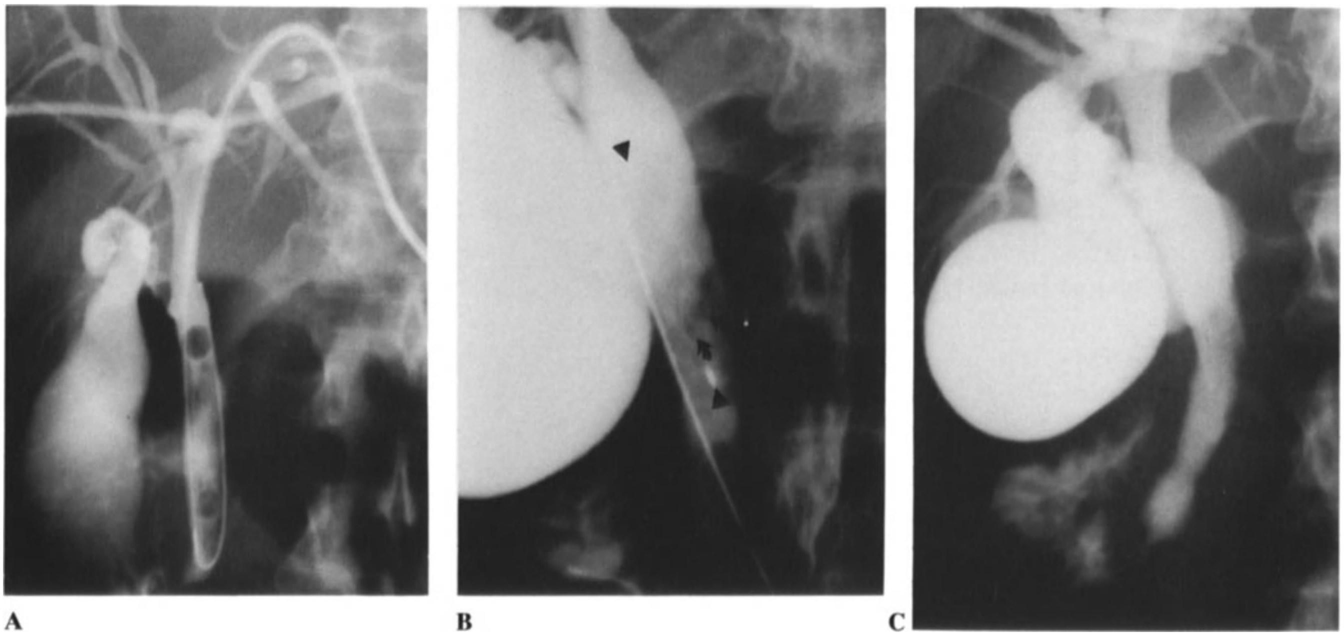
Direct opacification of the biliary tract by percutaneous transhepatic cholangiography immediately reveals the presence of stones, their location, their number, and the level of obstruction. If endoscopic retrograde cholangiopancreatography (ERCP) is used initially and an obstructing common duct stone is visualized, percutaneous transhepatic cholangiography affords further delineation of intrahepatic anatomy and stones. An alternative to percutaneous transhepatic cholangiography is direct puncture of the gallbladder and opacification of the biliary tract via the cystic duct.

Therapy of Biliary Stone Disease

There are many radiologic methods for the treatment of biliary stones. Perhaps the most important method is mechanical decompression to treat cholangitis. Percutaneous biliary drainage (PBD) along with antibiotics successfully treats even life-threatening cholangitis, thereby permitting the stones to be removed when the patient is more stable (Figure 12.10.1).

The PBD tract also provides access to the biliary tree for removal of the stones. Biliary stones may be removed *in toto* by baskets or may be fragmented (Figure 12.10.2). Fragmentation is performed percutaneously by mechanical means (Figure 12.10.3), by laser, or by electrohydraulic or ultrasonic lithotripsy. The appropriate tract size depends on the size of the stone and the instrument to be used for fragmentation (Figure 12.10.4). Transhepatic tracts as wide as 30F have been created and used.

Dissolution therapy is reserved for gallbladder stones.[8–10] Our agent of choice is currently ethyl propionate, although methyl tertiary butyl ether has seen much wider use. Ethyl propionate is less flammable, has a less-noxious odor, and is about as effective as methyl tertiary



A B C

FIGURE 12.10.1. Percutaneous treatment of acute cholangitis in a patient who was severely ill and had had multiple prior operations. *A,* Initial percutaneous biliary drainage was achieved via the right hepatic duct and served to decompress the bile ducts. *B,* A left-bile-duct access route served as a conduit for removal of stones one week later, after the patient had recovered from cholangitis. In this image the basket has engaged the stones. *C,* After basket removal of stones, the duct is clear and contrast flows into the duodenum.

butyl ether. Both of these agents will actively dissolve cholesterol gallstones, and both are considered investigational by the Food and Drug Administration.

A variety of techniques may be used to treat complex intrahepatic stone disease. Occasionally, multiple tracts are needed to provide optimal access to the stones. Occlusion balloons, dilatation balloons for strictures, flushing and irrigation maneuvers, and metal or plastic stents may be used in therapy.

Oriental cholangiohepatitis, the most fulminant intrahepatic stone disease, is the most common biliary stone disease in the Orient. It is characterized by intrahepatic and extrahepatic biliary sludge, mud, and stones that are composed of black pigmented material. Strictures are common, and gallbladder stones are seen in about one-third of cases. The worm *Clonorchis sinensis* is thought to be a secondary manifestation of this disease, not its cause. These patients usually undergo a surgical anastomosis to allow stones to drain into the intestine. After the operation, recurrent stones are managed percutaneously. No agent is able to dissolve these stones.[11]

Another therapeutic maneuver for intrahepatic stone disease is the Hudson-Russell loop. This is a jejunal loop that is buried subcutaneously and affixed to the bile duct to permit re-entry into the biliary tract. Repuncture of the loop allows repeated percutaneous access to the bile duct.

The so-called rendezvous technique, whereby the radiologist passes an antegrade guidewire past an obstructing bile duct stone to an endoscope that is situated in the duodenum is popular in some institutions. The endoscopist grasps the guidewire, and this maneuver permits access

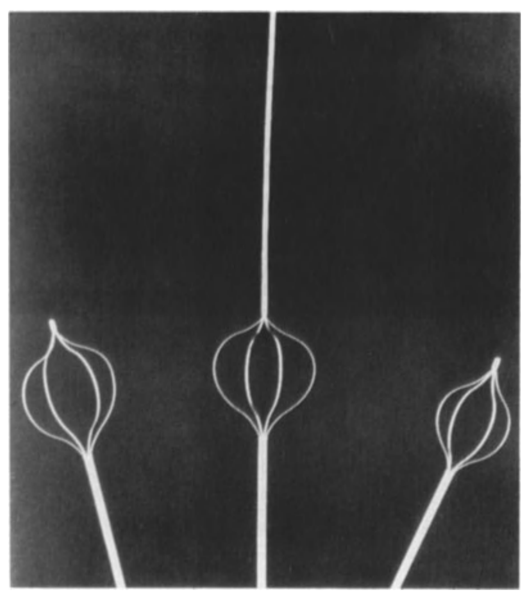
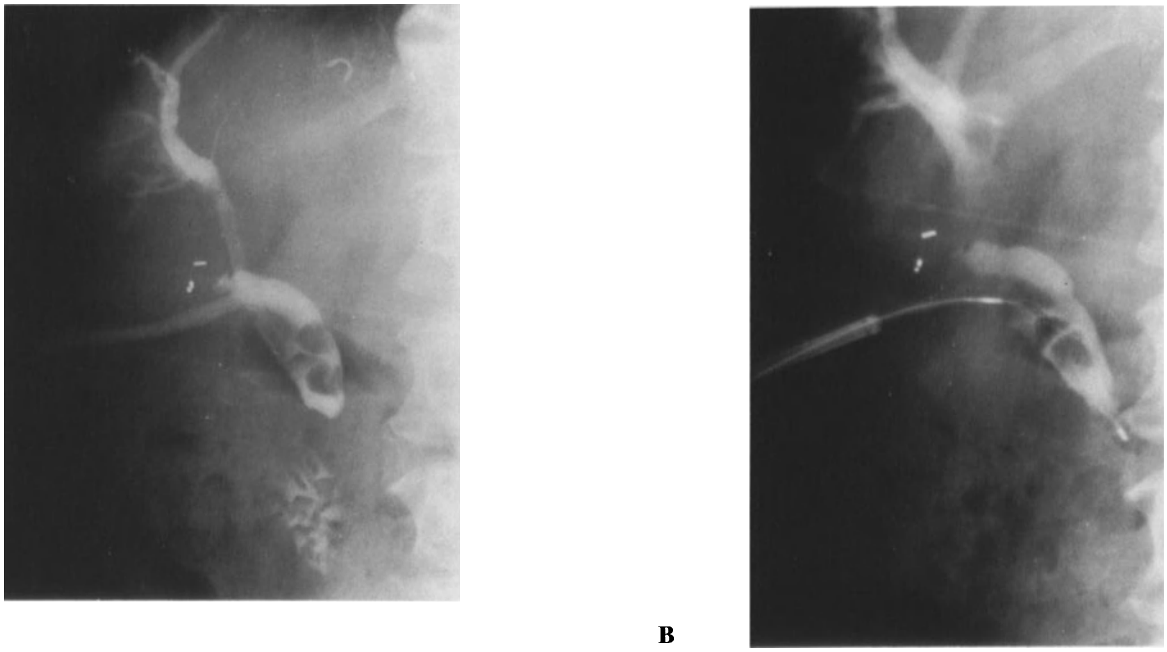
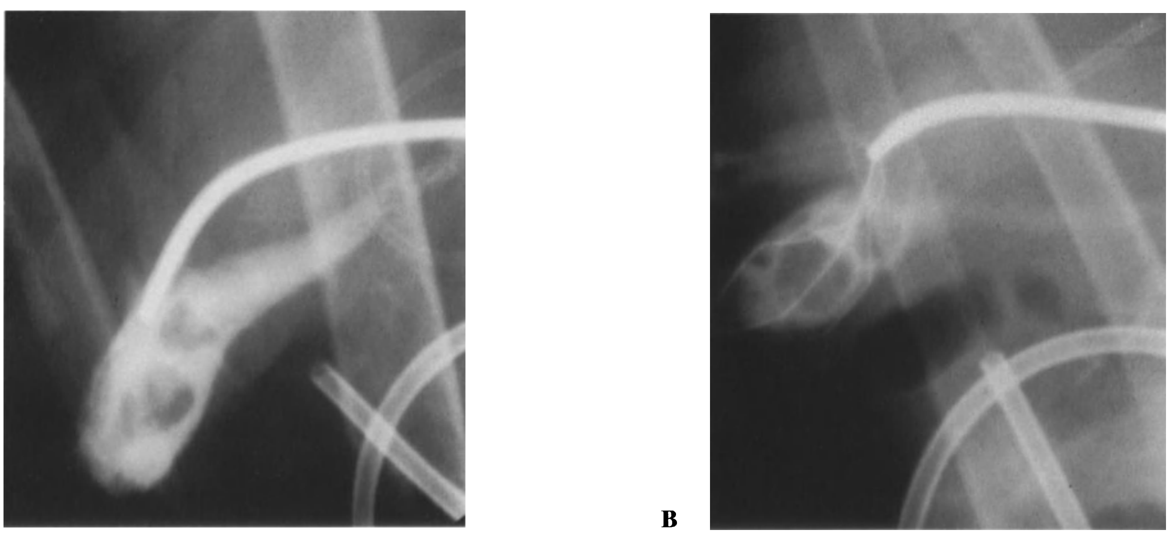


FIGURE 12.10.2. Various baskets used for percutaneous extraction of biliary stones; the middle basket has an attached guidewire for safety.



A B

FIGURE 12.10.3. Classic Burhenne technique for T-tube extraction of gallstones. *A,* Postcholecystectomy T-tube injection reveals several retained bile-duct stones. *B,* A basket has been inserted through the T-tube tract. The basket has engaged several stones. These stones were extracted through the tract.



A B

FIGURE 12.10.4. Percutaneous extraction of gallbladder stones. *A,* The sheath has been placed into the gallbladder percutaneously after percutaneous cholecystostomy for empyema of the gallbladder. The gallbladder is opacified via the sheath and multiple gallstones are noted. *B,* The basket has engaged several of the stones. The stones were crushed and removed percutaneously.

to the bile ducts from below. This facilitates retrograde removal of stones that otherwise would be inaccessible to the endoscopist. A final alternative is to manage the stone percutaneously.

Radiologic Imaging and Intervention for Complications of Laparoscopic Cholecystectomy

The benefits of laparoscopic cholecystectomy are clear, but perhaps because of the newness of the technique or anatomic variations, complications have been fairly common and sometimes life-threatening.[12,13] These complications are of two types—fluid collections and bile duct injuries. The former usually are due to leakage of bile from the cystic duct and the latter to accidental intraoperative injury to the common hepatic duct.

Detection of bilomas is done by ultrasound or CT imaging. To determine if there is secondary infection, image-guided needle insertion and diagnostic aspiration are performed. Percutaneous drainage is accomplished by insertion of a single-lumen catheter or a sump system. As long as all collections are evacuated by a sufficient number of catheters, this technique is usually successful and re-operation is avoided.

Treatment of bile duct injuries is more complex. The presenting problems of cholangitis, jaundice, and pruritus are treated by percutaneous biliary drainage. If the injury or stricture can be traversed, a stent is inserted or balloon dilatation is attempted. In most cases, once the patient's condition improves after percutaneous biliary drainage, surgical treatment with a hepaticojejunostomy is performed.

Complications after open cholecystectomy also may be treated percutaneously.[14] Re-operation is avoided in most patients. An interesting subset of these patients have inadvertent ligation of an aberrant right hepatic duct. In these patients, the percutaneous biliary drainage catheter aids the surgeon by serving as a landmark that permits identification of the ligated duct. This aids the surgeon to create an anastomosis between a jejunal loop and the ligated duct.

Summary

Diagnostic and therapeutic radiologic studies play an essential role in detecting biliary stones, treating those stones, and managing complications of therapy. The cooperation of the surgeon and radiologist is ultimately of great benefit for patients.

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13 Laparoscopic Antireflux Surgery

13.1 Laparoscopic Nissen Fundoplication for Gastroesophageal Reflux Disease

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Introduction

Gastroesophageal reflux disease (GERD) is a common disorder affecting up to 40% of the American population.[1] The resultant esophagitis occurs in all age groups, and medical therapy is not always successful. Patients unresponsive to acid-reduction therapy and those with early recurrence of symptoms after cessation of medical management often have an irreversible injury of unknown origin to the lower esophageal sphincter. The result is intractable reflux of gastric juice into the distal esophagus with symptoms such as heartburn, regurgitation, cough, dysphagia, and recurrent pneumonia secondary to aspiration.

Surgery for GERD was originally developed for correction of the associated hiatal hernia, often considered the primary etiologic factor for the disorder.[2] Symptom recurrence was common with this approach, and fundoplication procedures were devised to restore the competence of the lower esophageal sphincter. Results improved, but long-term follow-up revealed that symptoms returned in as many as 40% of patients. Iatrogenic esophageal perforation, postoperative splenic hemorrhage, and problems such as dysphagia, the gas-bloat syndrome, and fundal ulceration were reported.

In the last 20 years surgery for the correction of GERD has become more popular because precise operative techniques designed to correct specific deficiencies of the antireflux mechanism have improved long-term results.[3] Preoperative evaluation, including upper gastrointestinal endoscopy, esophageal manometry, and 24-hour pH monitoring has improved selection of patients who will respond favorably to an antireflux procedure.[4] Eighty to ninety percent satisfactory results at 10-year follow-up can now be expected with antireflux surgical procedures.[5,6]

After the success of laparoscopic cholecystectomy,[7,8] numerous minimum-access operations have gained popularity. Among the more-advanced procedures, laparoscopic Nissen fundoplication has been accepted as an appropriate investigational operation.[9–11] Early results have demonstrated reduced morbidity and a mortality rate comparable to that of open Nissen fundoplication. This chapter will review the diagnostic and therapeutic approaches to GERD, alternative laparoscopic antireflux operations, the technical aspects of laparoscopic Nissen fundoplication, technical difficulties, and our results with this operation.

Medical Therapy

Acid-neutralizing medications may be helpful to control heartburn and regurgitation. Medical treatment relies on antacids, postural therapy, dietary restrictions, and in more-severe cases, acid-reduction therapy using H_2-receptor antagonists or omeprazole, a hydrogen potassium ATPase inhibitor. Many patients do not follow a regular dosage schedule. Others take their medication in inadequate doses or as needed. Thus, the esophageal mucosa does not always heal.

Patients with good symptom response to traditional peptic ulcer H_2-blocker dosage levels and grade 1 or 2 esophagitis (Table 13.1.1) are treated for 6 to 12 weeks. Nighttime refluxers, patients with grade 3 to 4 ulcerative esophagitis, and the complications of esophagitis, such as aspiration pneumonia, stricture, and Barrett's esophagus, require higher doses of H_2-receptor antagonists given two to four times a day for 8 to 12 weeks or omeprazole for 8 to 12 weeks.[12] If symptoms persist, a prokinetic agent may be tried. Cisapride, a newly released prokinetic pharmaceutical with minimal side effects, may be helpful in some patients whose symptoms persist despite H_2-blocker therapy. This medication does directly affect lower esophageal body pressure when taken orally, and does increase the rate of gastric emptying. It has been demonstrated that cisapride can reverse the histologic changes of esophagitis as effectively as H_2 blockers.[13]

TABLE 13.1.1. Savory-Miller classification of reflux esophagitis.

Grade	Endoscopic features
1	One or more supravestibular nonconfluent mucosal lesions with or without exudate or superficial erosions. Erythema may accompany these findings.
2	Confluent erosive exudative lesions.
3	Circumferential erosive exudative lesions with mural inflammatory infiltration.
4	Chronic mucosal disease: ulcers, mural fibrosis, strictures, scarring with columnar epithelium or short esophagus.

Most authorities agree that an initial trial of medical management with H_2-receptor antagonists is reasonable before beginning a formal work-up for GERD. The duration of the trial should be determined by several variables, including symptom severity, breakthrough symptoms, and the patient's ability to pay for medication. Weight reduction, although sometimes helpful, rarely occurs. A careful assessment of early return of symptoms after cessation of medication is essential. If pretreatment symptoms recur within one week, further evaluation is indicated.

Testing

Upper Gastrointestinal Endoscopy

If initial medical therapy fails, endoscopy is appropriate to identify complications such as Barrett's esophagus, stricture formation, esophageal malignancy, peptic ulcer disease, duodenogastric reflux, or gastric outlet obstruction. Although an upper gastrointestinal radiographic series may be helpful in ruling out these disorders, endoscopy allows for biopsy and the evaluation of histologic sections. Endoscopy can also assist in predicting the need for continued aggressive acid-reduction therapy.

Various endoscopic grading systems have been introduced to assist in determining the severity of GERD. The presence of erythema, fibrin-covered erosions, or ulcerations indicates the need for further therapy. Table 13.1.1 lists the findings for grades 1 through 4, which are incorporated in the evaluation algorithm in Figure 13.1.1. In some cases no evidence of esophagitis is present on gross inspection or on biopsy of the distal esophagus, yet symptoms of heartburn persist. If medical management of these patients results in improved symptomatology, the presence of GERD can be assumed, and further medical management is appropriate.

Manometry

Esophageal manometry is beneficial because it accurately predicts the competence of the lower esophageal segment. Gastric juices will flow into the esophagus if the positive pressure of the abdomen exceeds the resistance of the lower esophageal sphincter mechanism. The resistance of the sphincter depends on three interrelated factors: average resting pressure, overall sphincter length, and abdominal sphincter length. A deficiency in one may be compensated by adequacy in another, but if all three are deficient, the patient will invariably have pathologic reflux.[14]

Esophageal-body motility is an important factor in patients with GERD and must be determined preoperatively.[15] Approximately 10% of patients with intractable esophagitis will have a competent lower esophageal segment but inadequate body function. A 360° fundoplication is not only unnecessary but contraindicated in these patients, because intractable postoperative dysphagia will result. Table 13.1.2 describes various manometric and pH-monitoring findings in patients with intractable GERD and gives the appropriate therapeutic options.

Twenty-Four-Hour pH Monitoring

Twenty-four-hour pH monitoring, first developed for clinical use by Johnson and DeMeester,[16] has become the "gold standard" for GERD. Twenty-four-hour pH monitoring discriminates between normal patients and those experiencing heartburn and regurgitation with an accuracy of 96%. Esophageal pH recordings can also determine the pattern of supine, upright, or combined reflux, findings that may have an important bearing on the etiology of esophageal-reflux disease. The combined modalities of pH monitoring, esophageal manometry, and upper gastrointestinal endoscopy have a high specificity and sensitivity for the accurate diagnosis of GERD.[17]

The test requires placement of a pH-sensitive probe into the distal esophagus. By convention, the probe is placed 5 cm proximal to the upper border of the lower esophageal sphincter. The probe is connected to a digital computerized recorder. The patient records episodes of heartburn, meal times, and changes in position. Data are entered into a preprogrammed computer, which produces a quantitative score based on the number and length of pH episodes below 4. The 3-mm probe produces minimal patient discomfort.

Gastric Acid Analysis

In the occasional patient with esophagitis, hyperacidity is a contributing factor. Hyperacidity is often found in patients who, on manometry, have normal esophageal-body function and a competent lower esophageal segment but a positive 24-hour pH score. In these cases it is possible that a small amount of acid reflux of a concentrated nature can result in abnormal esophageal acid exposure. Gastric-acid analysis is also indicated in patients with an inordinately high 24-hour pH score and those with a history

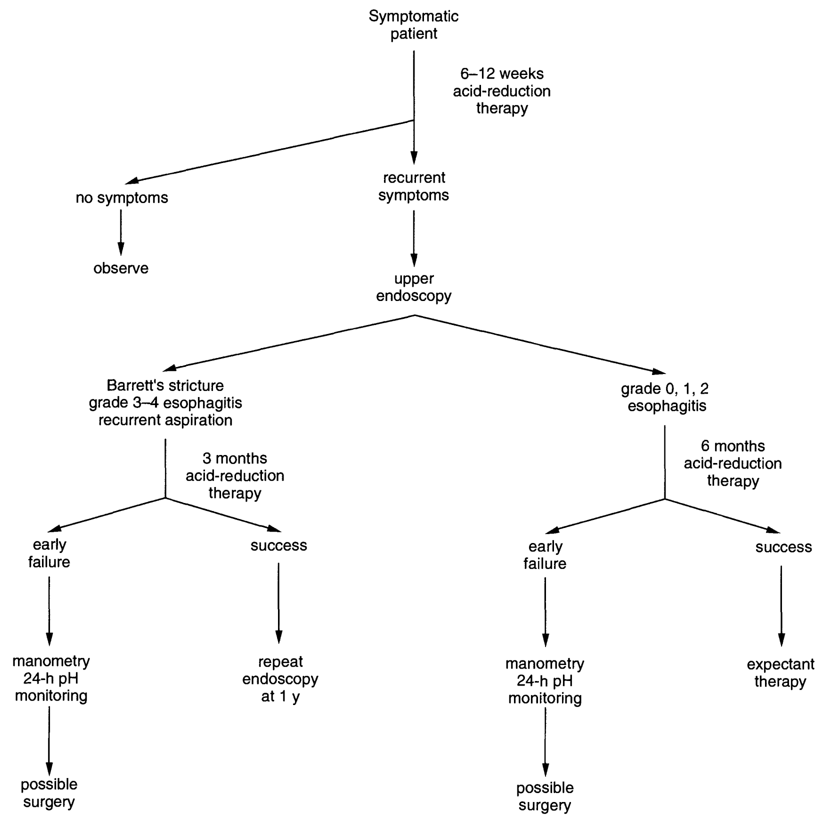

FIGURE 13.1.1. Treatment algorithm.

TABLE 13.1.2. Manometry 24-hour pH monitoring.

Results	
Competent LES Normal body motility Negative 24-h pH	Medical management.
Incompetent LES Normal body motility Positive 24-h pH	Fundoplication.
Incompetent LES Ineffective body peristalsis Positive 24-h pH	Loose fundoplication.
Incompetent LES Normal body motility Negative 24-h pH	Rule out alkaline reflux esophagitis. If present, consider fundoplication.
Competent LES Ineffective body peristalsis Positive 24-h pH	Acid-reduction therapy. (No good esophageal prokinetic agent available.)
Competent LES Ineffective body peristalsis Negative 24-h pH	Acid-reduction therapy.
Competent LES Normal body motility Positive 24-h pH	Gastric-acid analysis. If positive, consider proximal gastric vagotomy.
Incompetent LES Ineffective body peristalsis Negative 24-h pH	Rule out alkaline reflux esophagitis. Possible loose fundoplication.

of recurrent peptic ulcer disease in conjunction with GERD. A serum gastrin level is often obtained to rule out the Zollinger-Ellison syndrome. If the gastric analysis is positive for hypersecretion, a proximal gastric vagotomy may be indicated.

Indications for Antireflux Surgery

Failure of medical therapy is the most-common indication for surgery. Complications of GERD, such as nocturnal choking episodes, aspiration pneumonia, stricture formation, and Barrett's esophagus, accelerate the need for surgical intervention. Manometric and pH monitoring are essential in identifying appropriate candidates for surgery.

Manometry revealing an ineffective lower-esophageal sphincter and normal esophageal-body peristalsis together with positive 24-hour pH monitoring are indications for Nissen fundoplication. Patients with ineffective body peristalsis, a positive pH score, and an incompetent lower esophageal sphincter require some form of surgical correction. The motility disorder is often secondary to GERD and will not respond to prokinetic medication or improve with prolonged acid-reduction therapy. A loose Nissen fundoplication (a 2-cm space under the left limb of the wrap after suture placement) or a partial fundoplication, such as the Toupet, Hill, or Belsey Mark IV operation are suitable alternatives. Postoperative dysphagia can be avoided in most circumstances. If the patient has scleroderma with minimal or no lower esophageal peristalsis, experienced esophageal surgeons consider Nissen fundoplication to be contraindicated.

Duodenogastric reflux may be present in GERD and can be indirectly detected by an abnormally high alkaline score on 24-hour esophageal or gastric pH monitoring. Although the esophageal symptoms may be corrected by surgery, symptoms of bloating and dyspepsia may persist. A patient forewarned of this postoperative possibility will be less likely to be dissatisfied. Finally, in some instances manometry and pH monitoring may prove normal. If endoscopy is also normal, there is no further need for acid-reduction therapy.

Technical Aspects of Laparoscopic Nissen Fundoplication

Patient Position and Port Placement

Patients are placed either in the supine position, with the surgeon standing on their right side, or in a modified lithotomy position. If the lithotomy position is utilized, the knees are flexed only 35°. This modification of the standard lithotomy position permits free manipulation of long instruments. The surgeon stands between the legs, where he has easy access to the instruments (Figure 13.1.2). A 20 to 30° reverse Trendelenburg position improves exposure at the hiatus because gravity causes the fat and viscera to move toward the pelvis.

Port placement is demonstrated in Figure 13.1.3. A common tendency is to place the trocars too low, thus rendering the instruments too short for manipulation at the hiatus. To create the pneumoperitoneum it is sometimes necessary to place the Veress needle very deeply, and to avoid the falciform ligament, the needle should be angled slightly to the patient's left. The first trocar, which accommodates the laparoscope, is placed well above the umbilicus. The remaining ports are introduced under direct vision. All ports are 10 or 11 mm in diameter, thus providing access for larger instruments. Angulation of the ports toward the hiatus at the time of introduction facilitates easy instrument manipulation. Improper angulation requires extra and uneven forces to be applied to instrument handles.

Initially we used a 5-mm grasping forceps to elevate the lateral segment of the left lobe of the liver from the hiatus. Although this technique was adequate in most patients, it presented difficulties in those with an enlarged liver. We have found a liver retractor with three 10-mm-wide blades (Figure 13.1.4) to be effective and now prefer it. The retractor may be handheld or, if available, a mechanical holder attached to the table will suffice.

Retraction of the stomach and esophagus can be accomplished with a grasper or Babcock forceps introduced through the left subcostal port in the anterior axillary line. The first assistant stands to the patient's left, and the second assistant, on the patient's right, holds the liver retractor and camera. The angle between the instruments and the hiatus permits left lateral retraction of the esophagus and downward retraction of the stomach. Both are essential if the laparoscopic procedure is to be safely conducted. Instruments with a greater contact area are ideal

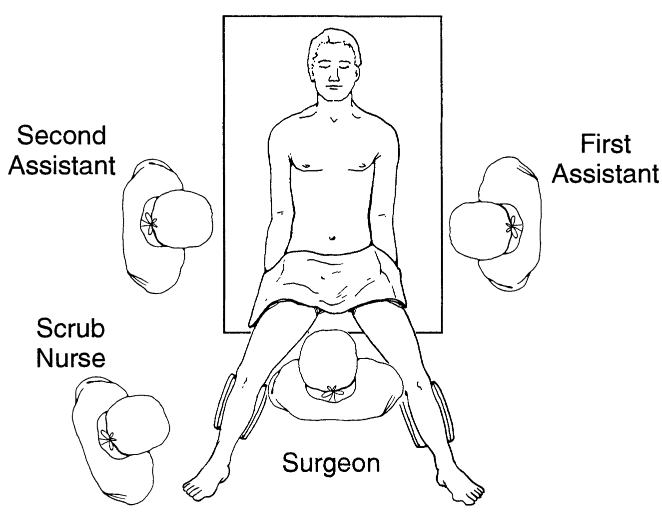

FIGURE 13.1.2. Positioning of the patient, surgeon, and assistants.

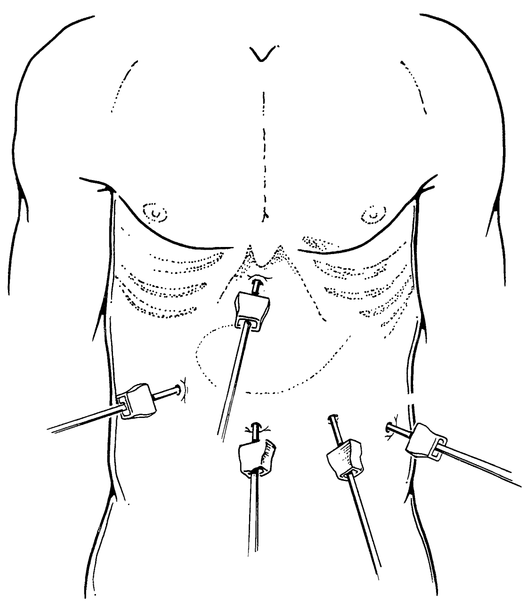

FIGURE 13.1.3. Port positions for laparoscopic Nissen fundoplication.

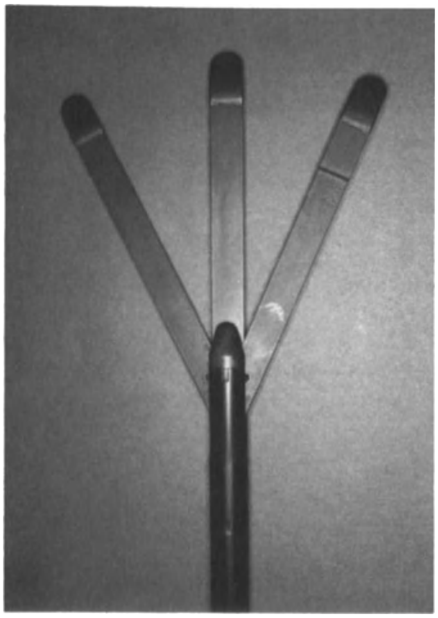

FIGURE 13.1.4. US Surgical Corporation's 10-mm liver retractor.

FIGURE 13.1.5. This Babcock grasping forceps is suitable for hiatal surgery because of its length (Ethicon, Inc.).

but do not entirely prevent the possibility of perforation. The grasping forceps shown in Figure 13.1.5 is our preferred instrument because it is longer and has an excellent locking mechanism that ensures a secure hold on the stomach when creating the wrap.

Meticulous hemostasis is critical to the success of this procedure. It is difficult to see anatomic structures if there is even a small amount of bleeding because blood accumulates in the hiatus even when the patient is in the reverse Trendelenburg position. Hemostasis can be ensured by applying cautery current liberally as tissue planes are developed. We prefer to use the L-shaped hook cautery rather than the cautery scissors. Traction is applied on small amounts of tissue, and the cautery current is used to divide the tissue. If excessive traction is applied, small blood vessels are disrupted, and troublesome bleeding may occur.

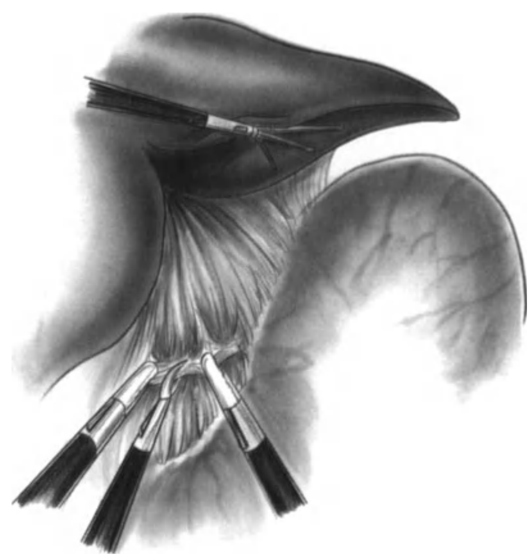

FIGURE 13.1.6. The line of dissection adjacent to the liver provides safe and rapid access to the hiatus.

Exposure

The initial maneuver, which exposes the distal esophagus, is division of the gastrohepatic ligament from about the level of the left gastric artery to the hiatus. It is important to stay close to the liver (Figure 13.1.6) and to be aware of the possibility that the left hepatic artery may be aberrant (as it is in 12% of subjects). Inadvertent damage to a left hepatic artery can result in significant hemorrhage. Dissection of the gastrohepatic ligament results in the identification of the right crus of the diaphragm. Even in the most obese patients this structure is easily found. Improper retraction of the liver or stomach is the only obstacle to identification of the right crus.

A complete dissection of the crural structures is accomplished, which exposes the landmarks necessary for safe posterior dissection of the esophagus. The hook cautery or cautery scissors is used to skeletonize the hiatus. It is especially important to expose the most-posterior aspect of the left crus as this is the most critical preliminary step in creation of the posterior window (Figure 13.1.7). Blunt dissection of the esophagus from the anterior and lateral aspects of the hiatus can easily be accomplished after exposure of the crural muscle fibers. If a hiatal hernia is

FIGURE 13.1.7. Complete exposure and dissection of the posterior aspect of the left crus is imperative.

FIGURE 13.1.8. Retraction of the esophagus with the first assistant's forcep and the surgeon's left-hand instrument facilitates dissection of the posterior left crus.

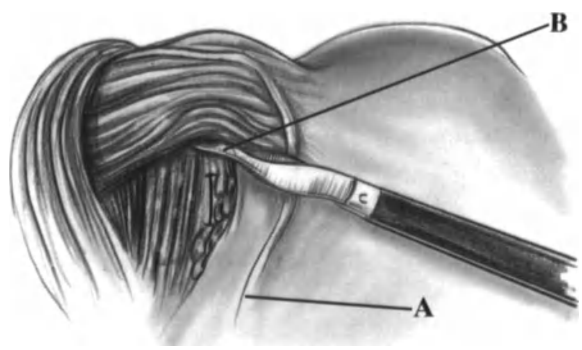

FIGURE 13.1.9. The posterior opening for the fundoplication is created just caudad to the posterior left crus.

present, the sac will be divided during exposure of the muscle fibers.

The esophagus can then be elevated by the first assistant's closed Babcock clamp. Grasping the esophagus for retraction is contraindicated. The end of the Babcock needs to be placed just inferior to the left crus to avoid dissection of the esophagus in the mediastinum, which can lead to a pneumothorax. Figure 13.1.8 shows the correct position of the surgeon's left-hand instrument tip before posterior dissection of the distal esophagus. It is important to note that this instrument also lifts the esophagus, thus helping to expose the essential landmark, the posterior left crus.

Creation of the Window Posterior to the Esophagus

The window is made just below the left crus and above the posterior gastric fundus (see Figure 13.1.9). Gastric and esophageal perforations have occurred when dissection was performed too inferiorly at point A in Figure 13.1.9 or too anteriorly at point B. It is very important that the posterior left crus be completely dissected before creating the window. It is 1 cm wide and has a firm consistency easily felt by the surgeon's right-handed blunt grasping forceps as it is swept inferiorly after left lateral and anterior retraction of the esophagus (Figure 13.1.10). In thinner patients, if retraction is correct, the posterior crus presents as a visible ridge of tissue covered by paraesophageal fat. The left crus can also be identified by closely observing the posterior vagus nerve as it curves over the structure (Figure 13.1.11). After complete dissection of the crus and blunt preliminary mobilization of

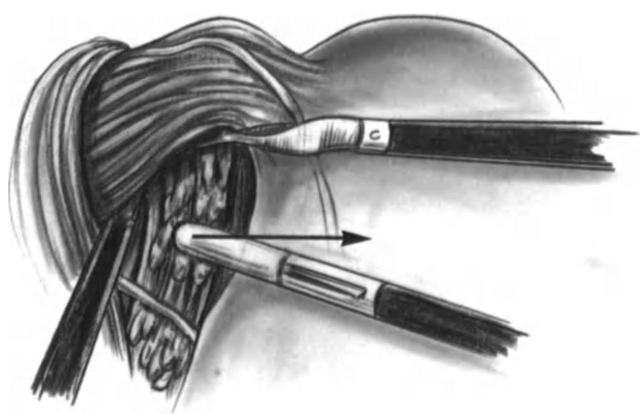

FIGURE 13.1.10. Identification of the left crus posterior to the retracted esophagus is accomplished most easily by instrument palpation.

FIGURE 13.1.11. The posterior vagus nerve drapes over the left crus.

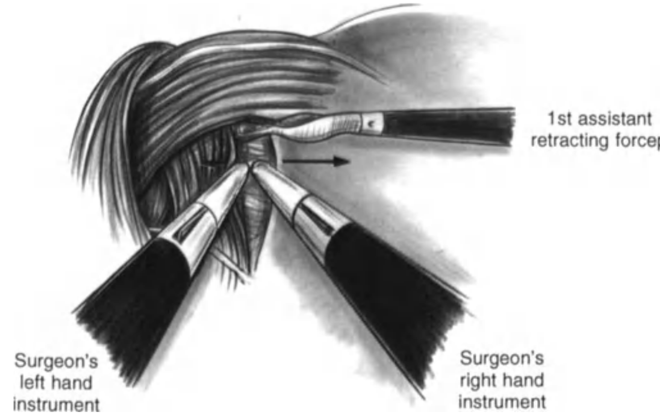

FIGURE 13.1.12. To safely create the posterior window closed blunt instruments are used.

the esophagus, the posterior vagus nerve will almost always be visible.

The posterior vagus is swept inferiorly by gentle blunt or cautery-assisted dissection. The window can then be created by exposing the muscle fibers of the posterior left crus. A safe position is 2 cm below the lower edge of the exposed esophagus at the level of the left crus and within a millimeter of the inferior edge of the posterior crus. A spreading action between the instrument tips of two 5-mm closed grasping forceps (Figure 13.1.12) will create a small opening. The angle of dissection is turned just caudad to avoid injury to the diaphragm, and the dissection is continued until a fine peritoneal tissue plane remains. After the surgeon breaks through the membrane with blunt dissection, the spleen or fundus will be clearly visible. The two closed forceps are spread to create a 4- to 5-cm opening. The first assistant's retracting forceps is then introduced through the window. Some surgeons prefer to place a Penrose drain around the distal esophagus to retract it.

Suturing the Crura Posterior to the Esophagus

Maximal abdominal length of the sphincter is essential to the success of a Nissen fundoplication. To secure the wrap in the abdomen, closure of the hiatus is necessary. We use 2–0 polypropylene suture (Prolene, Ethicon Inc.) on a straightened needle. Care must be taken to avoid injury to the posterior wall of the esophagus when placing sutures in the left crus. Knots are tied extracorporeally using a knot pusher. If the surgeon prefers a polyfilament suture, intracorporeal knot tying is more effective because the knot pusher does not slide well on polyfilament suture. After suture placement, a 60F dilator is introduced into the esophagus and passed into the stomach to ensure that the hiatus is not too tightly closed. Two deeply placed sutures are satisfactory for most patients. The right crus is often thinner than the left, and therefore we include the lateral peritoneal covering of the right crus to prevent the stitch from tearing out.

Mobilization of the Greater Curvature

Greater-curvature mobilization of the stomach is currently a matter of considerable debate. Our group feels that mobilization allows us to consistently construct a loose wrap.[3] This is accomplished by elevating the gastrosplenic ligament approximately 10 cm from the angle of His. An atraumatic finely serrated 5-mm grasping forceps should be used by the first assistant to avoid tearing fatty tissue or the short gastric vessels themselves. The surgeon holds the stomach so that the ligament is horizontal and under tension. Small amounts of tissue are divided with the L-shaped hook cautery to expose the vessels. An automatic clip applier is essential, and we apply two clips to each side of the vessel but without full skeletonization. Excessive dissection leads to unnecessary bleeding. To prevent retraction of vessels into the stomach wall, clips are placed on the gastric side approximately 1 cm from the greater curvature (Figure 13.1.13). To avoid conduction of the cautery current to clips and the stomach, three-quarters of the clipped vessel is cut with scissors and the last part is divided with the cautery current. The L-shaped cautery in the surgeon's right hand then holds up the divided vessel just medial to the clips on the splenic side, and the assistant repositions his forceps inside these clips. Tension is reapplied, and the next set of vessels are ligated. In most cases, we can ligate the short gastric vessels using a 0° laparoscope, but some surgeons feel that a 30° instrument is helpful.

The Fundoplication

After mobilization of the greater curvature, the liver retractor is removed from the right subcostal port, and a Babcock clamp is introduced. The esophagus is elevated, and, under direct vision, the Babcock is moved through the window until it can be visualized on the left side of the esophagus. The stomach is grasped approximately 6 cm from the angle of His and just posterior to the short gastric hemoclips and transferred to the Babcock clamp. The right limb of the wrap is pulled behind the esophagus between the posterior vagus nerve and the esophagus. The vagus nerve helps hold the wrap in place. Choosing the appropriate position for the left-limb sutures is crucial. We attempt to have the limbs be in continuity, so that traction on one limb moves the other. This avoids a spiral wrap, which can include the body of the stomach in the left limb of the wrap. Paradoxically a spiral wrap may create dysphagia, because the body of the stomach does not relax in concert with the lower esophageal segment, or recurrent reflux if the wrap is too loose. After the right limb is in position, we choose a point as high as possible on the anterior left surface of the stomach that will allow the two limbs to touch with a 60F esophageal Maloney bougie in place. This requires some testing. Placement of the dilator in the midesophagus during the procedure allows the anesthetist to easily reintroduce the dilator into the stomach to test the tightness of the wrap.

A Teflon-pledget-reinforced 1-cm wide 2–0 Prolene U stitch is our choice for the fundoplication (Figure 13.1.14). A full-thickness suture is placed through the stomach, but only the muscular wall of the esophagus is included to avoid a postoperative esophageal leak. Incorporation of the esophageal sutures is important, because they help to secure the wrap. Extracorporeal knot tying makes it possible to maintain tension as the suture is being tied. The completed wrap is shown in Figure 13.1.15.

Ports are removed under direct vision. A nasogastric tube is not used unless injury to the stomach or esophagus

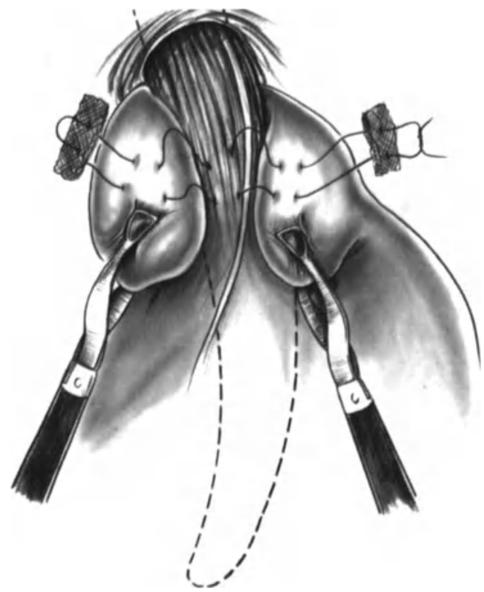

FIGURE 13.1.14. A short wrap over a 60F bougie will reduce the incidence of postoperative dysphagia.

FIGURE 13.1.15. Approximation of the limbs is preferable. An additional suture is placed to secure the wrap. The total length of the wrap is 1.5 cm.

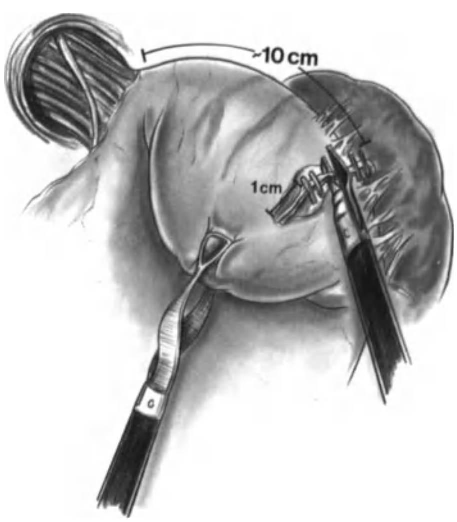

FIGURE 13.1.13. Placement of the hemoclips. A single hemoclip is preferred by some.

is suspected. A postoperative gastrografin swallow is selectively used.

Technical Difficulties

Hiatal Hernia

Gastroesophageal reflux disease is often, but by no means always, associated with a hiatal hernia. Multiple etiologic factors can contribute to excessive reflux and translocation of the lower esophageal sphincter into the thorax is but one of them. Preoperative evidence of a hiatal hernia is not a contraindication to laparoscopic antireflux surgery and in fact a small type-I sliding hiatal hernia sometimes facilitates the dissection. In the case of type-II combined sliding/paraesophageal hernias and type-III paraesophageal hernias there is excess areolar and sac membrane tissue in the hiatus after crural exposure. This can be a significant technical problem, and it makes identification of the left crus and posterior vagus nerve difficult. The patient is at risk for iatrogenic injury of the esophagus and stomach. The subcardinal portion of the stomach remains in the mediastinum after the hernia sac is disconnected from the crus. Anterior and lateral traction on the proximal stomach by the first assistant reveals extra sac and fibroareolar tissue. A combination of blunt and sharp dissection is required to establish the landmarks needed for safe posterior dissection and creation of the window. Palpation of the posterior aspect of the left crus with a 5-mm blunt probe can be helpful.

In patients with large paraesophageal hernias, closure of the hiatal defect can also be difficult. Posterior closure of the crus is easily accomplished in the case of smaller hernias but for large defects, anterior closure with mesh reinforcement is sometimes necessary. If the esophagus is widely mobilized, a fundoplication is appropriate to prevent reflux. The wrap also aids in preventing reherniation after crural closure.

Perforation

In elderly patients excessive traction on the anterior stomach can lead to gastric-wall injury and perforation. If this should occur, laparoscopic suturing may be carried out if the extent of the injury can be seen clearly, otherwise conversion to laparotomy is necessary. A delayed perforation on the greater curvature or at the angle of His can occur secondary to electrocautery burns. Arcing of current to hemoclips or contact injuries caused by cautery probes with inadequate insulation may result in tissue necrosis and perforation. Bipolar scissors can be used to avoid the problem, but most often judicious use of the hook cautery is all that is required. Posterior perforation of the esophagus is a vexing problem unless detected at the time of surgery. If the posterior dissection is difficult, insufflation of the esophagus and stomach and underwater testing is appropriate to rule out a through-and-through injury. Only experienced laparoscopic surgeons should attempt esophageal closure in this circumstance. Conversion to open laparotomy may be required and is indicated if precise tissue apposition cannot be accomplished.

Delayed perforation can occur secondary to full-thickness needle penetration of the esophageal wall during the fundoplication. Inclusion of only the muscular wall of the esophagus is easily accomplished if a ski needle is used and slightly less than a centimeter of tissue included.

Obesity

Safe entry into the upper abdomen of an obese patient can be ensured by closely observing the insufflator flow rate and pressure. If readings are not in the safe range, the Hassan technique is indicated. An experienced first assistant is especially important in these cases, because exposure is limited even if the patient is placed in the steep reverse Trendelenburg position. Difficulty may be experienced in bringing the posterior fundus behind the esophagus. This problem can be addressed by using two Babcock clamps: one for pulling the stomach around and behind the esophagus, and the other to maneuver the fundus into the posterior Babcock. The surgeon's left-hand grasping forcep retracts the medial gastric fundus and helps to gain adequate exposure of the posterior Babcock's instrument tip before the transfer.

Periesophagitis

Periesophageal scarring secondary to penetrating ulcers and stricture formation is somewhat predictable but is occasionally unexpected. Intermittent placement of a 40F bougie may be helpful in identifying the posterior aspect of the esophagus. Blind dissection is contraindicated and conversion to open laparotomy is necessary if hemostasis and safe identification of the posterior left crus and posterior vagus nerve cannot be established.

Alternative Laparoscopic Antireflux Procedures

Hill Repair

The laparoscopic Hill repair, like the open procedure, depends on intraoperative manometry to calibrate gastroesophageal closure and fixation of the abdominal esophagus to the preaortic fascia. Five ports are introduced and, after full mobilization of the distal esophagus and identification of both vagus nerves, four sutures are placed through the anterior and posterior phrenoesophageal ligaments and the preaortic fascia. A 32F bougie is used to stretch the sutures after manometric evaluation of the completed valve. Two additional sutures are placed between the fundus and the muscular crura to make the angle of His more acute. Early results with this technique have been satisfactory.[18]

Toupet Repair

The port placement, dissection of the muscular crura, and creation of the window in the Toupet repair is similar to that of Nissen fundoplication. If the hiatus is large, crural closure and a 360° wrap, rather than the Toupet, is indicated. McKernan, who has performed over 50 laparoscopic Toupet procedures, pulls the posterior fundus through the window and, if the stomach does not retract to the left of the esophagus, omits ligation of short gastric vessels.[19] He places separate nonabsorbable sutures through each crus and the fundus, followed by three interrupted sutures placed through the muscular wall of the esophagus and the fundus on the right and left side. This procedure is ideal for patients who have undergone a laparoscopic Heller myotomy or for those with poor esophageal motility in whom a 360° fundoplication might result in obstruction.

Results

Table 13.1.3 shows the results we obtained with our first 173 patients. The early results are comparable to those obtained with open Nissen fundoplication. Symptom control and postoperative morbidity and mortality were similar.[3,5,6] With the laparoscopic approach the average length of hospitalization was 2.8 days and, after the first 50 cases, nasogastric suction was not considered necessary. The average length of surgery was 2.5 hours and most patients were able to return to work quickly (3.1 weeks).

The serious complications in our series include one death from a duodenal perforation and three intraoperative perforations of the stomach that required closure. Two patients required transfusion, and one patient required re-operation for bleeding from a short gastric artery. Early breakdown of the crural repair occurred in two patients in association with postoperative bowel obstunction. No splenic injuries occurred. A small pneumothorax was noted in three patients, but none required a chest tube. One patient underwent re-operation for intractable heartburn and was found to have an excessively loose wrap. Conversion to open surgery was necessary in 6 of the first 34 patients but in only 1 of the next 139.

Conclusion

Laparoscopic Nissen fundoplication is safe and effective if carried out by experienced esophageal surgeons who have mastered advanced laparoscopic techniques. The learning curve is long, but the results are satisfactory. It is our impression that this procedure may have advantages over the open procedure beyond reduced pain and shortened hospitalization. The occurrence of prolonged early satiety and the gas-bloat syndrome is reduced, and the incidence of splenic injury has been zero in over 750 cases (our series and the series of Dallemagne and DePaula).[20] In the open operation the incidence is 2%. There were no splenic injuries even during the learning phase of the laparoscopic approach.

Several investigators have reported excellent results with other laparoscopic procedures for GERD. A multicenter randomized prospective trial to compare the results by symptom outcome and physiologic testing would be helpful. The long-term outcomes of the open operations have never been compared and, since the laparoscopic procedures essentially duplicate the technical aspects of the open operation, such a study would be valuable for all.

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TABLE 13.1.3. Early results of laparoscopic Nissen fundoplication.

No. of cases	No. of follow-ups	Length of follow-up	Conversion rate	Long-term complications*	Early complication rate†	Mortality rate	Satisfactory result**
173	100	12 mo	4.0%	3.0%	4.0%	0.6%	96.0%

*Dysphagia requiring dilatation, recurrent heartburn.
†Perforation, transfusion, re-operation.
**Visick 1 or 2.

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13.2 Laparoscopic Rossetti Fundoplication for Treatment of Gastroesophageal Reflux

Namir Katkhouda and Jean Mouiel

Introduction

Gastroesophageal reflux disease is a common disorder affecting at least a third of the population. A complex of abnormal anatomic and physiologic factors leads to an imbalance in the normal reflux and clearance of gastric acid from the lower esophagus.

Fundoplication corrects the basic anatomic weaknesses that led to the failure of the lower esophageal sphincter. A new high-pressure zone is created in the wrap to reinforce the existing lower esophageal sphincter, the angle of His is re-established to provide a new protective shutter-valve mechanism, and the crura are repaired to ensure an adequate length of intra-abdominal esophagus.[1] The Nissen fundoplication has repeatedly produced the best results with long-term relief of symptoms achieved in 80 to 90% of patients.[2] Several refinements to the original technique have reduced problems and enhanced reliability.

The feasibility of laparoscopic fundoplication repair has been established by several preliminary reports. Earlier authors employed experimental methods using ligamentum teres cardiopexy,[3] Angelchik prosthesis,[4] or an unmodified Nissen fundoplication.[5] Our earlier experience in the management of benign gastric disorders with gastrojejunostomy[6] and selective vagotomy[7] suggested that gastroesophageal reflux and symptomatic hiatal hernia could be elegantly treated by the laparoscopic method. We will describe the modified Rossetti short floppy fundoplication.

Technique

The operation is performed under general anesthesia with the patient in the lithotomy position. The surgeon stands between the patient's legs and two assistants stand on either side of the patient. A pneumoperitoneum is created by a Veress needle and maintained by electronic insufflation at a pressure of 14 mm Hg. Five trocars are inserted as shown in Figure 13.2.1.

1. 10 mm above and to the right of the umbilicus—the laparoscope.
2. 10 mm above and to the left of the umbilicus—the operating channel.
3. 10 mm left subcostal—the instrument channel.
4. 10 mm xiphoid—retractor.
5. 10 mm right subcostal—retractor, grasper.

A 0° telescope is used with two video screens, but a 30° telescope should be available. Exposure of the gastroesophageal region is achieved by placing the patient in a reverse Trendelenburg of 20 to 30° until the abdominal viscera descend out of the operative field. Nasogastric suction, and upward retraction of the left lobe of the liver using the xiphoid probe are also important. Once exposure has been achieved, the operation proceeds in three

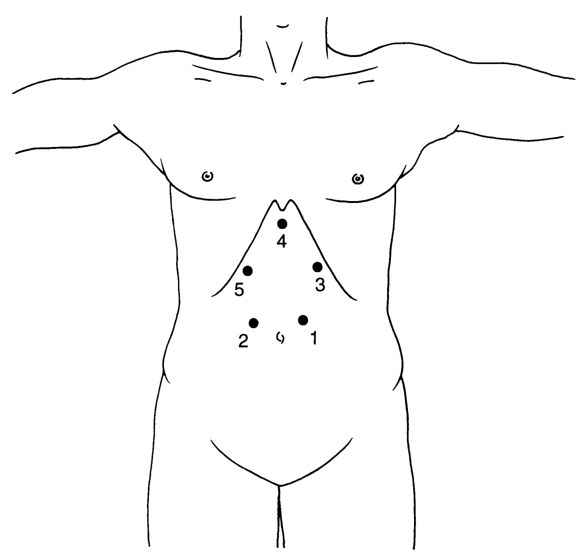

FIGURE 13.2.1. Port placement for fundoplication.

steps: mobilization and dissection of the hiatus; repair of the crura; and fundoplication.

A small window is made in the avascular pars flaccida to the right of the gastroesophageal junction (Figure 13.2.2). The right crus and posteromedial esophagus are seen to lie in close contact behind the peritoneum of the lesser sac. Movement of the nasogastric tube assists the surgeon in clearly identifying the safe avascular plane between the right crus of the diaphragm and the esophagus. The dissection continues posteriorly, freeing the attachments in the lower mediastinum and exposing the posterior vagal trunk. The esophagus is drawn up by blunt retraction by the assistant while the surgeon uses hook dissection. The medial aspect of the left crus courses up and away from the surgeon; it should not be followed or the pleura will be entered. Rather the dissection should cross under the left crus and toward the fundus of the stomach. If it is difficult to produce a window along the posterior greater curvature, the surgeon should not persist. Rather attention should be directed to completing the anterior dissection. The phrenoesophageal membrane is divided, the anterior vagus is identified and preserved, and the angle of His is cleared. The removal of a fat pad is mandatory. At this point a window can be created easily by returning to the posterior direction from the right side. Further mobilization of the fundus and division of short gastric vessels is unnecessary in a certain number of cases; the remaining attachments of the fundus to the diaphragm and spleen should be left undisturbed. A preliminary passage of the wrap should now be done to confirm that mobilization is adequate. The tightness of the wrap can be assessed by a simple test: the passed wrap should be able to stay behind the esophagus by itself after the insertion of a large bougie (56F or 60F). Otherwise, the need to reduce tension mandates freeing the short gastric vessels as in the original Nissen technique.

The Rossetti technique uses only the anterior gastric fundus in the wrap, whereas the original Nissen wrap brought both the anterior and posterior fundus around the esophagus (Figure 13.2.3). Next a 56F esophageal bougie is passed beyond the esophageal gastric junction along the nasogastric tube.

The crura are then repaired. The right and left crura are approximated posteriorly behind the mobilized lower esophagus. The crura may be held in place using a Babcock forceps during the process of suture repair. Three interrupted sutures in the most tendinous portion of the posterior crura are fashioned extracorporeally with 0 nonabsorbable sutures. A posterior crura repair is preferred in all cases.

The wrap is now fashioned (Figure 13.2.4). Atraumatic graspers are used to draw a fold of anterior gastric fundus retroesophageally, while the posterior gastric fundus remains attached to the spleen and diaphragm. The 360° wrap is completed by joining the wrap to the remaining

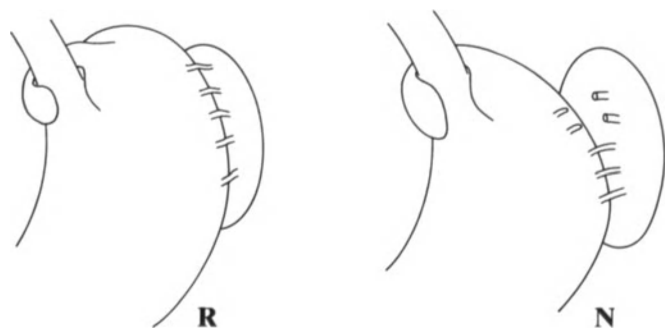

FIGURE 13.2.3. Comparison of Rossetti and Nissen maneuvers.

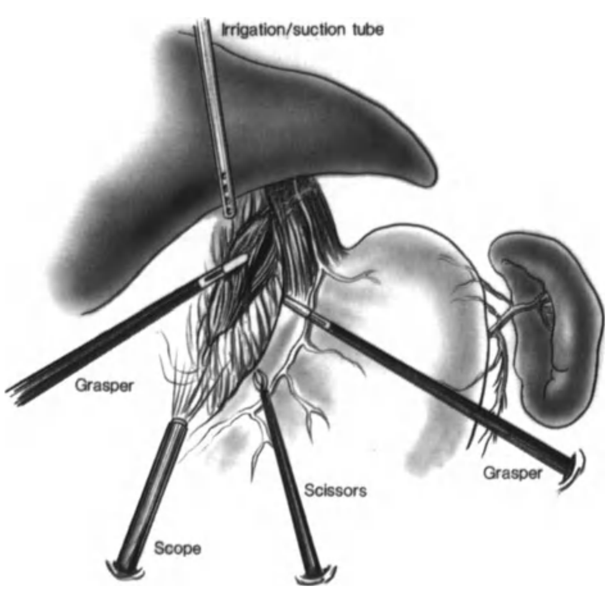

FIGURE 13.2.2. Mobilization and dissection of the hiatus.

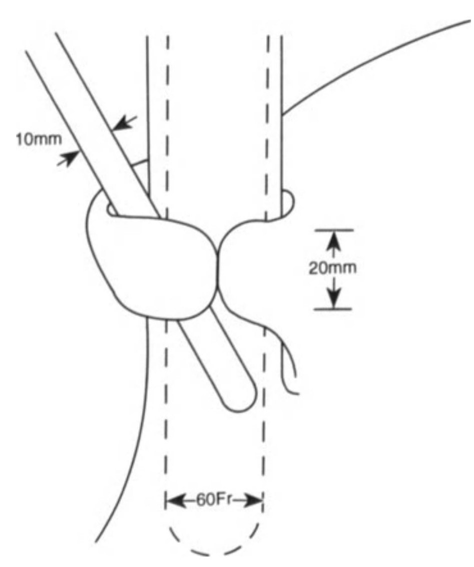

FIGURE 13.2.4. Technical aspects of the wrap.

anterior fundus. The fixation of the wrap is important, and several technical points should be stressed.

The wrap should be floppy, meaning loose enough to allow the free passage of a palpating probe between it and the esophagus. The 60F bougie should be passed repeatedly but very carefully through the wrap to ensure no resistance is encountered (Figure 13.2.4). As described by DeMeester, the wrap should be short: 2 cm in length centered on the lower esophagus.

Three sutures of 3–0 absorbable monofilament are placed intracorporeally using a 5-mm needle holder (Figure 13.2.5A). Finally, the wrap should be fixed to the gastroesophageal junction by two additional sutures to prevent slippage, disruption, or herniation (Figure 13.2.5B).

Patients and Results

The operation has been completed in 62 patients (20 female, 42 male) aged 38 to 71 years. All patients had undergone preoperative endoscopy and biopsy, barium swallows, 24-hour pH monitoring, and esophageal manometry. The average operating time was 80 minutes (range 40 to 165 minutes). No intraoperative injuries occurred, and no postoperative complications developed. The nasogastric tube was removed the following day in all cases. The average hospital stay was 3.3 days (range 2 to 6 days). Follow-up at eight weeks disclosed complete relief of symptoms in 89% of patients and a return to normal pH profile in 84%. Five patients continued to attend the clinic with incomplete relief of reflux symptoms.

Discussion

The long tradition of conventional surgery has provided sound guidelines for new laparoscopic techniques. Many years of clinical research have been devoted to understanding repairs of hiatus hernia with gastroesophageal

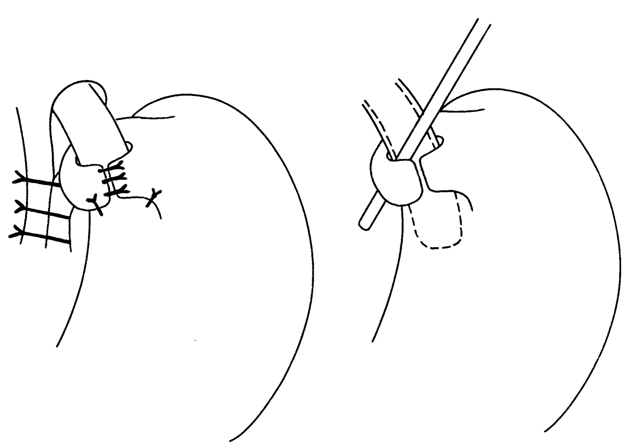

FIGURE 13.2.5. *A,* Wrap ready for fixation. *B,* Final appearance.

reflux. Already laparoscopic cholecystectomy has proved superior to the traditional open procedure. It would appear a *fait accompli* that laparoscopic fundoplication will supersede traditional surgery.

Symptomatic relief of reflux pain, heartburn, can be achieved by antacids protecting the esophageal mucosa, by medical reduction of gastric acid, and by prokinetic drugs. The remaining symptoms of regurgitation, vomiting, waterbrash, coughing with aspiration, and dysphagia are not influenced by medications. Yet even patients with these classic symptoms and the classic endoscopic signs of severe esophagitis related to a mechanical defect of the lower esophageal sphincter are rarely referred for surgery.

Manometry is mandatory in all patients, and 24-hour pH monitoring can identify a small group of patients with unusual esophageal symptoms but normal endoscopic esophageal appearance who have an incompetent lower esophageal sphincter that would benefit from laparoscopic fundoplication. The paraesophageal types of gastroesophageal hernia are also suitable for laparoscopic repair.

In the past patients selected for surgery bore the burden of a long and painful recovery. Laparoscopic fundoplication also allows the patient to avoid lifelong medication or postlaparotomy morbidity. The advantages of this operation should be fully appreciated by all gastroenterologists and surgeons treating reflux esophagitis.

Nissen fundoplication has reliably produced symptomatic relief, mucosal healing, and physiological postoperative pH levels in many large series.[8,9] It has proved superior to all other reflux operations in prospective randomized trials.[10,11] The long-term efficacy of this operation approaches 90%.[12] It has been modified many times to avoid common technical problems: injuries to the surrounding viscera (spleen, pleura, vagi) were recorded in 15 to 20% of cases;[13] early postoperative dysphagia and gas bloat in 35 to 40%;[14] and late postoperative slippage and disruption were estimated to occur in 10 to 15%.[15]

The Rossetti modification is to use only the anterior wall of the gastric fundus for the plication.[16] Dissection around the gastroesophageal junction is minimal, and the short gastric vessels are not divided. The wide mobilization originally described by Nissen was necessary to achieve the long (5 cm) wrap. The short wrap can easily be achieved using only the anterior fundus.

DeMeester[12] has proved conclusively that a wrap 1 to 2 cm in length provides full support to the lower esophageal sphincter without creating an overcompetent sphincter.[12] The fundoplication should be floppy to avoid the dysphagia and gas bloat typical of previous repairs.[9] We recommend that the wrap be made around a 60F intraesophageal bougie, according to DeMeester's studies. The space between the wrap and the esophagus should then admit a palpating probe.

Slippage of the wrap up or down or wrap disruption are due to excess tension and movement in the fundoplication.[15] These technical problems can be avoided by routinely repairing the diaphragmatic crura, thereby maintaining the repair in the abdomen. The wrap is also sutured to the gastroesophageal junction during the fundoplication to prevent migration and slippage.

The adaptation of this modified fundoplication to the laparoscopic technique was found to be simple, safe, and reliable. The technique avoids exposure of the spleen and division of the short gastric vessels, with the attendant risk of hemorrhage. The pleura can be avoided by not dissecting too far superiorly along the left crus, and the vagal trunks can be identified easily through the laparoscope. In contrast to alternative laparoscopic fundoplications no injuries to the pleura, gastric wall, or splenic vessels have been observed.[3,5]

The feasibility and efficacy of this operation have been established, and the necessary surgical skills and equipment should diffuse quickly through the surgical community. Caution and attention to detail will ensure universally good results in the treatment of gastroesophageal reflux.

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14
Laparoscopic Surgery of the Stomach

14.1
Principles of Peptic Ulcer Surgery

Namir Katkhouda, Johannes Heimbucher, and Jean Mouiel

Introduction

Despite successful medical treatment to reduce acid hypersecretion and eradicate *Helicobacter pylori,* surgery still plays an important role in the management of peptic ulcer disease. In the last two decades there has been a decrease in the number of elective operations, while the number of emergency operations for complications of peptic ulcers has increased. Taylor has shown that in the United Kingdom the mortality of duodenal ulcer disease, instead of diminishing, has been stable or risen slightly. It stands at 4,500 a year.[1] One might have expected a decrease in light of the introduction of effective antiulcer medications in the 1970s. The high recurrence rate, up to 90%, following discontinuation of medical therapy, and the consistently high morbidity and mortality should lead to a resurgence of interest in surgery for peptic ulcer disease.[2]

The central question remains: Which patients will benefit from which type of surgery? To answer this question, deep insight into the pathophysiology of peptic ulcer disease is necessary.

Surgical Physiopathology

Schwartz's aphorism "No acid, no ulcer," which dates from the early 1900s, is still accepted as true. The main factor in the pathogenesis of the peptic ulcer disease in the cases of both gastric and duodenal ulcers is acid.[3–5] Unfortunately, neither this factor nor other known pathogenic factors definitively explain all types of peptic ulcers. It seems that the pathogenesis of peptic ulcer disease is not limited to one single factor, but instead that it is very complex and multifactorial.

Knowledge of the physiopathology of both duodenal and gastric ulcers is needed to understand the effect of surgery on duodenal ulcer disease. Gastric acid hypersecretion is present in almost all patients with a duodenal ulcer, but as described by Johnson, only some patients who have gastric ulcer show a high acid pattern on gastric-acid analysis; other have a normal or a hypoacid pattern.[4] In patients with combined gastric and duodenal ulcer or ulcers in the prepyloric region (type 2 and type 3), hyperacidity is present, whereas in a high percentage of patients with the classical lesser-curvature gastric ulcer, there is hypoacidity. Davenport hypothesized hydrogen-ion back-diffusion through a damaged mucosal barrier as a cause of hypoacidity in these cases of gastric ulcer disease.[6]

Dragstedt introduced the concept of delayed gastric emptying in the pathogenesis of gastric ulcers.[7,8] The delay is caused by incomplete obstruction of the pyloroduodenal region or possibly by antroduodenal dysmotility, with stasis causing reactive hypergastrinemia and acid hypersecretion. This theory would explain Johnson's type 2 ulcer. However, many gastric ulcer patients have normal gastric emptying. Some duodenal ulcer patients, on the other hand, have a pathologic rapid gastric emptying. Because the gastric acid and pepsin are not sufficiently neutralized by the gastric chyme during the short period in the stomach, they may cause duodenal hyperacidity and duodenal ulcer.[5]

DuPlessis has shown pathologic duodenogastric reflux to be involved in the development of gastritis and gastric ulcers.[9] Bile and acid are a particularly potent combination for causing mucosal damage, as has been clearly demonstrated by Ritchie.[10]

Weakened mucosal resistance due to insufficient microcirculation, mucus secretion, and disturbed prostaglandin metabolism can also play a role in mucosal damage.[11] Diminished prostaglandin metabolism seems to be the reason for diminished duodenal production of bicarbonate, which leads to a high acid concentration in the duodenal bulb. The fact that recurrences are often at the same locality also indicates that impaired microcirculation and disturbed mucus secretion may be involved.

Another group of gastric ulcers are caused by various medications, such as corticosteroids or nonsteroidal anti-inflammatory drugs, and external agents like alcohol, which can cause mucosal damage to the gastric lumen.

The most recent advance in our understanding of the pathophysiology of peptic ulcer disease has been the discovery of the role of *H. pylori* infection.[12] But a causal relation has been shown only between *H. pylori* infection and type-B gastritis. That it causes duodenal ulcer disease has not yet been proven. Moreover, up to 50% of the asymptomatic general population is infected with *H. pylori.* We can reasonably deduce that *H. pylori* is another possible cofactor of gastroduodenal ulcer disease.[13]

Regarding Schwartz's theory, *H. pylori* infection is linked with hyperacidity,[14] although it has not yet been clearly shown whether the hyperacidity is necessary for the infection or a consequence of it. However, the obligatory coexistent gastritis in peptic ulcer disease is probably caused by *H. pylori* in most cases.

When considering a surgical approach to peptic ulcer disease, it is useful to differentiate those ulcers that could initially benefit from acid reduction procedure from those ulcers that will require resection. Acid reduction is required in duodenal ulcers regardless of the pathogenic cofactors and in type-2 and type-3 gastric ulcers (Johnson's classification).

Since gastric ulcers usually require resection and vagotomy, the main focus of the minimally invasive procedures has been on duodenal ulcers, which are adequately treated with acid reduction procedures only.

Diagnosis

The heterogenous causes of peptic ulcer disease mean that a differentiating diagnostic approach is important. Radiographic or endoscopic verification of the presence of a suspected ulcer gives information about the possible pathogenesis. Furthermore, histologic examination is mandatory to identify the occasional neoplasm. The possibility of *H. pylori* infection should be investigated. Tests in common usage include the CLO-urease test and histologic examination. The gastric secretion test with aspiration of gastric juice (basal acid output and maximal acid output) is widely used to analyze the patient's acid-secretion status.[15] However, the clinical value of this test is limited by the short study period and the overlap between the acid-secretion rates of healthy persons and those of patients with different gastroduodenal ulcer diseases.[16] Therapeutic decisions can be made on the basis of the test only in the case of conditions with markedly increased acid secretion, such as Zollinger-Ellison syndrome or antral hyperplasia. For a more precise diagnosis, ambulatory 24-hour pH monitoring with computerized analysis is necessary. This test also detects pH changes during the night, which are usually missed by gastric secretion analysis performed in the laboratory. It also makes it possible to study pH changes during mealtimes, when an aspiration study is technically impossible.

Medical Treatment

Because the causes of peptic ulcer disease are heterogeneous, no treatment is ideal for all cases. Instead there are various therapeutic options. The relapse rate after short-term therapy with H_2-blockers is up to 90%,[2] and complications such as bleeding, stenosis, or perforations occur in 3 to 6% of cases within the first six weeks of therapy. With continuous H_2-blocker prophylaxis, there is still 20% recurrence within 18 months.[17,18]

Long-term proton-pump blocker therapy is still controversial. The first triple-therapy regimen to eradicate *H. pylori* usually contained bismuth, and we already know of the scarring effect of this substance on the gastric mucosa. Also the more recently introduced combination of omeprazole and amoxycillin is not successful in all cases.[19,35] A relapse rate of between 6 to 10% one year after initial treatment and eradication of *H. pylori* is commonly observed. In addition, the organism frequently recolonizes the antrum after it has been "successfully" eradicated.

Even patients who are successfully treated are saddled with a very expensive drug dependency. Moreover, a portion of the ulcer population is *H. pylori* negative, and the treatment of this population is not yet standardized. Drug treatments also have side effects: carcinoid tumors have developed in the rat after long-term use of a proton-pump inhibitor,[20] and in humans, pseudomembranous colitis has been induced by triple therapy including antibiotics. To decide the issue, surgical and medical therapy should be compared in terms of complication rate, side effects, efficacy (recurrence rate), and cost.

Surgical Treatment

Dragstedt, in 1945, developed the first surgical treatment for peptic ulcers: truncal vagotomy and pyloroplasty.[21] This type of operation had low recurrence rates, but serious side effects, such as explosive diarrhea and dumping.[22] Bilateral truncal vagotomy and antrectomy have the lowest recurrence rate (1.2%) but a higher mortality and morbidity.[23] Personally, we think that gastric resections should not be recommended for a benign functional disease like a duodenal ulcer, or for that matter for any functional disease, unless there is no alternative.

Highly selective vagotomy, initially described by Johnston, has been the surgical treatment of choice for duodenal ulcer since 1970.[24,25] It avoids the undesirable side effects of truncal vagotomy and still gives good results. However, the success of the operation appears to be quite operator-dependent: the recurrence rate in the hands of the expert surgeons is 2 to 10% at 5 to 10 years, but for the average surgeon the recurrence rate ranges from 20 to 40%.[23,26] In some of his publications, Johnston warns that if this operation is performed by nonexperts, recurrence rates will be unacceptably high.[27]

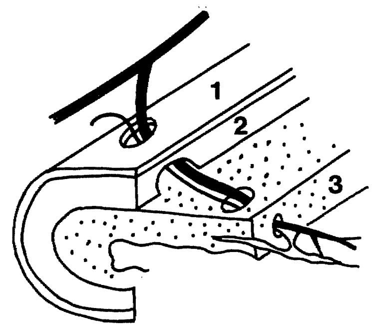
Because of this variability of results our operation of choice is posterior truncal vagotomy and anterior seromyotomy, first described by Taylor in 1982. This is a simple operation with the efficacy of bilateral truncal vagotomy but without its side effects.[28,29,34] It is also an operation that is less tedious than highly selective vagotomy and therefore not as operator-dependent. Nevertheless, we acknowledge that highly selective vagotomy performed in centers with expertise in advanced laparoscopic procedures produces good results.[33]

The Taylor procedure was first performed laparoscopically in Nice in 1989.[30–32] The operation is based on the anatomic studies of Latarget, who showed that the secretory nerves, originating from the anterior and posterior gastric nerves, course through the superficial seromuscular layer of the stomach before penetrating the gastric wall beyond the vascular pedicles. Division of the seromuscular layer only, sparing the inner mucosa, interrupts the secretory branches of the vagus nerves (Figure 14.1.1). It has been established experimentally that, to be efficacious, seromyotomy must be precisely 1.5 cm from and parallel to the lesser curvature.

In his original technique, described in 1979, Taylor advocated the incision of the seromuscular layer of the anterior and posterior aspects of the stomach beginning at the incisura cardiaca and coursing to the incisura angularis, which amounts to fundic denervation. In 1982, Taylor proposed replacing the posterior seromyotomy with posterior truncal vagotomy, as Hill and Barker had advocated in 1978.[25]

Smith and Burge showed that complete division of the posterior vagus nerve provides total denervation of the posterior parasympathetic territory without adverse secondary effects on the pancreas or the digestive tract.[37] This means that there is no secondary postoperative diarrhea and that antropyloric motility is preserved. Indeed, because anterior seromyotomy preserves the antropyloric branches of Latarget's nerve, adequate motility of the antropyloric pump is maintained and pyloric spasm precluded.[36] Moreover, this ensures normal physiologic emptying of the stomach and obviates the need for drainage procedures. Daniel had shown that preservation of the antropyloric branches of Latarget's nerve in the dog ensures adequate gastric emptying through vagovagal arcs.

Another variation on posterior truncal vagotomy and anterior seromyotomy was described by Gomez-Ferrer



Course of the branch of Latarjet's nerve in the gastric wall.

1 - serosa
2 - musculosa
3 - submucosa

FIGURE 14.1.1. Anatomic landmarks for lesser-curvature seromyotomy.

and Hannon.[38] It consists of posterior truncal vagotomy and stapled anterior seromyotomy. The authors called their technique stapled linear gastrectomy although stapled anterior seromyotomy seems a more appropriate name as one would not recommend gastrectomy for a duodenal ulcer. Gomez-Ferrer reported good results with this technique in open surgery and satisfactory initial results in laparoscopic surgery.

Minimally Invasive Surgery of Duodenal Ulcer Disease

The laparoscopic Taylor procedure was the first advanced laparoscopic procedure to be performed.[30] Other types of vagotomy, such as highly selective vagotomy or truncal vagotomy, were then successfully performed using laparoscopic or thoracoscopic minimally invasive techniques.[33] The results show these procedures have benefits similar to those of laparoscopic cholecystectomy. As happened with laparoscopic cholecystectomy, we can expect that the patient's acceptance of surgery will be increased by minimally invasive techniques. The success of laparoscopic surgery for duodenal ulcer disease will depend on sound patient-selection practices and the cooperation of fully informed gastroenterologists. Assuming there are 100,000 new ulcer cases per year in industrialized countries, and 2 to 5% of this ulcer population can reasonably be offered minimally invasive surgery, this amounts to between 2,000 and 5,000 operations per country per year, as an alternative to long-term medical treatment.

Advances in the management of this common and complex disease will be reached only if gastroenterologists and gastrointestinal surgeons work together, abandoning adversarial attitudes. At this time no study has shown that long-tèrm medical treatment is superior to adequate surgical treatment. Some authors should not forget the saying: Progress is the refusal of the past and the tender attachment to the past.

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14.2 Laparoscopic Vagotomies for Elective Treatment of Peptic Ulcer Disease

Namir Katkhouda and Jean Mouiel

Laparoscopic Posterior Truncal Vagotomy and Anterior Lesser Curvature Seromyotomy

Experience with basic laparoscopic procedures has made it possible to treat duodenal ulcer disease in elective cases by laparoscopic vagotomy.[1–3] All types of vagotomy can be performed: truncal vagotomy by an abdominal or thoracic approach or more selective procedures, such as highly selective vagotomy, posterior truncal vagotomy together with highly selective anterior vagotomy, or posterior vagotomy together with anterior seromyotomy.[4,5] Posterior truncal vagotomy with anterior seromyotomy as described by Taylor is our operation of choice, because it is rapid, reliable, and efficacious. The results we have obtained are comparable to those obtained with these techniques in open surgery.[6–9]

Indications and Patient Selection

In general, preoperative evaluation of candidates for laparoscopic treatment of chronic duodenal ulcer disease is similar to that for open surgery and similar to that for other laparoscopic procedures. In the elective setting, surgical intervention for duodenal ulcer disease is indicated for:

1. Patients whose disease is resistant to medical treatment despite perfect compliance for at least two years or who have had two or more proven recurrences after thorough medical treatment.
2. Patients who cannot be followed regularly because of geographical or socioeconomic reasons or who cannot afford antiulcer medication.
3. Patients who have had complications such as perforations or hemorrhage.

Preoperative Preparation

As in elective open surgery, preoperative work-up includes evaluation of general status and risk factors, as well as of the ulcer disease, which implies endoscopic and secretory investigations. Endoscopy documents the ulcer, which is usually linear and not accompanied by stenosis or hemorrhagic signs. Secretory tests include complete acidity evaluation: measurement of unstimulated, basal acid output (BAO) and of peak acid output (PAO) after stimulation with pentagastrin. More precise results regarding the gastral acidity pattern can be obtained by doing 24-hour pH studies.[10] These tests are necessary to evaluate the degree of hyperacidity and to identify deviations from the normal circadian rhythm of acid secretion in patients who are intractable to medical treatment. These tests are also useful to demonstrate postoperative reduction of acid output. Depending on the clinical features of the disease, a serum gastrin level should be obtained to exclude gastrinoma.

Surgical Procedure

As in open surgery, general anesthesia and endotracheal intubation are used. The creation and maintenance of pneumoperitoneum and the techniques of aspiration lavage, thermocautery, and laser cautery are the same as for other forms of laparoscopic surgery.

Patient Set-Up (Figure 14.2.1).

The patient is positioned in much the same way as for open cholecystectomy. The trunk is elevated 15°. It should be possible to tilt the patient laterally (left or right) 15°. The patient is placed in the supine position with the legs spread apart (French position). The operating surgeon stands between the legs of the patient, the room nurse and first assistant are on the patient's left, and the second assistant (the camera assistant) is on the patient's right. The videoendoscopic system with irriga-

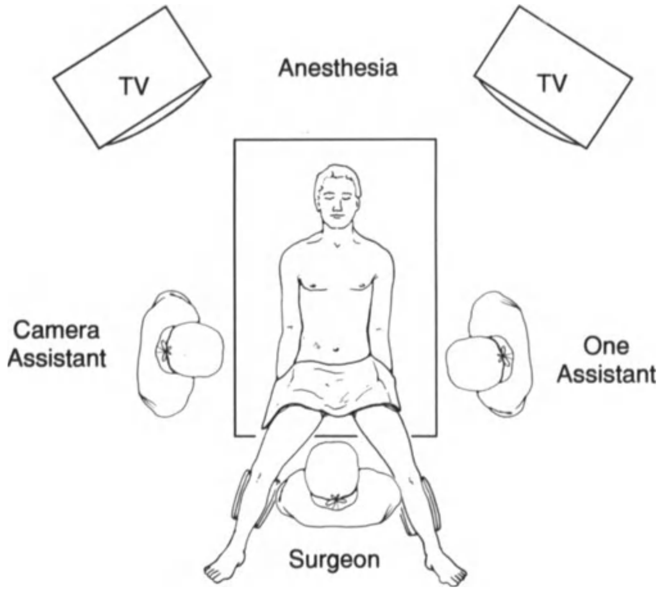

FIGURE 14.2.1. Patient set-up.

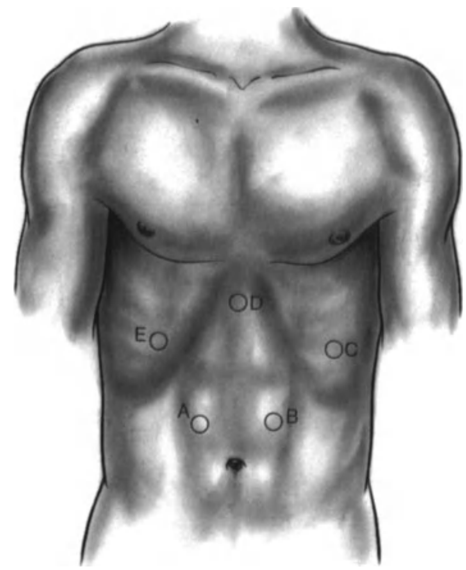

FIGURE 14.2.2. 10-mm trocar position (pentagon shape). *A*, 0° scope; *B*, operating channel; *C*, graspers; *D*, irrigation-suction probe; *E*, graspers.

tion/suction is placed on the patient's right, and a second monitor is placed on the patient's left. Good electrosurgery systems that have blending capabilities (Valleylab, Force 2) complete the operating-room equipment.

The patient is prepared and draped, and the instruments are laid out as for traditional gastric surgery, because an open operation may be required if it becomes apparent laparoscopic surgery is impossible or hazardous.

Instruments

In addition to the instruments commonly utilized for this type of surgery (Ethicon Endo-Surgery, Cincinnati, OH, and Karl Storz, Tüttlingen, Germany) we recommend:

1. An angulated hook coagulator/dissector with a canal for the evacuation of smoke (Storz)
2. Clip forceps (Ethicon)
3. Two Semm needle holders (Storz and Ethicon)
4. Absorbable monofilament sutures with 2-cm straight needles (Ethicon)
5. Endoloops with preformed Roeder knot (Ethibinder)
6. Application systems for laser coagulation and division and collagen spray (Tissucol, Immuno, Inc.)

Trocar Positions (Figure 14.2.2)

Once the pneumoperitoneum has been created, the first trocar to be inserted is the videolaparoscopic 11-mm port, which is introduced one-third of the distance between the umbilicus and the xiphoid process. Originally we then inserted three 5-mm and one 11-mm trocar under visual control. We now use four 10-mm trocars so that we can move the camera from one port to another.

These accesses are closed at the end of the operation. In the case of the 10- or 11-mm trocars, closure includes fascia closure after complete exsufflation of the abdomen.

Exploration

The abdominal cavity is explored as soon as the videolaparoscope is inserted. The surgeon should make sure the operation can be done without any major problems and particularly that the liver can be retracted so that the operative area is visible. Associated lesions amenable to laparoscopic surgery should be noted (adhesions, appendicitis, cholecystitis, biliary cyst). If the operation is impossible or seems dangerous or difficult, open surgery is, of course, preferred. The patient should be forewarned of this possibility.

Hemostasis Procedures

Several procedures may be used to maintain hemostasis:

1. The L hook coagulator is used with monopolar current to coagulate small-caliber vessels safely. Electrical scissors are used for most of the dissection.
2. The Nd:YAG laser with a contact fiber coagulates superficial surfaces.
3. Titanium clips are used for gastric vessels, which must first be skeletonized.
4. Suture ligation with 15-cm 4–0 monofilament is used as in open surgery.

All types of knots (flat, double, or Roeder) may be made. The Endoloop is required only rarely in this operation. Running sutures may also be employed: the suture may be stopped with a knot secured by a clip, if knot-tying represents a difficulty.

Technique of Posterior Truncal Vagotomy and Anterior Seromyotomy

The procedure consists of three steps: approach to the hiatal area, posterior vagotomy, and anterior vagotomy.

Approach to the Hiatal Area (Figure 14.2.3)

This lateral approach is key to all dissections of the gastroesophageal junction. The left lobe of the liver is retracted with the xiphoid probe. The lesser sac is entered through an opening in the pars flaccida held between two angulated graspers, which present the areolar tissues to the hook coagulator/dissector. Dissection is continued until the fleshy portion of the right crus is reached. If a left gastric vein is encountered, it may be divided between two clips, but only if it presents an obstacle. The hepatic branch of the vagus nerve should be avoided if possible, although it has not been proven that injury to this nerve causes clinically significant postoperative complications.

Posterior Truncal Vagotomy (Figure 14.2.4)

The two major landmarks for posterior truncal vagotomy are the caudate lobe and the right crus, which can be grasped by the right-side grasping forceps and held to the right while the coagulator/dissector hook or scissor opens the pre-esophageal peritoneum. The abdominal esophagus is retracted to the left, allowing visualization of the areolar tissue. The posterior vagus nerve, easily recognized by its white color, can then be identified. While gentle traction is exerted on the nerve, adhesions are divided after coagulation, and the nerve is transected between two clips. A segment of the nerve is retrieved for histologic verification.

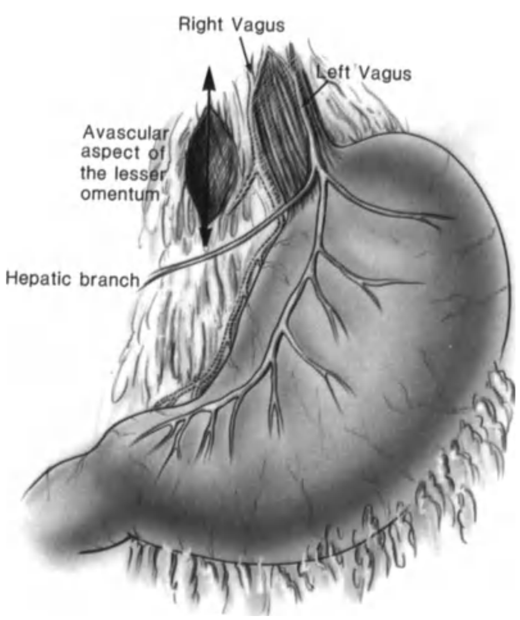

FIGURE 14.2.3. Approach to the hiatal hernia.

Anterior Seromyotomy (Figures 14.2.5 and 14.2.6)

The anterior aspect of the stomach is spread between two grasping forceps. Starting at the esophagogastric junction, the line of incision is outlined by light electrocoagulation parallel to and 1.5 cm distant from the lesser curvature. The line starts at the posterior aspect of the angle of His and stops 5 to 7 cm from the pylorus at the level of the first branch of the crow's foot. The two most distal branches of the nerve are left intact to ensure that the antropyloric innervation remains functional. Seromyotomy is then performed with the hook coagulator set at average intensity and monopolar current, making equal use of the coagulation and division. The hook incises successively the serosa and then the oblique and circular superficial muscle layers. The two borders are grasped and gently spread apart mechanically at the same time, thus breaking the remaining deep circular fibers. Electrocautery completes the division when necessary.

Once the last muscle fibers have been divided, the submucosa and mucosa can easily be identified as it pops out of the incision by its typical blue color. Because of the camera's magnification, the surgeon can easily verify that no holes have been inadvertently made in the mucosa. This has never happened in our experience. When the surgeon makes the incision, two or three short vessels may be encountered. They are divided before starting the seromyotom, as in Taylor's technique, after they are lifted off the seromuscular layer with the hook coagulator/dissector and identified. The ends may be clipped or suture-ligated. It is of utmost importance that the incision be anatomically accurate and that perfect hemostasis be achieved.

Upon completion, the seromyotomy appears as a 7- to 8-mm trench in the gastric wall. Air is then injected through the nasogastric tube to make sure that there are no leaks. Methylene blue can also be injected for the same purpose, and at first we did this consistently. The seromyotomy is closed by an overlapping running suture (Figure 14.2.7) knotted at both ends and secured by clips if need be. Hemostasis may be completed by applying fibrin collagen (Tissucol, Immuno Corp, Vienna). This will prevent postoperative adhesion and allow perfect hemostasis. Abdominal closure is performed without drainage.

Postoperative Management

As in all laparoscopic procedures, the postoperative course is usually very simple. Postoperative pain is min-

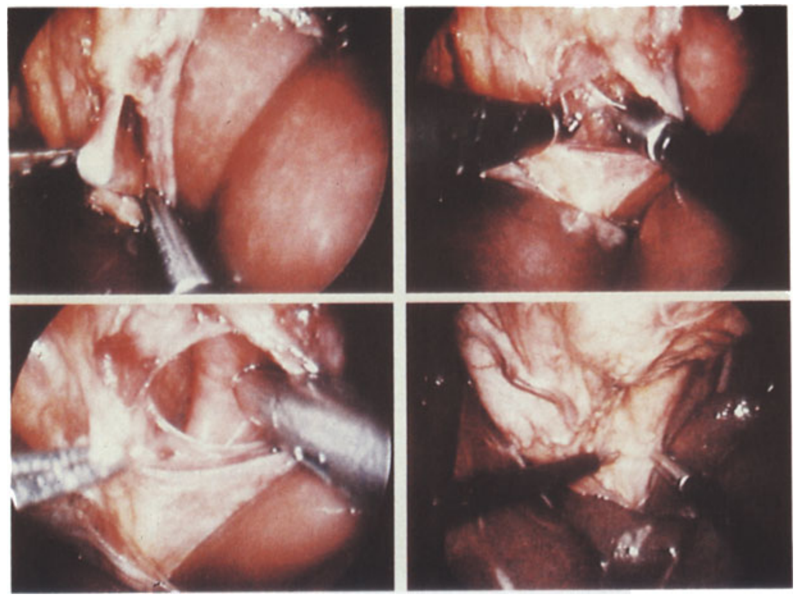

FIGURE 14.2.4. Posterior right truncal vagotomy. *A,* Two landmarks: caudate lobe and right crus. *B,* Opening the mesoesophagus. *C,* Looking for the right vagus between the right crus and the esophagus. *D,* Right posterior vagotomy.

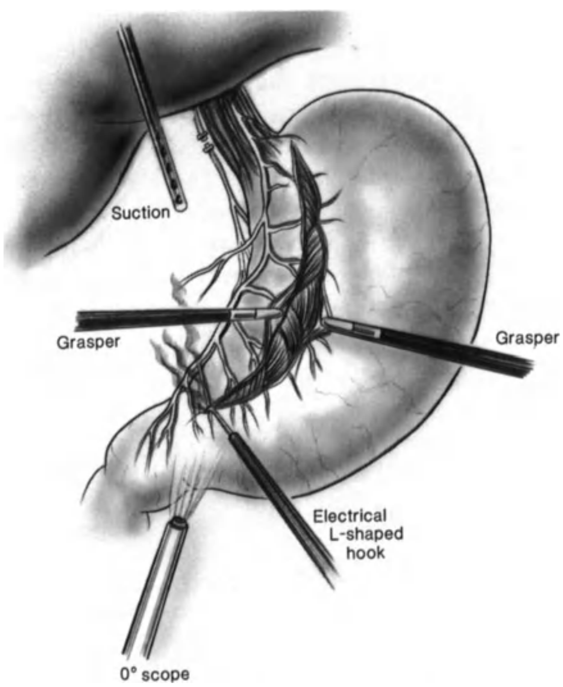

FIGURE 14.2.5. Anterior lesser-curvature seromyotomy.

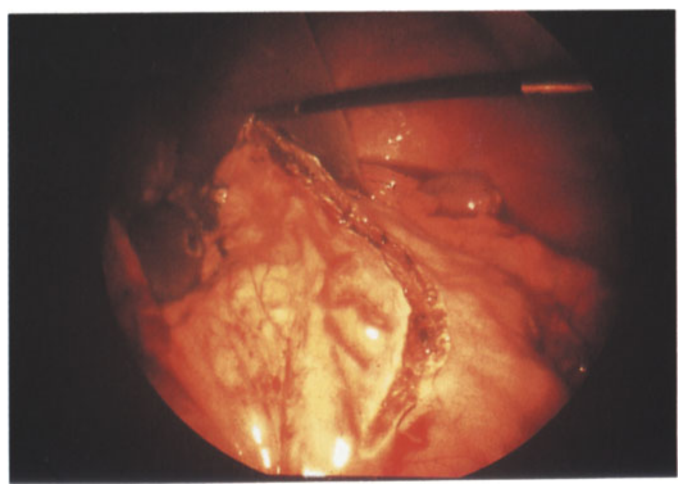

FIGURE 14.2.6. Completed seromyotomy.

imal because the surgical wounds are very small. Because they are infiltrated with local anesthesia, systemic analgesia is unnecessary. Early ambulation is possible, and patients may resume oral light soft meals at 24 hours and may be discharged three days after operation, or even earlier in some cases. Our hope is to be able to perform 1-hour laparoscopic vagotomies on an outpatient basis.

Clinical Results

By September 1993, we had performed 90 laparoscopic Taylor's procedures for chronic ulcer disease (76 in Nice,

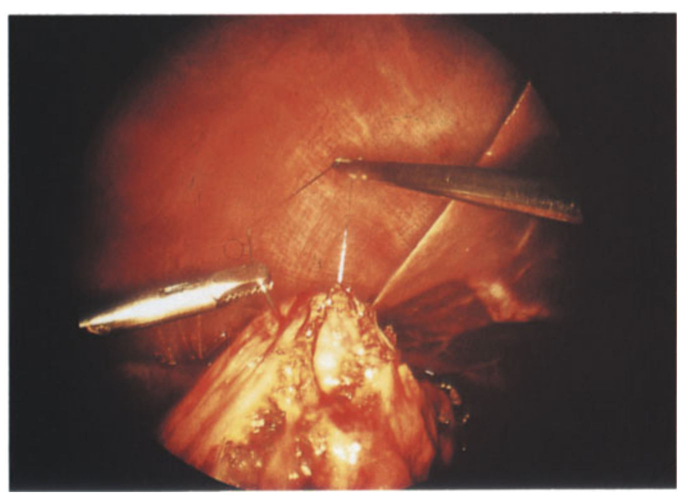

FIGURE 14.2.7. Overlap suture of seromyotomy.

14 elsewhere). Mean patient age was 33 years (the range was 19 to 61 years). Forty-six patients had been symptomatic for at least four years. They had an average of 2.8 relapses per year in spite of well-conducted medical treatment (antacids, H_2 blockers, or omeprazole). Of these patients, six had a history of hemorrhage that had been stopped with endoscopic and medical treatment. None of the patients had complications such as hemorrhage or stenosis at the time of operation. Six patients had surgery because their geographical or socioeconomic circumstances made long-term medical treatment impossible. There was no mortality and no conversions to open surgery. Three patients had mild diarrhea, which was treated conservatively. Three patients complained of postoperative fullness when they were on bezoar, but the symptom subsided completely with papain. One patient had postoperative gastroesophageal reflux requiring reoperation two months later. This patient had had reflux before the operation and mild reflux during preoperative work-ups. No postoperative functional disorders were found in any of the other patients.

Endoscopic investigations performed two months postoperatively showed that the ulcer had healed completely in all but three patients, who had residual asymptomatic scars. Secretory studies at two months documented a decrease in BAO and MAO of 79.3 ± 1.3% and 83.4 ± 1.2%, respectively. Late-recurrence assessment showed a recurrence rate of 3.8% after follow-up ranging from 2 to 41 months.

Discussion

The results obtained with this procedure are similar to those reported by Taylor in a study of 605 patients who underwent open vagotomy performed by 11 different surgical teams. Our postoperative mortality and morbidity were very low. Only one postoperative death (0.16%), due to myocardial infarction, was recorded. Necrosis of the lesser curvature or gastric fistula was not observed. Digestive comfort was thought to be satisfactory in 94% of patients who were graded Visick 1 or 2. None of the patients developed dumping syndrome, and only two patients complained of persistent diarrhea. Ulcer recurrence occurred in only 1.5% of the 481 patients who underwent surgery during the five-year period.

Taylor's procedure is practically as simple and effective as truncal vagotomy. Acid secretory reduction is similar and the five-year recurrence is 3 to 6%. The principal advantages are the absence of secondary effects, particularly dumping and diarrhea, and the absence of gastric-emptying disorders.

Oostvogel showed that Taylor's procedure is as effective as highly selective vagotomy in improving gastric motility and reducing acidity.[12,14,15] Its other advantages, underscored by all the authors who have used this technique, are its reliability, rapidity, and the consistency with which good results are obtained. Moreover, anatomic variations in Latarget's nerve do not influence the outcome. This is confirmed by the experience of several other authors, including Triboulet, Kahwaji, and Grange, and by our personal open-surgery experience.[1–3,5,15–17]

Conclusion

Laparoscopic vagotomy is as effective and safe as open vagotomy in the treatment of duodenal-ulcer disease intractable to medical therapy. This technique opens new possibilities in the treatment of the duodenal ulcer because it is not invasive and the outcome has been uniformly good. Although medical treatment has improved, the recurrence rate for ulcer disease is as high as 90% per year, whatever the agent used.[18] Although drugs have been widely used for more than 10 years, they have not decreased the mortality from complications of ulcer disease, especially in the elderly. For these reasons, we believe that there is still a place for elective surgical treatment of the duodenal ulcer, and that the procedure of choice is posterior truncal vagotomy and anterior seromyotomy. Performed laparoscopically, Taylor's procedure represents a surgical improvement that can compete with long-term medical therapy. The clinical outcomes and cost effectiveness of these alternatives should be evaluated by a comparative prospective multicenter study. As is true for all new techniques, however, the patient-selection procedure for laparoscopic surgery should be the same as that for open surgery to ensure that it can be done with safety.

Laparoscopic Highly Selective Vagotomy (Figure 14.2.8)[19]

Bilateral highly selective vagotomy is certainly possible and several teams have performed it. This operation, however, appears to be tedious. It usually lasts several hours and even then there is a risk some vagal nerves will be missed. Missing a nerve, as Johnson and Amstrup have showed, will lead to ulcer recurrences. Indeed, in several of their studies, they concluded that this operation is very demanding and sensitive to the skills of the surgeon performing it. They warned that ulcer recurrence may be unacceptable if this operation is performed by untrained surgeons. However, some laparoscopy experts are performing this operation in a satisfactory manner.

The operation usually consists of a step-by-step ligation of the neurovascular bundle, as in open surgery. This is done using clip appliers and scissors, and great care should be taken to ensure that the Latarget's nerve is never injured. The surgeon must also free about 8 cm of esophagus and roll it to clear its posterior aspects of all

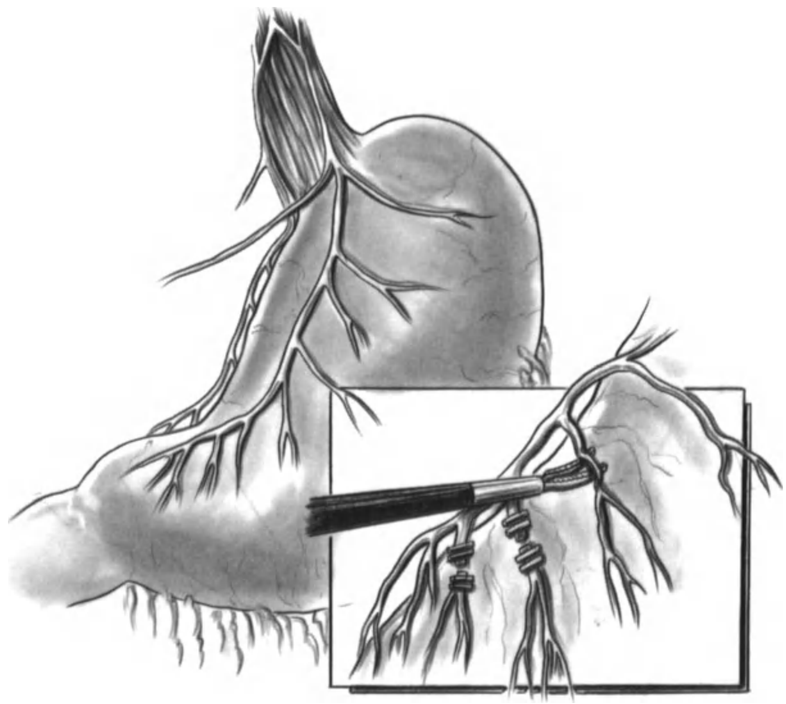

FIGURE 14.2.8. Laparoscopic highly selective vagotomy.

nerve fibers, especially the criminal nerve of Grassi. It is also possible to use bipolar cautery to coagulate and destroy the neurovascular bundles, but this is an experimental approach that needs more assessment.

One danger of highly selective vagotomy, which is fully described in the following chapter, is that a hematoma of the lesser omentum might compress Latarget's nerve. If both branches of Latarget's nerve are compressed or injured, the result is denervation similar to that of a bilateral truncal vagotomy.

Another potential problem is a necrosis of the lesser curvature. This is, however, a rare event and can usually be avoided by a reperitonization of the lesser curvature with a small running suture at the end of the operation.

Laparoscopic Posterior Truncal Vagotomy and Anterior Stapled Seromyotomy (Linear Gastrectomy) (Figure 14.2.9)[19]

This procedure is a modification of the anterior seromyotomy procedure in which a laparoscopic linear stapling instrument is used to excise a full-thickness strip of the anterior gastric wall along the lesser curvature. After performing the posterior vagotomy as previously described, the pylorus and the branches of Latarget's nerve are visualized. A site 6 to 7 cm proximal to the pylorus is identified, and the edge of the lesser curvature is exposed using Babcocks. A gauge is then applied across the full thickness of the stomach to determine the proper stapler cartridge. Then the Endolinear cutter is fired several times. It usually takes about six staples to complete the linear gastrectomy. This operation has been performed by several authors, including Gomez-Ferrer and Hannon, with good results. It is costly. We would also remark that this procedure should be called an anterior stapled seromyotomy, because the term linear gastrectomy misleads gastroenterologists advocating a conservative approach to duodenal ulcers.

Laparoscopic Posterior Truncal Vagotomy and Anterior Highly Selective Vagotomy (Figure 14.2.10)[19]

A final variation on the vagotomy is the posterior truncal vagotomy and anterior highly selective vagotomy. This can be described as half a bilateral truncal vagotomy and half a bilateral highly selective vagotomy. Indeed, it involves part of each of the procedures, namely, removing the posterior vagus trunk and removing the anterior neurovascular bundles, which are branches of the anterior Latarget's nerve. Therefore, the surgical technique has already been described in this chapter.

This operation was first described by Hill and Barker, whose clinical experience was with about 30 patients. This limited experience is the major drawback of this operation, which otherwise seems an elegant one, although it retains some of the tedious features of highly selective

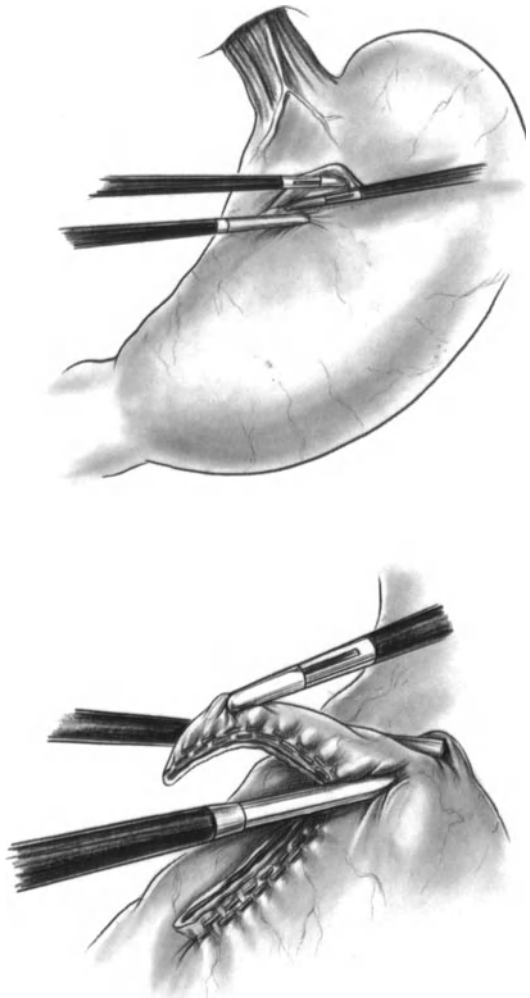

FIGURE 14.2.9. Laparoscopic stapled seromyotomy (linear gastrectomy).

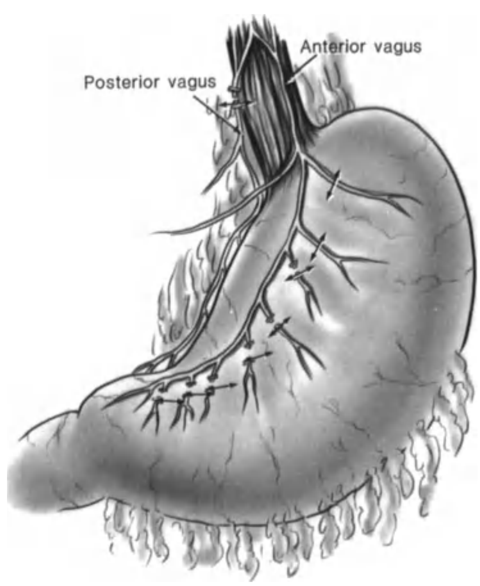

FIGURE 14.2.10. Posterior truncal vagotomy and anterior highly selective vagotomy.

vagotomy, namely, the need to control each neurovascular bundle along the lesser curvature of the stomach. This operation can be simplified by using a bipolar cautery device to denervate the branches of the anterior Latarget's nerve.

Another way to perform this operation would be to use the harmonic scissors (Ultracision), which will cut and coagulate all of the neurovascular bundles without thermal damage, preserving all branches of Latarget's nerve and avoiding electrical injury of the lesser curvature. This operation has been clinically performed by Zucker and Bailey, but they have abandoned it. We think there is a place for this procedure, however, if it is assessed experimentally before it is practiced clinically.

Thoracoscopic Bilateral Truncal Vagotomy (Figure 14.2.11)

An ideal indication for bilateral truncal vagotomy is a recurrent ulcer after performance of a Billroth II gastrectomy. Adhesions from the first operation can prevent a second abdominal approach. If the recurrent peptic ulcer is known to be benign, a thoracoscopic bilateral vagotomy can be an elegant answer to the surgical problem.

We usually use a left-sided approach, with the surgeon standing behind the patient. As in a left posterior lateral thoracotomy, the patient, under general anesthesia, lies on his side with the left lung excluded with a Carlen's tube. Four trocars are then inserted in a triangular pattern with the thoracoscope between the two main operating trocars. The fourth port is reserved for the irrigation and suction device, which can also serve as a palpation probe.

The operation begins with the division of all adhesions. The pleura is then incised in front of the aorta. This allows the dissection of the esophagus. Moving the nasogastric tube will allow localization of the esophagus in the

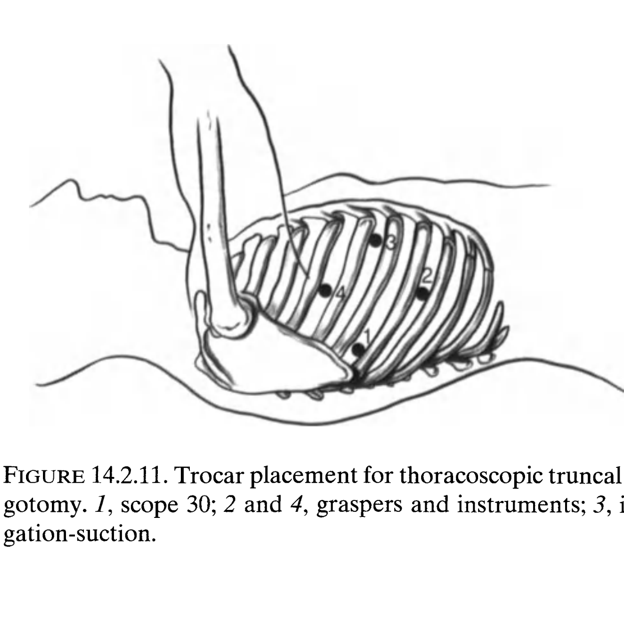

FIGURE 14.2.11. Trocar placement for thoracoscopic truncal vagotomy. *1*, scope 30; *2* and *4*, graspers and instruments; *3*, irrigation-suction.

event of severe adhesions. It is also possible to use an illuminated bougie (Bioenterics, Inc.) to localize the esophagus. An atraumatic isolated hook is then utilized. All the vagal nerves are dissected and divided. All white fibers are nerves and should not be confused with normal esophageal muscle fibers. At the end of the operation, the esophagus is peeled and free of any nerve fibers. Limited oozing of blood can be managed by inserting a small 4- × 4-in. piece of gauze through one of the ports to compress the blood. Electrocautery of the esophagus should be utilized as little as possible, because there is considerable danger of postoperative esophageal necrosis. The operation is finished by inserting a thoracic drain through one of the trocar ports and closing the other ports.

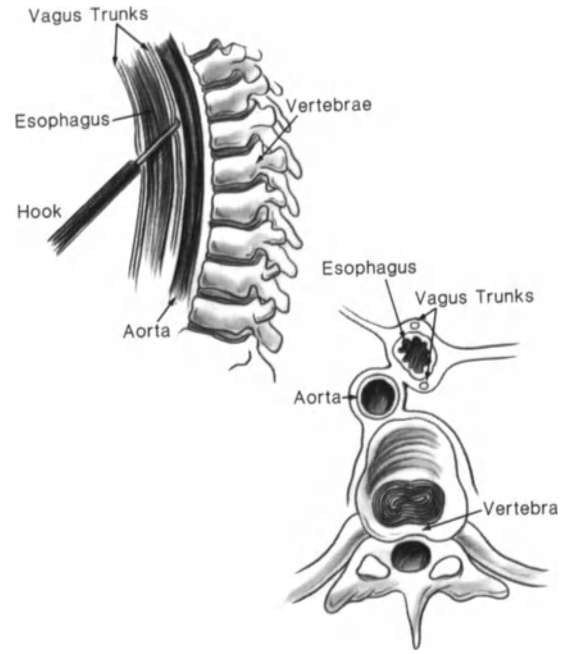

FIGURE 14.2.12. Thoracoscopic truncal vagotomy.

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14.3 Treatment of Complications of Peptic Ulcers

Namir Katkhouda and Jean Mouiel

Introduction

Surgical Anatomy

According to older anatomy textbooks, there is only one periesophageal plexus formed by a single vagus nerve lying diffusely in the midline, which condenses into a large posterior trunk termed the abdominal vagus, all other branches being considered collaterals.

It should be noted that in the area of the lower esophagus, which is where vagotomy, whether thoracic or abdominal, is performed, in 90% of cases a large posterior trunk and a second anterior trunk can readily be identified. These are the trunks that are sought and divided at surgical vagotomy. The posterior branch is always single and large, and the anterior branch is often finer and accompanied by one or two supplementary branches.

These two trunks divide at the level of the cardia. The *anterior trunk* gives off the gastrohepatic branches, which run in the upper part of the lesser omentum at the lower border of the left lobe of the liver and divide into hepatic, biliary, and pyloric branches, the latter being important for pyloric and antral motility. The gastric branches reach the anterior wall of the stomach after forming the anterior Latarget's nerve, which runs parallel and 1 to 2 cm distant from the lesser curvature of the stomach, ending as the *crow's foot* at the incisura, some 6 cm before the pylorus.

The *posterior trunk* gives off two types of branches:

1. A large coeliac branch, which joins the right coeliac ganglion, forming, with the greater splanchnic nerve, the loop of Wrisberg. Some of its fibers may run along the hepatic and gastroduodenal arteries to reach the greater curve of the stomach: they have a minimal physiologic role.
2. Several gastric branches, which reach the posterior of the stomach. These nerves form the posterior Latarget's nerve, which follows the course of the anterior branch but is smaller. It also ends as a crow's foot.

This anatomy explains the different types of vagotomy:

Truncal vagotomy (TV) involves section of the main trunks proximal to their division, which results in complete denervation of the stomach, pylorus, biliary tree, and alimentary tract. This operation can be carried out through the thorax or the upper abdomen.

Selective vagotomy (SV) preserves the extragastric branches but denervates the antrum. This operation is not widely performed anymore.

Highly selective vagotomy (or proximal gastric vagotomy, PGV) preserves the antral nerve supply by not cutting the terminal branches of Latarget's nerve.

Truncal vagotomy and anterior seromyotomy combine a unilateral posterior truncal vagotomy and highly selective vagotomy. This operation, which avoids the side effects of a bilateral truncal vagotomy, is our preferred one.[1,2]

There are two other anatomic features of surgical importance:

1. The gastric nerves do not anastomose within the stomach wall.
2. The nerve fibers are intimately related to the vessels, so that dividing them leads to some devascularization of the stomach, especially in the region of the lesser curvature. This is important in highly selective vagotomy because of the risk of ischemia of the lesser curvature.

Patient Selection

Laparoscopic treatment of intractable duodenal ulcers is employed for patients whose ulcers have not healed despite thorough medical treatment comprising H_2 or proton-pump blockers or after *Helicobacter pylori* infection has been treated with triple therapy.[3] Patients who are *H. pylori* negative (6%) could also be offered a laparoscopic vagotomy. Some patients who suffer recurrences after discontinuation of medical treatment are also candidates for surgical treatment.

Although antisecretory drugs have been available for more than 10 years, there has been no decline in the mortality from ulceration. It is important to address the issue of intractable ulcer disease because it is apparent that medical treatment cannot effectively control *all* ulcers.

Management of Complications of Peptic Ulcers

Management of Gastric Outlet Obstruction

Gastric outlet obstruction is a common complication of ulcers. It can be treated by laparoscopic bilateral truncal vagotomy and gastrojejunostomy.

Laparoscopic Total Vagotomy

Basic positioning and trocar insertion—The patient is placed in a supine position with legs spread apart. The operating surgeon stands between the patient's legs (in the French position). The pneumoperitoneum is created by insufflating carbon dioxide and maintaining a pressure of 14 mm Hg under electronic control. Five trocars are introduced into the upper part of the abdomen: one for the videolaparoscope, one for the operating instruments, two lateral trocars for the grasping forceps, and one subxyphoid port for the retractor or the irrigator.

Exploration—The abdominal cavity is explored as soon as the videolaparoscope is inserted to ensure that the planned operation is feasible and particularly that the liver can be retracted. Other associated lesions amenable to laparoscopic surgery are noted. For us cirrhosis is a contraindication for an advanced laparoscopic procedure.

Technique of the posterior truncal vagotomy[4,5]—The left lobe of the liver is retracted using a xiphoid palpation probe and the vascular part of the lesser sac is opened with electric scissors above the hepatic branch of the vagus nerve. The dissection is continued to the level of the right crus of the diaphragm.

The two landmarks for a posterior truncal vagotomy are the caudate lobe and the right crus of the diaphragm (Figure 14.3.1). The right crus is seized with the right grasping forceps and retracted to the right to expose the esophageal peritoneum, which is incised along the length of the border of the right crus. This allows the abdominal esophagus to be separated and lifted outward, permitting access to its posterior wall. Within the depths of this angle, the right cord of posterior vagus is localized. It can be recognized by its pearly appearance. The nerve is transected between two clips and a 1-cm section is removed for histologic confirmation.

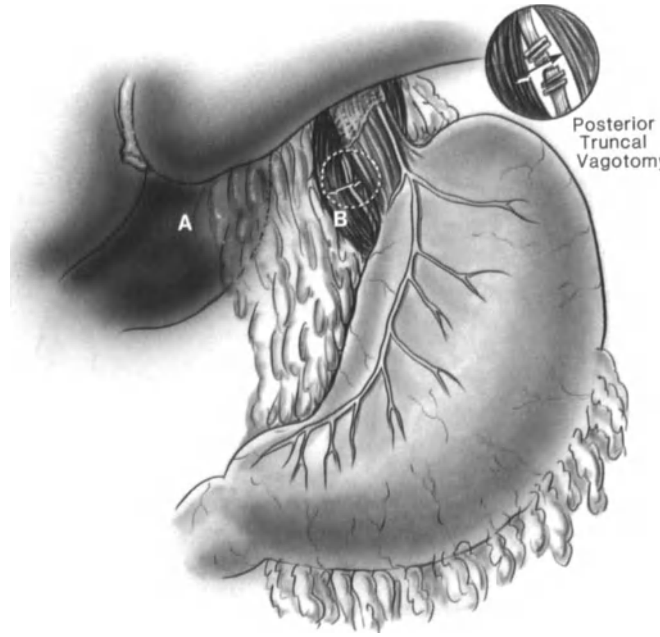

FIGURE 14.3.1. Landmarks of right posterior vagotomy. *A,* Caudate lobe. *B,* Right crus.

Anterior truncal vagotomy—This type of vagotomy consists of sectioning several trunks of the anterior vagus. Transection of these fibers is easy because they overlie the muscular fibers of the esophagus. The only difficulty occurs at the left edge of the esophagus, where some branches, even large ones (the criminal branch of Grassi), can be overlooked. Using the traction forceps, the esophagus can be rolled to the right to expose its left edge, so that the criminal nerves can be clearly seen.

Laparoscopic Gastrojejunostomy (Figure 14.3.2)

The same ports can be used, but one lateral one should be enlarged to allow the introduction of the Endolinear Cutter 60 (Ethicon, Inc., Cincinnati, OH). The first loop of the jejunum is grasped and apposed to the greater curvature. It is sometimes necessary to free some branches from the right gastroepiploic artery before the jejunum loop can be anastomosed onto the posterior aspect of the greater curvature. This must also be done as close as possible to the pylorus to have a physiologic gastrojejunostomy.

The gastroepiploic surface of the stomach and the antimesenteric side of the jejunum are apposed and held with endoscopic Babcock clamps (Ethicon, Inc., Cincinnati, OH). A small gastrotomy and an enterotomy are made to allow the introduction of the jaws of the endolinear cutter and stapler. A gauge is used to measure the gut-wall thickness and to stimulate firing of the endolinear cutter 60 (Ethicon, Inc., Cincinnati, OH). After the surgeon checks that the posterior and inferior aspects are free, the stapler is fired, removed, reloaded, and refired

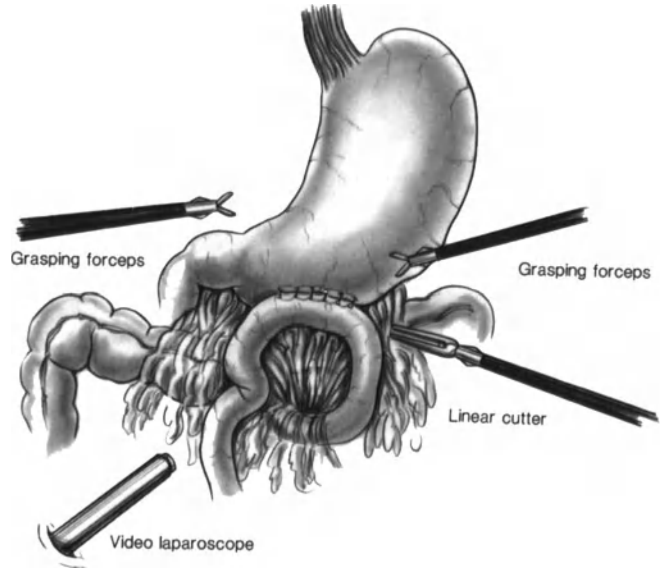

FIGURE 14.3.2. Laparoscopic gastrojejunostomy.

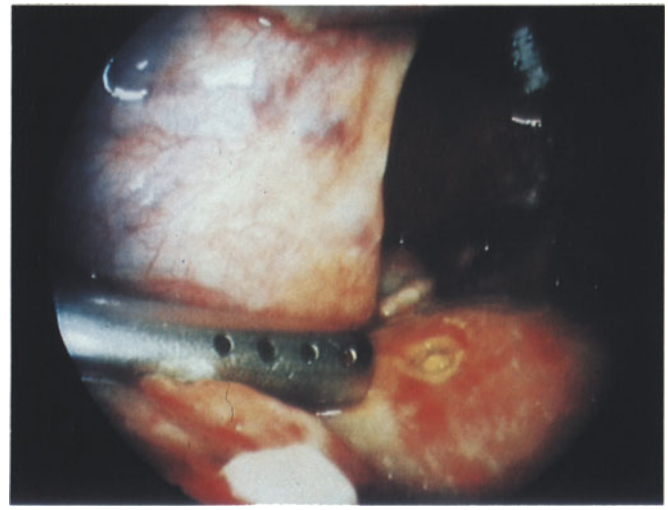

FIGURE 14.3.3. Laparoscopic view of perforated duodenal ulcer.

if needed. Usually if the 60-mm instrument is used, a second firing is not needed. A side-viewing laparoscope can then be introduced into the lumen of the gut and the staple edges inspected for bleeding. The gastrojejunostomy openings are then closed in an open V fashion, either with an endocutter without the blades or with sutures. Finally, a reinforcing suture in the apex of the anastomosis is performed, and hemostasis is checked again (Figure 14.3.5).

Management of Perforations of Duodenal Ulcers (Figure 14.3.3)

The most suitable therapy for patients presenting with an acute perforation, diagnosed clinically and on plain x-rays, depends on the time that has elapsed since the perforation and the individual's clinical status. Laparoscopic management appears most appropriate for those patients with signs of progressive chemical peritonitis who are seen within 12 hours of ulcer perforation.[6,7] In patients who present 48 hours or more after ulcer perforation and who remain stable with minimal peritoneal findings, the opening may already have sealed. In these individuals, continued medical management, gastric-tube suctioning, and antibiotic and acid-reducing medication may be the most appropriate therapy.

In contrast, patients who present with a rigid abdomen and septic shock are not candidates for laparoscopic intervention. These individuals require immediate fluid resuscitation, stabilization of their vital signs, and, when appropriate, exploratory open laparotomy.

Instruments—A detailed description of the various instruments needed for laparoscopic surgery can be found elsewhere in this book. The ability to place sutures and to tie surgical knots is extremely important when performing emergency laparoscopy. Laparoscopic closure of a perforated duodenal ulcer can only be accomplished with sutures; no stapling device can perform this closure safely. A variety of laparoscopic needle holders are now available, and the surgeon should have one or more of them on hand. The choice of suture material depends on the surgeon's preference. For most laparoscopic procedures, we prefer a nonabsorbable material.

Operative technique—If the preoperative diagnosis is a perforated duodenal ulcer, then a slight modification is made to the usual placement of the laparoscopic trocars. The videolaparoscope is placed in the umbilicus; two lateral trocars are placed on the midclavicle line; and the fourth trocar, for the irrigation and palpation instruments, is placed under the xyphoid (Figure 14.3.4). After all four trocars are inserted, intra-abdominal exploration is undertaken to locate the suspected duodenal lesion. The diagnosis of perforation is confirmed by the finding of a fluid collection overlying the distal stomach and duodenum and by the presence of food fragments. The surgeon should bear in mind that there are often many false membranes over the abdominal organs and that often, the perforation is completely covered by the gallbladder. The inflammatory adhesions have to be gently removed, usually beginning at the hepatic surface. Once the left lobe of the liver is free, it can be retracted superiorly. The dissection is then continued along the surface of the duodenum until the margins of the perforation are clearly visible. At that time, a small-caliber palpation probe can be safely introduced into the orifice to determine the exact size of the opening and the extent to which surrounding tissues are involved.

Peritoneal lavage—It is mandatory to perform a thorough and intensive peritoneal lavage with at least 8 L of fluid. This irrigation must flush all quadrants of the abdomen. We think this is probably the single-most-important step in the entire procedure. The procedure should only be completed once this lavage is finished. It eliminates all of the irritating septic liquid and will also help stabilize the patient's vital signs, because fewer bacteria will be present in the abdomen and bacteria will be less likely to invade the bloodstream.

Closure of the perforation—Before closure of the perforation is attempted, the edges of the ulcer should be gently debrided. Care should be taken in the debriding not to create a hole too large to be sutured. Several different methods of closure can be employed, but all require the use of intracorporeal knot-tying techniques. Two laparoscopic needle holders are used to maneuver and place the suture within the wall of the duodenum. One must be careful not to stitch the duodenum shut. A bougie may eventually be inserted in the duodenum to calibrate the duodenum lumen. Sutures must be performed intracorporeally because the duodenum is fragile in these patients. Extracorporeal knot tying requires tension on the suture that might cause it to tear the tissues. Both straight needles and curved needles are now available. Our preference is for curved needles attached to a segment of nonabsorbable suture material 15 cm in length (Figure 14.3.5).

Small perforations with relatively healthy-appearing adjacent tissues may be managed with direct suture closure. With larger perforations, we use a technique that incorporates a vascularized pedicle of omentum into the closure (the Graham patch). There are alternative techniques. In one a flexible endoscope is guided into the stomach and the duodenum, the omental patch is pulled within the ulcer using a grasping biopsy forceps, and the patch is then secured in place (Figure 14.3.6).

One last alternative, described by Champault, is simply to apply fibrin glue (Tissucol Immuno Corp., Vienna) over the perforation to glue the omental patch to the perforation. In this case, an esogastric tube is mandatory and

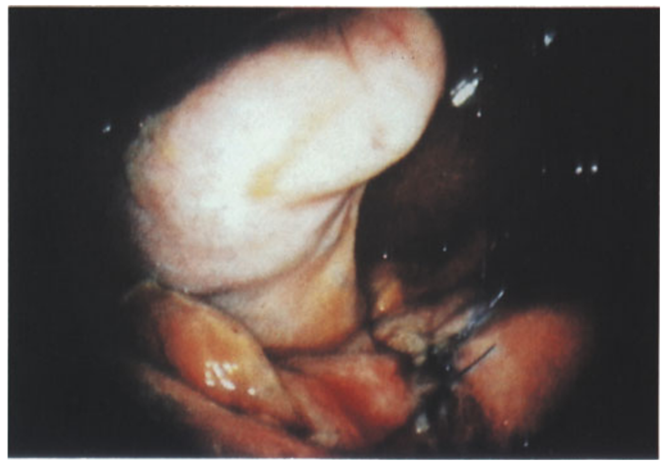

FIGURE 14.3.5. Repair of perforated ulcer using interrupted sutures.

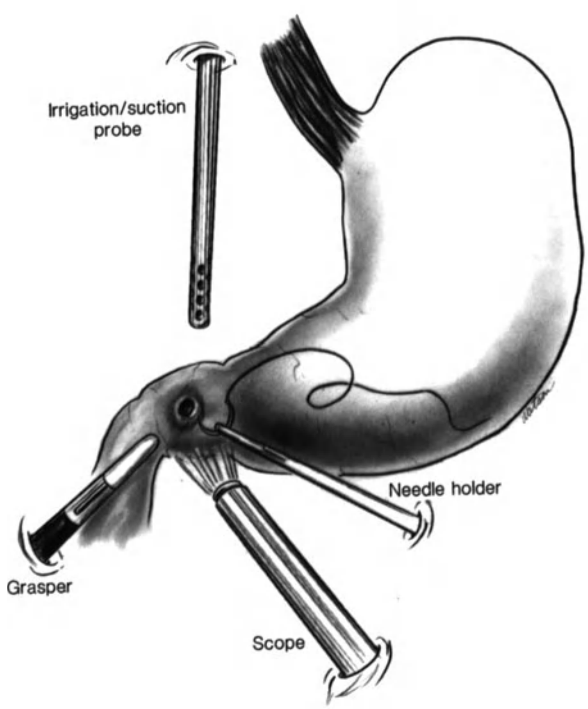

FIGURE 14.3.4. Laparoscopic treatment of perforated duodenal ulcer. Trocar placement.

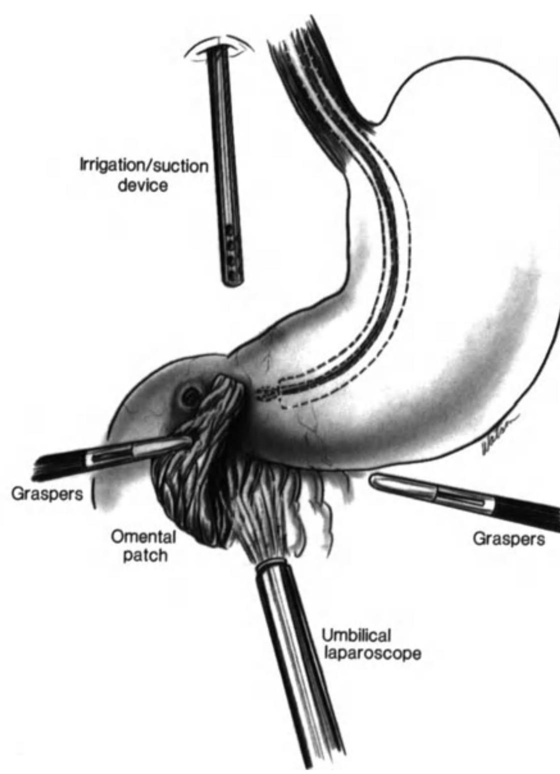

FIGURE 14.3.6. Omental patch combined with flexible esogastroduodenal scope.

should be positioned so that the distal tip is near the site of the ulcer closure. Finally, a drain is placed to avoid any postoperative complications. Ten cases were managed with this technique with good results.

Management of Recurrences After Vagotomy: Technique of Laparoscopic Bilateral Truncal Vagotomy and Antrectomy

It is known that there is a change in the pattern of evolution of ulcer disease after a vagotomy. Indeed, many patients who suffer a recurrence after a vagotomy will probably now be easier to treat with conventional antiulcer therapy. Why this is so is not clear, and there has been no published study on the subject. In the event of recurrence after vagotomy and inefficacy of adequate medical treatment, a more aggressive approach is possible. A laparoscopic bilateral truncal vagotomy and antrectomy could be done to remove, if possible, the ulcer and the gastric-secreting area. Of the alternatives this procedure also has the best recurrence rates. It can be done completely with the laparoscope. In addition, the same description applies to the laparoscopic Billroth II gastric resection. The only difference is the extent of the resection.

The laparoscopic bilateral truncal vagotomy has been described above. This laparoscopic antrectomy is performed in the same way as in open surgery. Reconstruction is very similar to that done during gastrojejunostomy. The difference is that the specimen is usually removed before doing the anastomosis.

Technique of Laparoscopic Antrectomy (Figure 14.3.7)

The first step is to open the gastrocolic ligament under the right epiploic vessel. This is done using electric scissors. Clips are used to secure all vessels and prevent any hemorrhage. The stomach can then be retracted cephalad using a Babcock, which exposes the posterior aspect of the duodenum. The posterior area of the duodenum is carefully dissected, as in open surgery, using an atraumatic grasper in the left hand and electric scissors in the right hand. It is usually necessary to ligate the right epiploic vessel after its division from the gastroduodenal artery. The right gastric artery at the upper limit of the duodenum is then found and ligated between two clips and two Endoloops to secure the hemostasis.

The next step is to transect and close the duodenum using an Endolinear cutter (Ethicon, Inc., Cincinnati, OH) (60 mm if possible; the 30-mm cartridge is usually too small to achieve a safe closure). The line of sutures is inspected, and hemostasis is meticulously and carefully completed. The distal part of the antrum can then be exposed with one grasper and dissection along the lesser curvature performed step-by-step, using the clip applier as required. The 30° telescope gives a good view of the posterior aspect of either the stomach or the lesser sac. Any large vessel encountered is dissected and cut between two clips.

Finally, although it is sometimes possible to perform the anastomosis between the stomach and the jejunum with the specimen in place, the gastric specimen is usually removed first. Several firings of the endolinear cutter 60 suffice. The surgeon can then follow the technique for gastrojejunostomy described above. The same careful inspection of the interior of the anastomosis is done, and the closure of the enterotomy holes for the introduction of the instruments is performed meticulously to avoid stenosis. It is mandatory, before firing the endolinear cutter, to insert a bougie in the distal jejunal loop to ascertain the diameter of the anastomosis. The operation is completed by a vigorous lavage. No drain is needed.

Complications of Elective Surgical Treatment

Management of Complications of Bilateral Truncal Vagotomy and Balloon Dilatation by Laparoscopic Pyloroplasty (Figure 14.3.8)

Balloon dilatation to achieve a type of pyloroplasty is usually not very effective, and there is a risk of postoperative stenosis. Stenosis can be handled initially by an endoscopic balloon re-dilatation, keeping the balloon inflated for 45 seconds. This will sometimes but not always be effective. In the latter case, the only solution is either to perform a hand-sewn laparoscopic pyloroplasty or to convert to open surgery. A hand-sewn pyloroplasty is performed exactly as would be the open procedure. The pylorus is incised, and the muscle clearly divided. It is then sutured using at least seven interrupted stitches of 3–0 proline, according to Heinecke-Mickulicz. The suturing is extramucosal and care must be taken that no mucosa are interposed between the sutures, as this will inevitably result in leakage. At the end of the pyloroplasty, the suture line is checked by insufflating the stomach and filling it with diluted methylene blue. The operation is usually finished by the insertion of an abdominal drain that is removed a few days later.

Complications of Posterior Truncal Vagotomy and Anterior Seromyotomy

Although there are two potential complications associated with this procedure, we have encountered only one in our practice and then in only one patient and during the operation. No re-operation was required. This complication is bleeding from gastric vessels that run across the anterior aspect of the stomach. Although the bleeding occurred during the operation in our case, it could occur postoperatively.

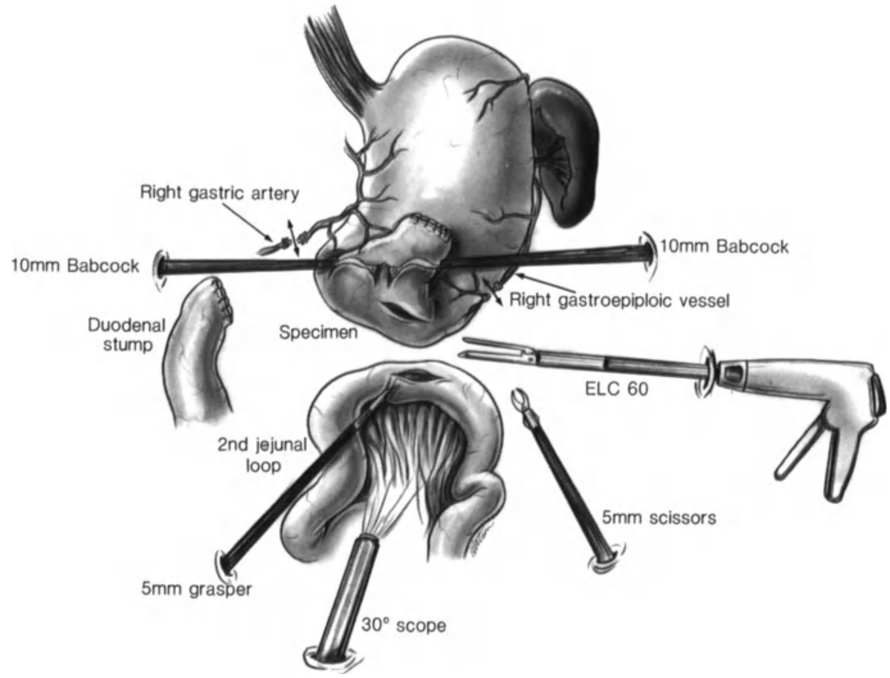

FIGURE 14.3.7. Laparoscopic bilateral vagotomy and distal gastrectomy.

When bleeding occurs during the operation, it is mandatory to grasp the vessel with an atraumatic clamp before trying any hemostatic maneuvers. Applying clips in an uncontrolled fashion will only lead to more problems, because each clip will interfere with the positioning of the next clip. After control of the vessel has been gained with the atraumatic forceps, the area is rinsed. Usually the hemorrhage has been controlled. It is then possible to place the clip precisely and to avoid any further bleeding.

If the bleeding occurs postoperatively, it is more serious. Usually a quick re-laparotomy is necessary. Usually the bleeding is localized to one of the first two vessels encountered when starting the seromyotomy, that run near the angle of His. Control of the hemorrhage should be achieved in the same manner that it would be if the bleeding had occurred during the operation. The best way to prevent hemorrhage is to achieve intraoperative control of each of the vessels before performing the anterior seromyotomy. This is accomplished by using a curved scissor to free the vessel and a double ligation of the vessels using clips. An overlap suture will prevent any blood oozing from the seromyotomy, which could result in a postoperative hematoma.

The second complication is perforation of the mucosa. This complication is a problem only if it is not recognized, but nonrecognition can lead to serious postoperative problems, such as peritonitis. Therefore, we recommend that surgeons who lack experience end the procedure by filling the stomach with methylene blue and checking the seromyotomy line. If there is any suspicion of mucosa perforation, it is mandatory to close the perforation using two or three overlapping stitches. Perforation of the mucosa can be prevented by staying above the mucosa and the submucosa, the layer which contains all of the vessels. Indeed, only an incision of the serosa and the muscle layers is needed in this technique and will achieve good denervation of the lesser curvature. When performing the seromyotomy, it is extremely important to grasp both edges of the stomach and combine the effects of traction with those of electrocautery. An electrosurgical device with a blended current setting should be available.

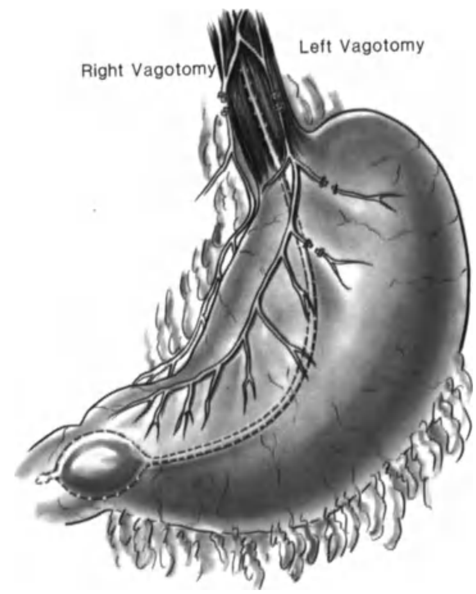

FIGURE 14.3.8. Bilateral truncal vagotomy and balloon dilatation.

Some bezoars can also cause complications, ultimately due to some gastric stasis. This is not controllable during the operation. The only treatment consists of papain syrup, which will easily dissolve the bezoar.

Complications During and After Highly Selective Vagotomy

A. Disruption of the Vagal Innervation of the Stomach

One of the big dangers of this operation, especially in the obese patient, is that the branches of Latarget's nerves will be sacrificed during the dissection. This will inevitably lead to a pyloric spasm and gastric stasis with severe postoperative side effects. The difficulty with this complication is recognizing it, especially in fatty lesser omentum. Once the injury is identified, it is necessary to achieve a pyloroplasty with balloon dilation, which is not as effective as a traditional surgical pyloroplasty.

B. Hematoma of the Lesser Sac Due to Uncontrolled Bleeding

Hematoma may disrupt the anatomy of the branches of Latarget's nerve and could result in injury to the main trunk itself. Moreover, if a compressive hematoma is present, its postoperative effect could be very similar to that of a bilateral truncal vagotomy. It is therefore very important to perform highly selective vagotomy very meticulously, using clips. Others have advocated that hemostasis of the nerve bundles together with the small vessels be achieved using bipolar electrocautery devices. This technique appears promising, although no data are available on its effectiveness.

Another way of achieving highly selective vagotomy is to use vascular cartridges in endolinear cutters. This makes the procedure very expensive, and the hemostasis obtained with cutters is not always satisfactory.

C. Injury to the Esophagus

One of the possible complications of highly selective vagotomy is injury to the esophagus. This is the most serious complication. It can be prevented by very careful dissection behind the esophagus. It is mandatory to free at least 8 cm of the esophagus so that all the criminal nerves of Grassi, which run on the posterior aspect of the esophagus can be controlled. A window is usually made under the left crus. This allows the esophagus to be encircled and a penrose drain, which will enable lifting of the esophagus and easier dissection of all of the nerves behind the esophagus, to be inserted. All of the branches under the drain should also be taken out using a curved hook. Care should be taken not to use electrocautery on this particular aspect of the esophagus to avoid electrical injury to this very fragile organ.

Treatment of Hemorrhagic Peptic Ulcers[8,9]

Endoscopic treatment of a visibly bleeding gastroduodenal artery is very controversial, and no surgical technique has been shown to effectively control the bleeding. Indeed, laser cautery, electrocautery, or even the application of clips (except in the hands of Sohendra, who has extensive experience with endoscopic clips) will not achieve good control of the hemorrhage, and there is a high risk of rebleeding. Therefore, the only realistic alternative is open surgery using the Weinberg procedure. This consists of opening the duodenum, localizing the bleeding, suturing the bleeder, closing the duodenum, and then performing a truncal vagotomy, if the patient can tolerate the extra time needed for this procedure. This procedure nevertheless performed through a midline incision has a nonnegligeable morbidity and mortality rate due to the preoperative general condition of the patient.

An interesting possibility for the future is a laparoscopic endo-organ procedure (Figure 14.3.9). This might prove to be of great utility for the control of bleeding duodenal ulcers. It consists of the introduction of the laparoscope through the umbilicus and the simultaneous introduction of trocars in the gastric pouch. This allows the introduction of graspers and instruments in the stomach itself. After a pyloric dilatation, maintained with a special instrument, it may be possible to see the bleeding area directly and thus to achieve its hemostasis. Hemostasis could be achieved with a specially devised clip, an intragastric suture, or even an external suture tied on

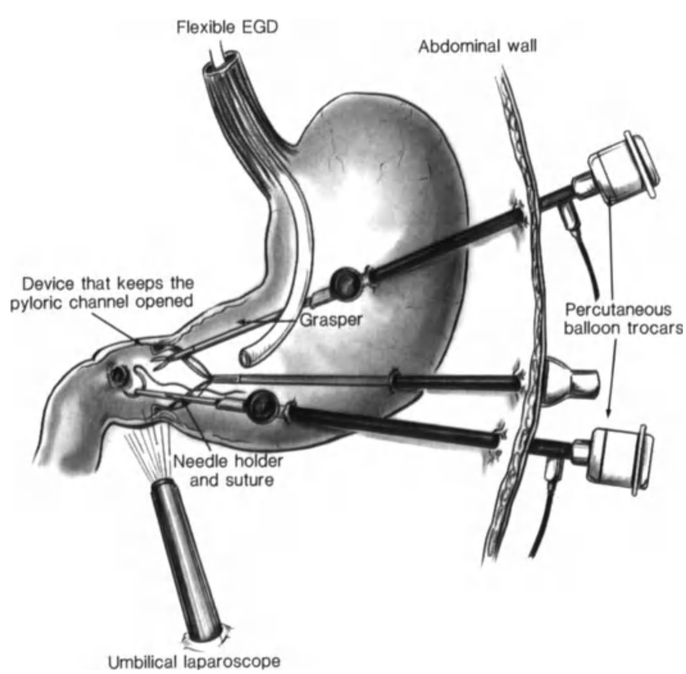

FIGURE 14.3.9. Endo-organ surgery on a bleeding peptic ulcer.

the external aspect of the duodenum. This procedure is still experimental, however, and needs more investigation.

Conclusion

Although *H. pylori* contributes to the development of duodenal ulcers, some 6% of the duodenal ulcer population is *H. pylori* negative.

Moreover, complications due to noncompliance with medical treatment are still frequent. Socioeconomic factors contribute to this problem. Laparoscopic treatment of peptic ulcer with posterior truncal vagotomy and anterior seromyotomy could prove to be a cost-effective alternative to long-term medical management. Complications of peptic ulcer disease can be managed laparoscopically, but with the exception of treatment of perforated ulcers, all procedures require specific skills and expertise. Laparoscopic management of perforated duodenal ulcers is easy to perform and should be considered as the next learning step after laparoscopic cholecystectomy and appendectomy.

In conclusion, one should emphasize the importance of laparoscopic suturing techniques for handling emergency or complicated situations. We should always keep in mind that laparoscopic procedures only *duplicate* proven open procedures.

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15
Laparoscopic Appendectomy

Brian C. Organ

Laparoscopic Appendectomy

Appendectomy continues to be one of the procedures most commonly performed by general surgeons. In the United States, 550,000 appendectomies are performed each year, 54% for appendicitis, 47% incidental to some other procedure.[1] Appendicitis in its classic form is easily diagnosed. However, in the very young, the elderly, and the female, it can be difficult to diagnose. This is borne out by a reported negative exploration rate between 15 and 20% in the total population and between 30 and 45% in young women.[1–3] Judicious use of laparoscopy evaluation in the diagnosis and treatment of right lower quadrant pain will improve the management of appendicitis.

Historical Review

The Egyptians undoubtedly had knowledge of the appendix, because the hieroglyphics on funerary jars containing the intestines refer to the "worm" of the bowel. The first known drawings of the appendix were by Leonardo da Vinci in 1492; later Vesalius depicted the appendix in his work *De Humani Corporis Fabrica* in 1543. Verheyen in 1710 called this feature the "appendix vermiformis."[4]

A number of physicians and surgeons from the 1500s to the 1800s reported cases or autopsy findings of perforation, abscess, and foreign bodies (fecalith, bird shot) located within inflamed appendices.[4] In 1827, Melier correctly ascribed purulent "iliac tumor" to inflammation of the appendix,[5] but this theory was widely criticized by his fellow surgeons. In 1830, Goldbeck collected 30 cases and accurately reported the symptoms and signs of appendicitis.[4] He believed, however, that the process, which he called "perityphlitis," began in the cecum, a belief that prevailed for the next 60 years.

Reginald Fitz is credited with describing the symptoms and signs of early appendiceal inflammation in 1886, coining the term "appendectomy," and advocating early removal of the appendix as a cure.[6]

The first recorded surgical removal of the appendix was performed at St. George's Hospital in London, by Claudius Amyand in 1735. The patient was an 11-year-old boy who had a right scrotal hernia and fecal fistula as a result of a pin perforating the appendix. William West Grant of Davenport, IA, became the first physician to surgically remove an appendix in the United States in 1885.[4]

Charles McBurney popularized early operation for acute appendicitis, described the sign of point tenderness in the right lower quadrant of the abdomen (McBurney's point), and popularized the "muscle splitting" (McBurney) incision.[8]

Between 1900 and 1925 the mortality from acute appendicitis was 50%, or 15 out of every 100,000 persons in the United States could expect to die each year from appendicitis. No consensus could be reached about the timing of surgical intervention. Today, with improvements in diagnosis, perioperative care, surgical skills, fluids and electrolyte management, and antibiotic therapy, mortality has declined to 1 per 100,000 persons.[2] The morbidity from appendicitis is 5 to 8%, with wound infections accounting for one-third of all morbidity . Death is more likely when appendicitis occurs at the extremes of age or when there is underlying cardiorespiratory disease, diabetes, or cancer. The increased mortality in these groups is related to decreased physiologic reserves, delay in diagnosis, or a reluctance to operate on patients in high-risk groups.

The effect of delayed diagnosis and surgery on morbidity and mortality cannot be overemphasized. This is why the many reports indicating a clinical diagnostic accuracy of 67 to 80% for acute appendicitis[3,9,10] are of concern and why laparoscopy has so much to contribute to the treatment of appendicitis.

Laparoscopy has been used since the turn of the century to examine abdominal pathology,[11] and is extensively utilized by gynecologic surgeons to diagnose pelvic pathology. A number of investigators have assessed patients with right lower quadrant abdominal pain laparoscopically in an effort to decrease the negative appendectomy rate.[10,13] Patterson-Brown and colleagues reduced their negative appendectomy rate from 22 to 7.5%.[12] Leape and colleagues reported a series in which 12 of 32 patients who were examined laparoscopically were spared a laparotomy and all of those who needed an appendectomy received prompt treatment. Other authors have reported the successful use of laparoscopy in the assessment of abdominal pain or the evaluation of tumors and traumatic injuries.[14,15]

Laparoscopic appendectomy for the uninflamed appendix was initially performed by Kurt Semm, professor of surgery at the University of Kiel in 1983.[16] Since then, many surgeons have reported laparoscopic appendectomies or laparoscopically assisted appendectomies for the treatment of appendicitis (Table 15.1).

Laparoscopic Technique

Preoperative considerations are the same for laparoscopic appendectomy as for an open procedure. Contraindications to the laparoscopic approach, such as multiple previous lower abdominal procedures, should be considered. A single dose of a broad-spectrum antibiotic is administered intravenously, and the patient is counseled for both laparoscopic and open appendectomy. A nasogastric tube and urinary catheter are emplaced once the patient is anesthetized. They reduce the risk of aspiration of stomach contents or bladder injury when the trocar is inserted and improve visibility within the abdomen.

Many variations on the laparoscopic appendectomy have already been proposed, all of which employ three or four trocars. As with all laparoscopic procedures, basic surgical principles of exposure, retraction, and ligation or coagulation of the blood vessel should be adhered to.

All patients are placed in the supine position (Figure 15.1A); female patients for whom the diagnosis is questionable can be placed in the modified lithotomy position to facilitate placement of a uterine manipulator transvaginally, which facilitates pelvic visualization. Some surgeons prefer to place all patients in the lithotomy position because the monitor is more visible when the assistant is on the patient's right and the camera is between the patient's legs (Figure 15.1B).

Pneumoperitoneum is established utilizing a Veress needle inserted into an infraumbilical stab wound. In patients who have had previous surgery the Hasson direct visualization technique is used instead. The abdomen is inflated with CO_2 to 12 to 15 mm Hg. A 10- or 12-mm trocar is then placed in the infraumbilical site and a 0° laparoscope inserted. Complete and thorough inspection of the abdominal cavity is conducted to ensure no intra-abdominal trauma occurred during Veress needle or trocar insertion, to ascertain the presence of appendiceal disease, and to look for other causes of right lower quadrant pain or coexisting pathology (i.e., adhesions, phlegmon, or additional abscess pockets).

Positioning of additional trocars for appendectomy depends on the body habitus of each individual. In the three-trocar method (Figure 15.2), the surgeon inserts a 5-mm trocar in the right upper quadrant, taking care to avoid the superior epigastric vessels. The surgeon places a third 10- or 12-mm trocar in the suprapubic or left lower quadrant region, taking care to avoid the bladder and inferior epigastric vessels. Some surgeons prefer to switch these two trocars. A fourth 3- or 5-mm trocar placed in the right lower quadrant may be necessary to provide additional appendiceal retraction (Figure 15.2). This trocar is especially useful if the appendix is too small or too inflamed to be safely grasped with forceps during appendiceal dissection. The trocar allows a pretied chromic ligature to be passed around the appendix.

The appendix is retracted anteriorly and cephalad or medial with a grasper, placing the mesoappendix on tension (Figure 15.3). Which trocar is used depends in great part on the location of the appendix. With the mesoappendix under tension, a plane is opened between the base of the appendix and the appendiceal artery. The artery, which is usually visualized with minimal blunt dissection, is doubly ligated with endoscopically placed ties or clips and then divided (Figure 15.4). Following ligation of the appendiceal artery, the mesoappendix is separated from the appendix by means of electrocautery, sharp dissection, or laser cautery. Three endoscopic loops are placed on the appendix: two endoscopic pretied ligatures are placed at the appendicocecal junction; a third ligature is placed on the appendiceal side approximately 5 to 10 mm from the two previously placed ligatures (Figure 15.4). The appendix is then transected between the appendiceal and appendicocecal-junction ligatures and extracted from the abdominal cavity through the 10- or 12-mm trocar, which prevents the appendix from contaminating the anterior abdominal wall.

TABLE 15.1. Published series of laparascopic appendectomy.

Series	Year	No. of patients
Gangal & Gangal[22]	1987	73
Schreiber[23]	1987	70
Gotz, et al.[24]	1990	388
Browne[26]	1990	100
McKernan & Saye[25]	1990	32
Pier, et al.[30]	1991	625
Valla, et al.[28]	1991	465
Nowzardan, et al.[27]	1991	43
Geis, et al.[21]	1991	30
O'Regan[29]	1991	21
Saye, et al.[34]	1991	109
Byrne, et al.[38]	1992	31

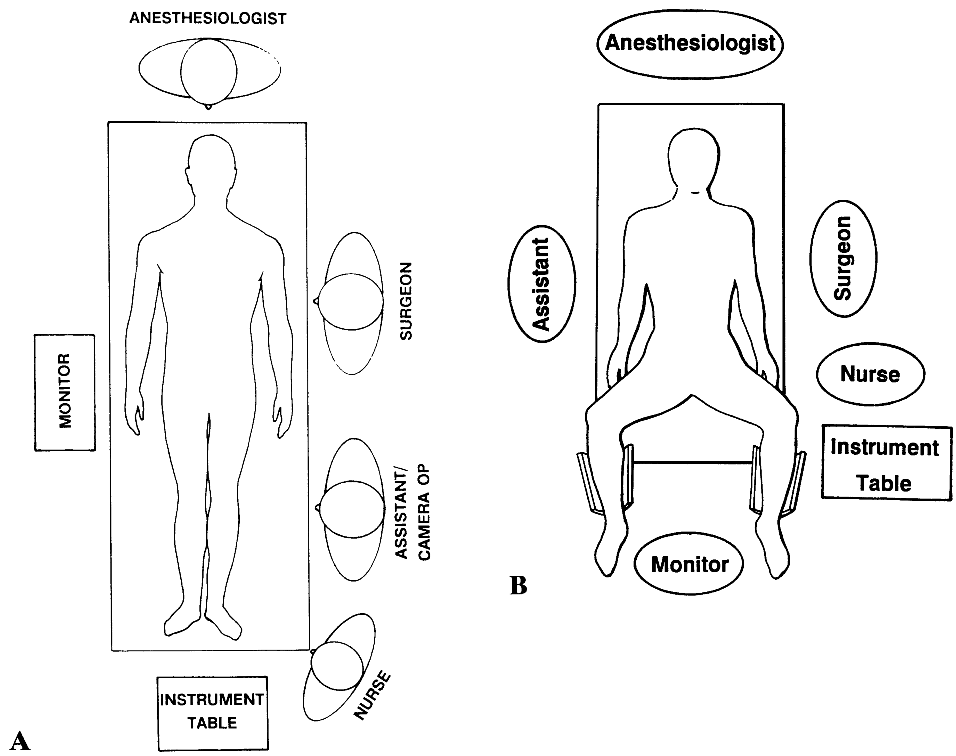

FIGURE 15.1. Room set-up for laparoscopic appendectomy. *A,* Surgeon on patient's left, monitor opposite (supine position) or *B,* surgeon between legs (lithotomy position).

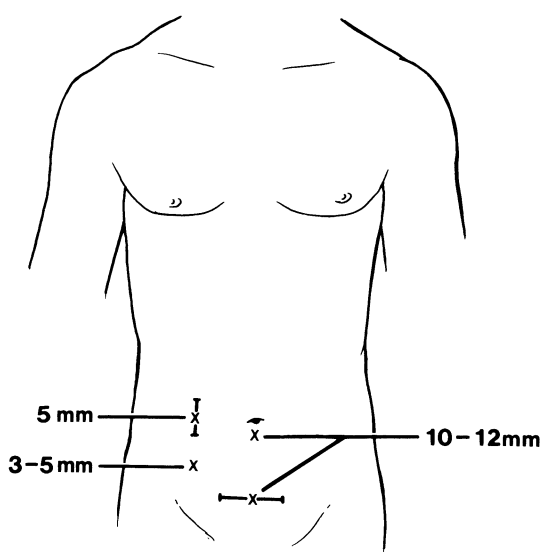

FIGURE 15.2. Cannulae placement for a three- or four-trocar method.

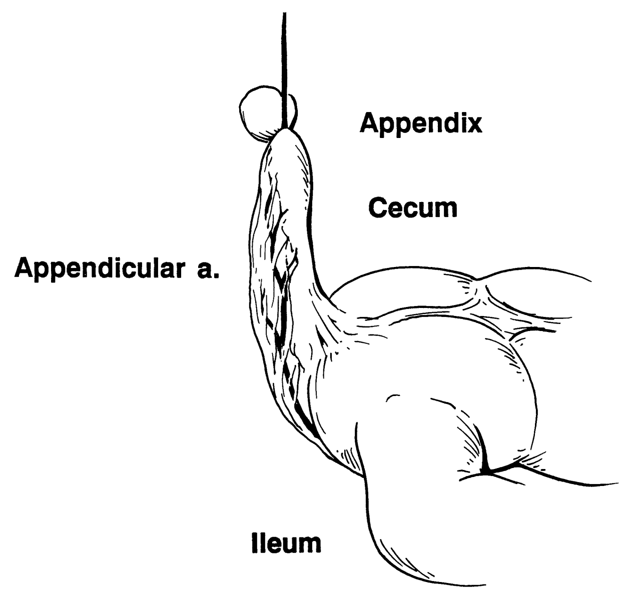

FIGURE 15.3. Appendix is retracted, putting the mesoappendix in tension for stapling or ligature placement.

Alternatively, a stapling device can be used for appendectomy.[17] This is accomplished by grasping the appendix with either atraumatic grapsers or an Endoloop and applying the laparoscopic stapling device across the mesoappendix or the base of the appendix (Figure 15.5).

The appendix can be extracted through either the 10- or 12-mm working trocar or through an enlarged incision. A rubber bag is placed via the trocar into the abdominal cavity. The appendix is placed within the bag, and then extracted through a trocar of the incision (Figure 15.6).

Following removal of the appendix, the operative site should be carefully examined, and irrigation and cautery employed to staunch bleeding if needed. The appendiceal stump is sealed by electrocautery (Figure 15.7), which

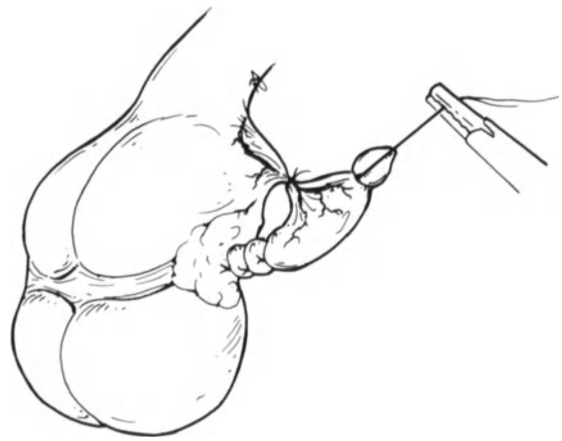

FIGURE 15.4. Appendiceal base and artery are ligated with suture prior to division.

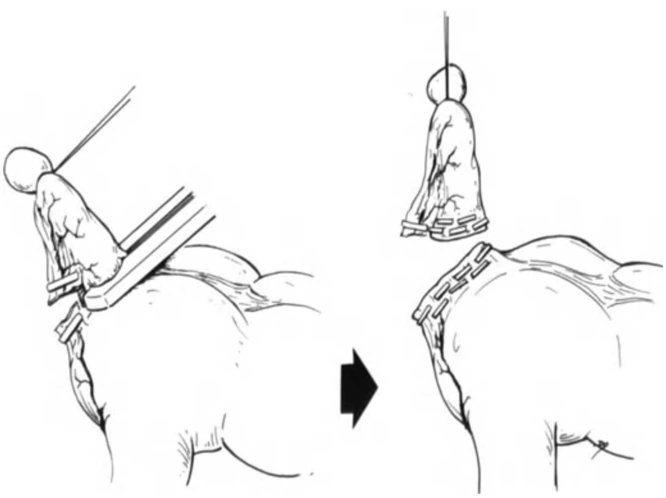

FIGURE 15.5. Hemoclips are placed on the appendiceal artery. Appendix is ligated and divided using laparoscopic stapler.

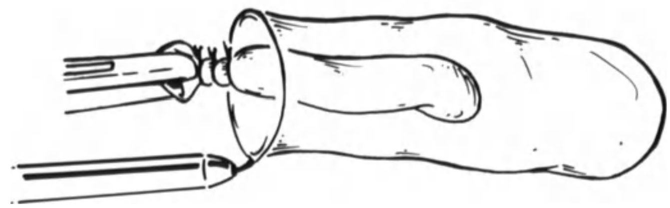

FIGURE 15.6. The appendix is placed within an endoscopic specimen-retrieval bag. If necessary, the specimen and bag can be removed by enlarging the trocar-site incision.

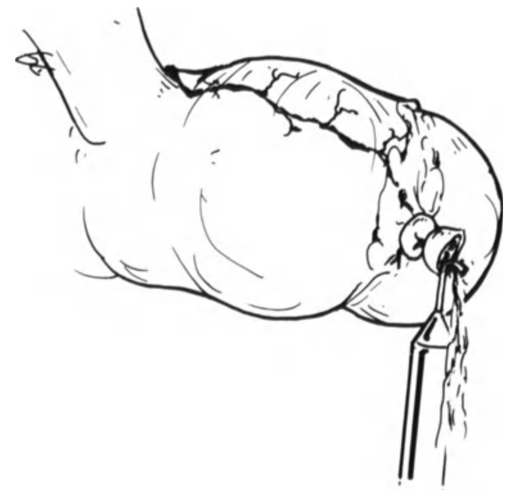

FIGURE 15.7. Mucosa of appendiceal stump is cauterized.

TABLE 15.2. Special equipment requirements for laparoscopic appendectomy.

- Uterine sound/tenaculum for uterine manipulation
- Laparoscopic loop ligatures
- 5-mm-to-3-mm reducing sleeve
- Suction/irrigation system
- Laparoscopic linear stapling device (30 mm)
- Endoscopic retrieval bag
- 2–0 silk/Vicryl suture with straight or curved needle

obliterates the mucosa and sterilizes the stump. Some feel that cauterization is not necessary.[18]

Special equipment used in laparoscopic appendectomy is listed in Table 15.2.

Special Considerations

Retrocecal Appendix

Occasionally, the appendix lies retrocecal either completely or partially. When the abdominal cavity is viewed laparoscopically, inflammation or purulence will be seen in the right paracolic region. This should not be cause for alarm. The lateral peritoneal attachments of the cecum are taken down and the cecum is retracted cephalad (Figure 15.8). A 30 to 45° laparoscope is useful for this dissection. If a 30 to 45° scope is not available, then the table can be tilted left-side-down and a 0° scope inserted into the umbilical port. The lateral peritoneal attachments can then be cut through a trocar in the right lower quadrant. Once the retrocecal appendix is mobilized, the appendectomy is completed as outlined above.

The Normal Appendix

When a normal appendix is encountered, every surgeon feels chagrined. A systematic evaluation for other causes of acute right lower quadrant abdominal pain must be done. The cecum and terminal ileum should be examined for inflammatory changes suggesting Crohn's disease, infectious ileitis (*Yersinia*), Meckel's diverticulitis, or mesenteric lymphadenitis. It is also important to examine the

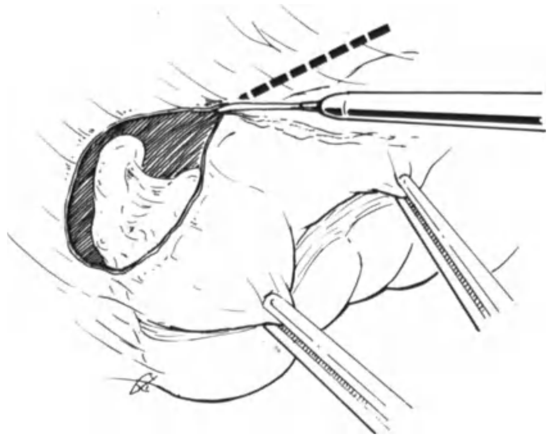

FIGURE 15.8. Division of the lateral peritoneal attachments to expose a retrocecal appendix. An angled (30 to 45°) scope is useful for this maneuver.

colon for changes of diverticulitis and to inspect the right upper quadrant to rule out cholecystitis or a perforated peptic ulcer.

In women, the pelvic organs should be visualized so that pelvic inflammatory disease, tubovarian abscess, ectopic pregnancy, and ovarian tumors are excluded. Placement of the operating table in Trendelenburg position and manipulation of the uterus with a uterine tenaculum emplaced preoperatively improve visualization of the pelvic anatomy.

In cases where other pathology has been identified as the source of abdominal pain and the appendix appears normal, there appears to be little justification for removal. However, numerous reports have demonstrated that there can be discrepancies between the surgeon's opinion, the macroscopic appearance of the appendix, and the opinion of the pathologist.[8,19] Lau and colleagues in a prospective study of 1,699 patients reported that 19% of patients thought to have a normal appendix macroscopically were found to have acute appendicitis on histopathologic exam and 77% thought clinically to have acute appendicitis were normal.[20]

As surgeons increasingly utilize the laparoscope to assess right-lower-quadrant abdominal pain, they will increasingly face the problem of the management of the normal-appearing appendix. A decision tree for laparoscopic appendectomy has been suggested:[21]

1. If the appendix is grossly inflamed, perform a laparoscopic appendectomy.
2. If the appendix does not show evidence of acute appendicitis and there is no other visible cause for the abdominal symptoms, the appendix should be removed laparoscopically.
3. If the appendix does not show evidence of acute inflammation but there is evidence of pelvic disease (ovarian cysts, pelvic inflammatory disease, or Crohn's disease of the ileum), the appendix should be removed to avoid future confusion between appendicitis and a recurrence of these other disease processes.
4. If the appendix shows no signs of inflammation but there is another obvious abdominal process requiring surgical intervention, treat the primary disease (such as ischemic bowel disease, perforating diverticulitis, etc.). Do not perform an appendectomy.

Perforated Appendicitis

Patients with perforated appendicitis are usually more toxic than patients with simple appendicitis and appendectomy presents a technical challenge for the surgeon. The surgical principles are the same whether intervention is open or laparoscopic:

1. Preop intravenous hydration.
2. Broad-spectrum or combination antibiotics that will cover gram-negative and anaerobic bacteria.
3. Appendectomy with aspiration of purulent material from the peritoneal cavity, vigorous irrigation of the peritoneal cavity, and drainage if an abscess is found.

The laparoscopic approach may be superior for patients with generalized peritonitis because of better visualization of the peritoneal cavity, which permits more precise irrigation and ensures localized abscess cavities will be seen. To perform irrigation during open surgery a generous extension of the right-lower-quadrant incision is often needed.

The Appendiceal Mass

There is a group of patients who present some days after the onset of symptoms that suggest appendicitis, and on examination are found to have a mobile or fixed mass in the right iliac fossa. If an adult is first seen when symptoms are subsiding and a well-localized periappendiceal mass is palpated by physical examination, it is reasonable to start IV antibiotics and observe until resolution. This can be followed by interval appendectomy in six weeks. If symptoms do not resolve, prompt appendectomy or drainage of the appendiceal abscess (operative or CT-guided) should be performed.

If the symptoms are of recent onset and the mass is mobile, the surgeon expects to find an appendiceal phlegmon or abscess. If the mass is detected after induction of anesthesia, appendectomy with or without drainage is the treatment of choice. On encountering an appendiceal phlegmon or abscess, the surgeon must decide whether he possesses the skills to perform this procedure laparoscopically or the patient would be best served by conversion to open surgery. The risks of causing iatrogenic intestinal injury when dissecting out the appendix from the inflamed, matted loops of intestine or of opening an abscess cavity and spreading purulent material throughout an otherwise normal abdominal cavity should be considered. Abscesses might be better managed by a surgical incision directly over the purulent mass. Those surgeons who attempt laparoscopic appendectomy in this situation should remember that the dissection will be bloody, difficult, and, at times, blind.

Identifying the cecum and terminal ileum will lead the surgeon to the appendix. It may be necessary to mobilize the cecum to provide better visualization. The cecum should be dissected with a Kittner blunt probe or hydrodissected, especially if the abscess cavity is not well formed. Care should be taken not to disturb adherent coils of intestine or omentum on the medial side of the mass. Once the appendix is identified and removed, the abscess wall should be extensively debrided (a 10-mm suction/irrigator is helpful) and copious irrigation is recommended (1 to 2 L is not unusual). Patients can be in various positions during abdominal irrigation, but the steep Trendelenburg should be avoided to prevent accumulation of fluid in the upper abdomen. Drains are inserted through a 10-mm trocar and brought out through one of the existing trocar sites or a separate puncture site made for the purpose.

Review of the Literature

Semm first described laparoscopic removal of the veriform appendix nearly a decade ago.[16] In the interim, spurred by the rapid acceptance of laparoscopic cholecystectomy, many investigators have reported their experience with laparoscopic appendectomy (Table 15.1).

Gangal and Gangal reported 73 patients who underwent laparoscopic appendectomy utilizing gynecologic tubal banding technology.[22] These authors felt that although it was more time-consuming, laparoscopy offered improved visualization, was technically feasible, and decreased wound infection rates and postoperative pain.

In 1986, Schreiber reported his experience with 70 females who underwent laparoscopic appendectomy.[23] Of the 70, 3 were pregnant and 40 (56%) underwent a concomitant gynecologic procedure. They reported one complication; a cecal perforation in a patient with heat damage to the cecum caused by cauterization of the appendiceal stump too close to a previously placed ligature. This injury required a laparotomy, closure of the fecal fistula, and drainage. Their recommendation was to cauterize at least 5 mm from the cecum. They agreed with other authors that laparoscopic appendectomy was usually safe and provided a means of diagnosis in ambiguous cases, and reported that patients quickly returned to normal activity.

Gotz and colleagues reported their experience with 388 laparoscopic appendectomies in 1990.[24] Seventy-four percent of the patients suffered from acute appendicitis, and five had perforated appendicitis. In 12 cases, they were forced to convert to a conventional procedure; all of these conversions were among their first 50 laparoscopic procedures. Lack of experience made it difficult for them to deal with bleeding, adhesions, abnormal position of the appendix, or corpulant body habitus. The rate of negative findings was 12%. There were some interesting secondary findings: one Meckel's diverticulum, one carcinoid tumor of the appendix, and one cecal diverticulum. These authors experienced a slippage of the loop ligature from the appendiceal base following coagulation of an appendiceal stump that was too short. They too stressed that the appendiceal stump should be coagulated 5 to 7 mm distal to the loop ligature. Postoperative abscesses were observed in two cases and required a laparotomy. Sixty-four percent of patients were able to ambulate on the day of the operation. Patients expressed great satisfaction with the more cosmetic incisions and the quick return to normal activity. The authors concluded that laparoscopic appendectomy is safe, practical, can be learned quickly, and may cost less because of shorter hospital stays; however, they provided no data to support the last assertion.

In 1990, McKernan and Saye reported 32 patients who underwent laparoscopic appendectomy in which an argon laser was used for dissection, cutting, and cautery.[25] The first 2 patients were hospitalized overnight, the remaining 30 were treated as outpatients, and all resumed normal activity within seven days. Their recoveries were uneventful, and no complications were reported. The authors concluded that diagnostic laparoscopy enables the surgeon to diagnose and treat abdominal pain more definitively and much earlier. Laparoscopic appendectomy was deemed a viable alternative to traditional procedures and the argon laser was deemed a safe instrument, in trained hands, for vaporizing adhesions or cutting the appendix and mesoappendix. They agreed with earlier authors that patient acceptance of smaller incisions and decreased postoperative pain was good. Additionally, they suggested that uncomplicated appendicitis could become an outpatient procedure.

Also in 1990, Browne reported 100 consecutive cases of laparoscopically guided appendectomy.[26] The laparoscope was used to locate the appendix, and the appendectomy was performed outside of the abdominal cavity. No intra-abdominal abscesses or serious complications were noted, but seven patients developed wound infections. The author concluded that this method of extracorporeal resection was simple, safe, reliable, and effective, especially in cases of chronic appendicitis.

In 1991, Nowzaradan and colleagues reported 43 consecutive patients who presented with right-lower-quadrant abdominal pain and had a preoperative diagnosis of possible appendicitis who were evaluated by laparoscopy.[27] Of the 43, 31 had acute appendicitis, 28 of the 31 underwent laparoscopic appendectomy, and 3 who had perforated appendices underwent open procedures. Of the 11 patients with normal appendices, 8 underwent incidental appendectomies, 7 by laparoscopy, and 1—a patient who had severe endometriosis—by conventional laparotomy. Four appendices of normal appearance were left alone and required no further therapy. These authors concluded that laparoscopic appendectomy results in less postoperative pain, morbidity, and adhesions, is superior cosmetically, and is associated with shorter hospitalization and faster return to normal activity.

Valla and colleagues reported 465 pediatric laparoscopic appendectomies in 1991.[28] Ninety-three percent showed evidence of acute appendicitis and 70 (15%) had extra-appendiceal lesions found at the time of the laparoscopy. These included: 30 adhesions, 16 inguinal hernias, nine ovarian cysts, three Meckel's diverticulum, three salpingitis, one Crohn's disease, and one primary pneumococcal peritonitis. There was no mortality, and only 5 of the 465 underwent conversion to laparotomy. There were 17 (3.6%) intraoperative incidents and 14 (3%) postoperative complications. Four of these required laparotomy, two for intra-abdominal abscess and two for hernia repair. Repeat laparoscopy was performed in a patient with early obstruction and a second patient's residual intraperitoneal abscess was drained with laparoscopic guidance. The authors concluded that the drawbacks of laparoscopic appendectomy are the initial expense of laparoscopic equipment, longer operations during the surgeon's learning phase, and potential complications not associated with traditional procedures, such as the shoulder pain that accompanies pneumoperitoneum. The advantages of laparoscopic appendectomy they identified are easy and rapid identification of the appendix even when it is in the ectopic position, and more complete and thorough aspiration and irrigation of the abdominal cavity. Wound infection and abscesses were essentially eliminated and the incidence of postoperative intra-abdominal infection was markedly decreased. They cautioned that patients presenting with apparent appendiceal phlegmon may be at greater risk if the laparoscopic approach is used because of the potential for iatrogenic intestinal injury. The authors also recommended that patients with a localized purulent collection and otherwise normal abdominal cavity would be best served by percutaneous drainage through a surgical incision centered directly over the palpable purulent mass. This approach minimizes the risk of spreading purulent material throughout the peritoneal cavity.

Also in 1991, O'Regan of Vancouver, BC, reported his experience with 21 patients who underwent diagnostic laparoscopy, 12 of whom eventually underwent laparoscopic appendectomy.[29] Eleven of the 21 were found to have acute appendicitis. One was a young woman who had been repeatedly hospitalized for acute abdominal pain but did not have acute appendicitis. Five patients underwent appendectomy through a McBurney incision following laparoscopic identification of the inflamed appendix. The rationale for this was not given. The author did comment, however, that decreased wound infection rates resulted when the appendix was withdrawn through the trocar shaft and therefore did not contaminate the layers of the anterior abdominal wall.

Olsen reported on the use of a linear stapling device to perform laparoscopic appendectomy in 1981.[17] He advocated the use of the stapling device rather than a loop ligature because it provided a quicker, more secure, and superior ligature of the appendiceal stump, especially in the case of inflammation, and eliminated the spillage that occasionally occurs with the loop ligature.

Pier and colleagues of Linnich, Germany, updated a report of 625 laparoscopic appendectomies in 1991. Of 678 cases, 625, or 92%, underwent laparoscopic appendectomies. Only 2% underwent conversion to conventional appendectomy. The authors had a 28% conversion rate in their first 50 cases but none of their last 589 underwent conversion. In 6%, conventional appendectomy was undertaken from the start, either because a laparoscopically trained surgeon was not present or the patient was unwilling to undergo a laparoscopic appendectomy, considered a new procedure. Of the 625 patients who underwent laparoscopic appendectomy, 14% showed no signs of actual inflammation, 70% had subacute appendicitis, and 3% had recurrent appendicitis. Among the 431 patients with acute appendicitis, there were 70 phlegmons, and 10 gangrenous and 9 perforated appendices. In 121 patients (19%), fecalith was a probable cause of the appendicitis. The authors reported an average operative time of between 15 and 20 minutes. They concluded that their experience has reinforced their earlier beliefs that laparoscopic appendectomy was a practical procedure in the treatment of all stages of appendiceal inflammation.[24] The main benefits of the procedure are reduced traumatization of the tissues and irritation of the intestines, which may result in fewer adhesions, greater patient comfort, shorter hospitalizations, and earlier return to work. They expressed some concern that surgeons often begin by performing laparoscopic cholecystectomy, an undertaking that requires more skill than laparoscopic appendectomy. Pier and colleagues suggest that laparoscopic operations be learned in order of difficulty, speculating that there would be fewer discouraging experiences and fewer complications if this were done.

Two prospective randomized series have appeared in literature. One by McAnena and colleagues reported on 65 patients with the signs and symptoms of appendicitis who were randomly assigned to either open or laparoscopic appendectomy.[31] Attwood and colleagues reported on 62 consecutive patients whose treatment was also randomized. The data from these studies is depicted in Table 15.3.

Both studies concluded that laparoscopic appendectomy is a safe and feasible option of the management of acute appendicitis in most cases. Current studies suggest that it shortens hospital stays and significantly diminishes the risk of postoperative wound infection. Patients also seem very satisfied with the cosmetic results of laparoscopic surgery, as other authors have noted. Both authors concluded that laparoscopic appendectomy has a role in the management of appendicitis.

Table 15.4 displays the results of an economic comparison of open and laparoscopic appendectomy. Fritts and Orlando demonstrated that total hospital charges were not significantly different.[33] However, the charges for specific items were strikingly different; room and board charges for the laparoscopic appendectomy group were 24% lower than those for the conventional appendectomy group, whereas the charge for operating room is 26% higher for the laparoscopic appendectomy group, largely because operating time was 32% longer. The greatest disparity was in the operating and supply charges, which were 22 times greater in the laparoscopic group. The authors point out that future cost-containment efforts must be directed towards minimizing the expense of endosurgical equipment and maximizing the use of nondisposable supplies.

A study by Schroder and colleagues, published in 1993, is the most comprehensive study in the literature to date.[34] They reported several significant advantages and one disadvantage of laparoscopic appendectomy for acute appendicitis. Hospital stays were shortened, intramuscular analgesia requirements were decreased, postoperative pain was minimized, and convalescence was shorter. In their view, cost, operative time, and the unavailability of laparoscopic equipment militate against the procedure. Increased hospital costs for the laparoscopic appendectomy group were a result of higher equipment costs and the anesthesia charges generated by increased operative time. They found that use of a linear stapling device does not decrease operative time but that, as other

TABLE 15.3. Prospective randomized trials of open and laparoscopic appendectomy.

	McAnena et al. (1992)		Attwood et al. (1992)	
	Open (n = 36)	Laparoscopic (n = 27)	Open (n = 32)	Laparoscopic (n = 30)[1]
Age (yr)	24 (14–64)	18 (14–60)	20.8 (12–39)	26.8 (15–67)
Sex M:F	14:22	14:15	—	—
Operating room time (min)	52 (15–90)	48 (20–120)	51 (15–100)[3]	61 (20–130)[3]
Conversions		2 (13.5%)		2 pts. (7%)
Neg. apply %	28%	26%	3 (6%)	4 (13%)
Postop days	4.8 (1–21)	2.2 (1–11)[4]	3.8 (1–7)[4]	2.5 (1–7)
Wound infection	4 (11)	1 (4)[2]	1[2]	0
Postop complications	1 (1.7%)[3]	0	3[2,4]	0
Return to activity (days)	—	—	38	21
Median dose of i.m. analgesics	5 (2–12)	1 (0–5)[4]	—	—

1. 3 Normal appendices left in place.
2. 2 Urinary retention; 1 prolonged ileus.
3. $p < 0.05$.
4. $p < 0.01$.

TABLE 15.4. Economic comparison of open and laparoscopic appendectomy.

	Fritts/Orlando (1993)		Schroder et al. (1993)	
	Open (n = 206)	Laparoscopic (n = 58)	Open (n = 39)	Laparoscopic (n = 99)[1]
Age (yr)	35.1 (16–93)	30.2 (17.61)	34 (± 10.4)	31 (± 10.5)
Sex M:F	64% M	58% M	51:50	30:59
Operating room time (min)	67	87	45.4	60.4
Conversions	—	4 (6.8%)[2]	—	7 (7%)
Neg. apply %	—	4 (7%)	28%	26%
Hospital cost[3]	$6,369	$6,711	$6,213	$8,683
Postop days	4.1	2.7	3.8	2.7
Wound ifection	—	3 (5.2%)	2	2
Return to activity (days)	—	7	20.5	15.4
Postop complications	1 (1.7%)	0	6	7

1. 3 Normal appendices not removed.
2. Trocar injury to the right external iliac vein in one, one anatomically difficult, two abscesses.
3. Operating room supplies: Open $55; lap. $1,222.

authors have found, operative and hospital costs decrease as surgeons do more cases. They found no difference in the rate of wound infection or postop ileus between laparoscopic and open procedures.

Discussion

The value of the laparoscopic approach may not be immediately obvious to those accustomed to the conventional open procedure. Although laparoscopic appendectomy was reported four years before laparoscopic cholecystectomy, it has not been incorporated into surgical practice with the same speed. Many surgeons feel they are currently able to remove an appendix through a small incision, achieving many of the benefits of a laparoscopic procedure. However, when a normal appendix is encountered, the incision is usually enlarged for a more thorough evaluation. Additionally, given the complications and increased costs that accompanied the industry-supported and consumer-driven rise of laparoscopic cholecystectomy, many surgeons have become cautious about adopting laparoscopic procedures. Many surgeons are waiting for good information about the morbidity, cost-effectiveness, and long-term consequences of laparoscopic appendectomy. There are also economic, sociopolitical, and medicolegal issues to be considered. Is the laparoscopic approach safe? Is it cost-effective? And is it patient-friendly?

This chapter presents reported experience regarding the feasibility and safety of laparoscopic appendectomy in more than 2,200 patients. The advantages are: less postoperative pain, shorter hospital stays, earlier return to normal activity, less postoperative morbidity, decreased wound-infection rates, fewer adhesions (less-persistent pain and bowel obstruction),[36] less-frequent postoperative ileus, and superior cosmetic results. Many authors also agree that because laparoscopic appendectomy allows the surgeon to inspect the abdominal cavity much more completely, it may be the technique of choice, especially in cases of unknown etiology or diffuse intra-abdominal purulence.

Current techniques utilizing linear stapling devices, angled cameras, pretied loop ligatures, and better-designed instruments for intracorporeal suturing have dramatically decreased operative times for laparoscopic procedures. As surgeons and operating-room staffs acquire more experience with diagnostic laparoscopy for the evaluation of right-lower-quadrant abdominal pain and other abdominal maladies, it seems inevitable that the laparoscopic approach will be more commonly used, and most investigators report reduced operative times with increasing experience.

The disadvantages of the laparoscopic approach are complications common to laparoscopic procedures, increased costs (for equipment, disposable instruments, and training), increased operative time and use of operating-room resources, frustrations related to the staff's unfamiliarity with laparoscopic equipment and procedures, and difficulties that arise because of the surgeon's lack of training or judgment. Unfortunately, there may be surgeons operating without adequate laparoscopic training and, more importantly, without the judgment to appreciate the risks to which this lack of knowledge exposes the patient.[34]

Cost remains an overwhelming theme, particularly against the backdrop of healthcare reform. Incidental (negative appendectomy) and uncomplicated appendectomy may well become outpatient or overnight-stay surgeries. The increasingly knowledgeable healthcare consumer is demanding laparoscopic techniques when available.

Technological advances likely to influence the treatment of appendectomy will concern wound healing and the breakup of fibrinous exudate laden with bacteria, which attaches to surfaces, serving as the nidus for future infections, and the development of laparoscopic methods that don't require general anesthesia or pneumoperitoneum.

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16
Laparoscopic Small-Bowel Surgery

Daniel T. Martin, David E. Pitcher, and Karl A. Zucker

Introduction

Although the small intestine comprises approximately 70 to 80% of the length of the gastrointestinal tract and 90% of the mucosal surface area, only about 3 to 6% of tumors involving the intestines arise in the small bowel. Nonmalignant disorders of the small bowel are equally uncommon. Therefore, resective surgery of the small intestine is uncommon and the operative procedure most commonly performed on the small bowel is perhaps that for the placement of enteral feeding appliances. Although the small intestine is often used as a conduit during other major surgery, this chapter will be devoted to the laparoscopic surgery on the small intestine itself.

Since the small bowel is endowed with a longer mesentery, greater mobility, and smaller diameter than the large intestine, it is better suited to laparoscopic intervention. To date, most of the small-bowel laparoscopic procedures reported in the literature have been for the placement of feeding tubes, though there have been isolated reports of resections for Meckel's diverticulum.[1,2] It seems reasonable that this approach could also be considered for creation of jejunal interposition limbs for esophageal replacement or for gastric bypass in the morbidly obese. In addition, one can imagine that in the rare cases where small-bowel free grafts are needed, harvest of these grafts might be done laparoscopically.

Small-Bowel Resection and Anastomosis

If one is presented with a localized area of small-bowel pathology (as happens in Crohn's disease), certainly a minimally invasive approach that would allow the patient more-rapid recovery should be considered. In addition to resections, there may be opportunities to perform controlled enterotomies or bypass procedures.

The appropriate placement of equipment in the operating room cannot be emphasized enough. An otherwise uneventful operation can become an ordeal if the surgeon has to strain to see a monitor or simply must rearrange things in the process of trying to get an operation started.

After establishing pneumoperitoneum, the cannula placement is based on the most logical arrangement for the anticipated operation, thus, there is no standard.

With the technology of stapling anastomoses already well established, the development of staplers exclusively for laparoscopic use was inevitable. First to appear were the 30-mm Endo GIA (Auto Suture Company, a division of the US Surgical Corporation, Norwalk, CT) and the 60-mm Endo Linear Cutter (Ethicon Endo-Surgery, Cincinnati, OH). These instruments simplified the techniques used in laparoscopic appendectomy and small-bowel resection. They were designed exclusively for intestinal use and were used to perform partial or wedge resections of bowel, such as in the elective management of a Meckel's diverticulum (Figure 16.1). Most recent de-

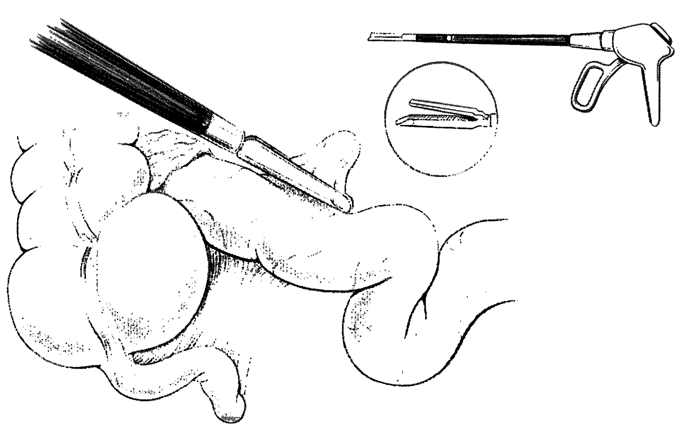

FIGURE 16.1. The first linear endoscopic staplers were designed exclusively for intestinal use and were used to perform partial or wedge resections of bowel, such as in the elective management of a Meckel's diverticulum.

velopments in the area of staple size and configuration have increased the versatility of the staplers and allowed surgeons to perform more-extensive intestinal surgery. The mesentery of the intestine can now be rapidly divided with the same instrument loaded with staple cartridges designed expressly for hemostasis. This technique does not require skeletonization of the mesenteric vessels and allows a wide *en bloc* resection, which is important in the case of malignant diseases (such as carcinoid tumors).

Specimen extraction does not generally pose a problem since the large (33 mm) cannulae now available (Ethicon Endo-Surgery, Cincinnati, OH) can be used to remove less-bulky small-bowel specimens (Figure 16.2). If for some reason the specimen cannot be removed by this route, a small muscle-splitting incision can be used instead, maintaining the advantages of minimally invasive techniques. To avoid spillage or possible seeding of a tumor, an impermeable sack may be used to remove the specimen.[3,4]

Anastomoses may be accomplished intracorporeally with the newer laparoscopic stapling devices or may be constructed extracorporeally using suturing or stapling techniques (Figure 16.3). The critical principles of bowel anastomosis must always be observed to prevent leakage or stricture. Most conditions needing small-bowel resection require that a specimen be removed. Most authorities prefer a small muscle-splitting incision, which allows one to remove the specimen and perform the anastomosis in one step. The proper name for this approach would then be laparoscopic-assisted small-bowel resection.

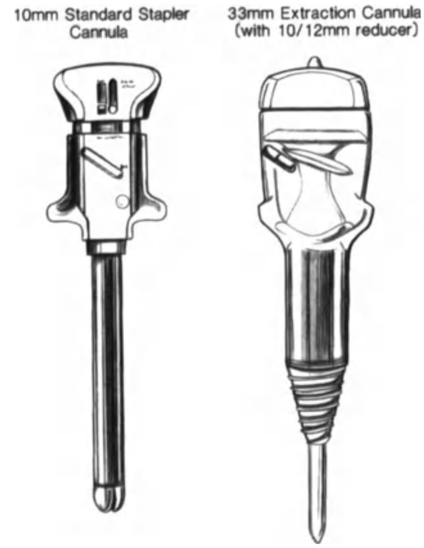

FIGURE 16.2. Specimen extraction does not generally pose a problem since today's larger 33-mm cannulae (Ethicon Endo-Surgery, Cincinnati, OH) can be used to remove many specimens.

Enteral Access for Nutritional Support

Jejunostomy is a well-established procedure for feeding malnourished patients.[6,7] Laparoscopic techniques are useful for gaining access to the gastrointestinal tract when endoscopic placement of tubes is not possible due to proximal obstruction, severe gastroesophageal reflux, contraindications for percutaneous endoscopic gastrostomy (PEG), or previous upper-abdominal surgery. Laparoscopic jejunal access, either for a placement of a jejunostomy tube or the creation of a Roux-en-Y enterocutaneous jejunostomy, requires three or four abdominal punctures and atraumatic bowel-grasping forceps. The left midabdominal site is generally located in the midclavicular line, approximately midway between the umbilicus and xyphoid, providing adequate egress for the tube or allowing placement of the stoma, if the more permanent method is employed (Figure 16.4).

The proximal jejunum is identified by retraction of the transverse colon superiorly, demonstrating the ligament of Treitz, and the bowel is "run" for a distance of 60 to 100 cm (Figure 16.5). Once the preferred segment of small bowel has been identified, it can be eviscerated through a dilated umbilical cannula site after the laparoscope is moved to the left-sided cannula (Figure 16.6). After the bowel is brought to the surface of the skin, the surgeon, maintaining an appreciation for proximal and distal ends, can perform the enterotomy and tube placement, and create a Witzel tunnel (Figure 16.7). If this method is utilized, sutures must be kept short and the proximal and distal suture needles left attached so that the bowel can be secured to the anterior abdominal wall after it is returned to the abdominal cavity and the tube is brought out through the left midabdominal cannula. The umbilical fascial defect is then reapposed to allow re-insufflation of the abdomen. Intracorporeal suturing techniques are used to attach the bowel to the abdominal wall, using the sutures previously placed along the Witzel tunnel.[8,9] The Stamm technique of jejunostomy placement can also be followed if so desired. Various laparoscopic stapling devices may eventually be used to secure the bowel to the abdominal wall, but at this time there are no manufacturer recommending this use for the products.

In another technique, the bowel is tacked to the anterior abdominal wall in the appropriate location with T-fasteners (Ross Laboratories, Columbus, OH) introduced percutaneously through a needle and an 8F catheter is inserted through a peel-away introducer with a J-wire (Figure 16.8).[10] One of the advantages of this technique is that it does not require laparoscopic suturing and knot-tying skills.

An alternative method of accessing the gastrointestinal tract for long-term alimentation is to create a cutaneous

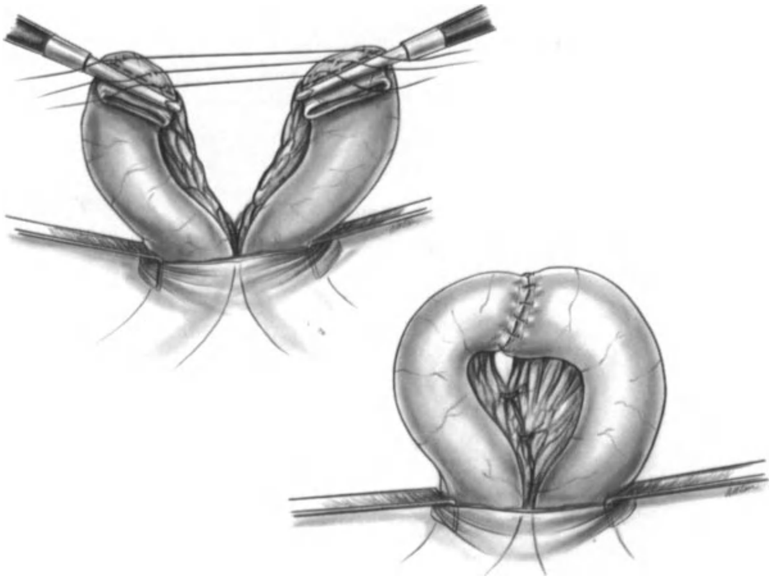

FIGURE 16.3. Anastomoses may be accomplished intracorporeally with the new laparoscopic stapling devices or may be constructed extracorporeally using suturing or stapling techniques.

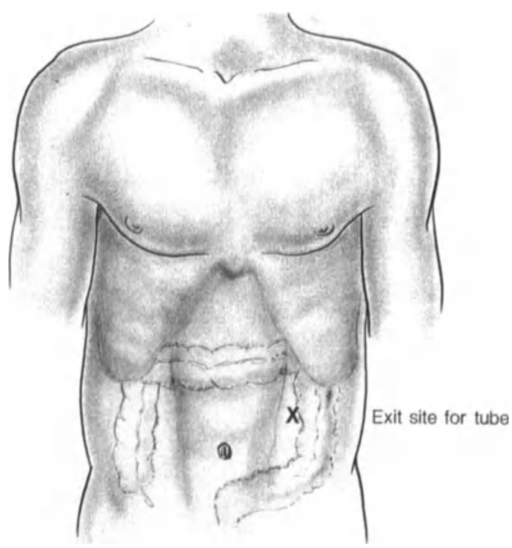

FIGURE 16.4. For procedures to provide jejunal access, the left midabdominal site is generally located in the midclavicular line, approximately midway between the umbilicus and xiphoid. It provides adequate egress for a jejunostomy tube and allows placement of the stoma if the more permanent method is employed.

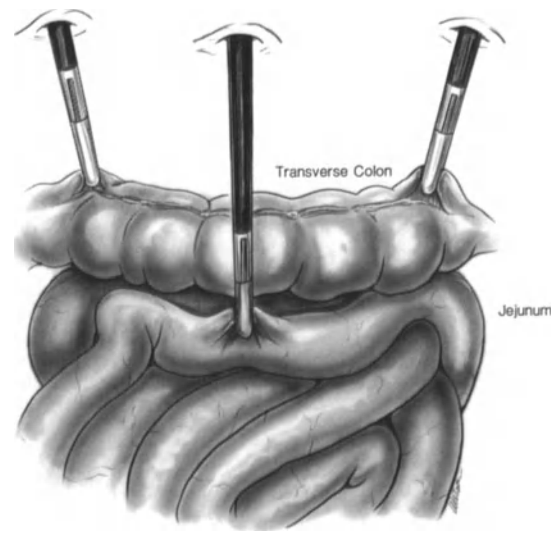

FIGURE 16.5. During procedures to provide jejunal access, the proximal jejunum is identified by retraction of the greater omentum over the transverse colon demonstrating the ligament of Treitz. The bowel is then followed for a distance of 60 to 100 cm.

Roux-en-Y jejunostomy. Four cannulae are positioned as depicted earlier and a loop of jejunum approximately 100-cm distal to the ligament of Treitz is eviscerated through the dilated umbilical fascial defect. Roux-en-Y limb construction is then accomplished by dividing the bowel with a stapling device and creating a 30-cm isoperistaltic limb (Figure 16.9). The mesentery is then trimmed from the end of this limb, and a cutaneous stoma is fashioned. Jejunojejunostomy is accomplished with sutures or staples, the anastomosis is dropped back into the abdominal cavity, and the mesenteric defect closed. The space lateral to the Roux limb may also be eliminated by suturing the bowel to the lateral abdominal wall.

Diagnostic Laparoscopy in Small-Bowel Disease

On rare occasions, opportunities for diagnostic laparoscopy for diseases that involve the small bowel may present themselves. Whether this is for bleeding, inflammation of a Meckel's diverticulum, or occult gastrointestinal hemorrhage, laparoscopic or laparoscopic-assisted inter-

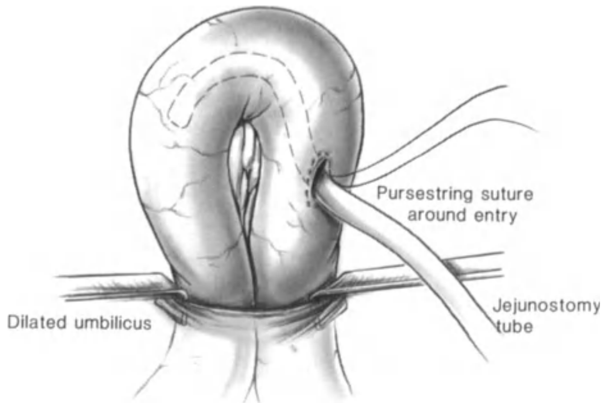

FIGURE 16.6. Once the preferred segment of small bowel has been identified, it can be eviscerated through a dilated umbilical cannula site, after the laparoscope is moved to the left-side cannula.

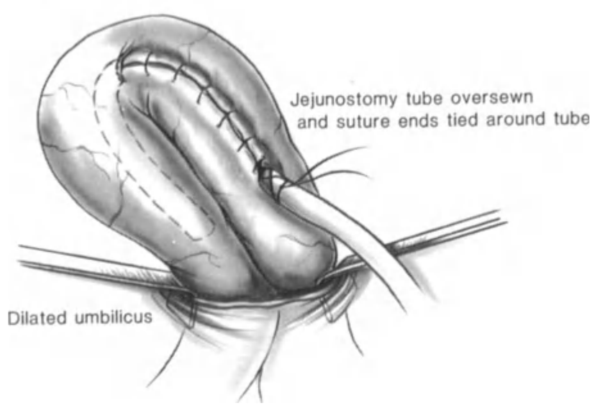

FIGURE 16.7. After bringing the bowel to the surface of the skin, the surgeon performs an enterotomy and tube placement and creates a Witzel tunnel.

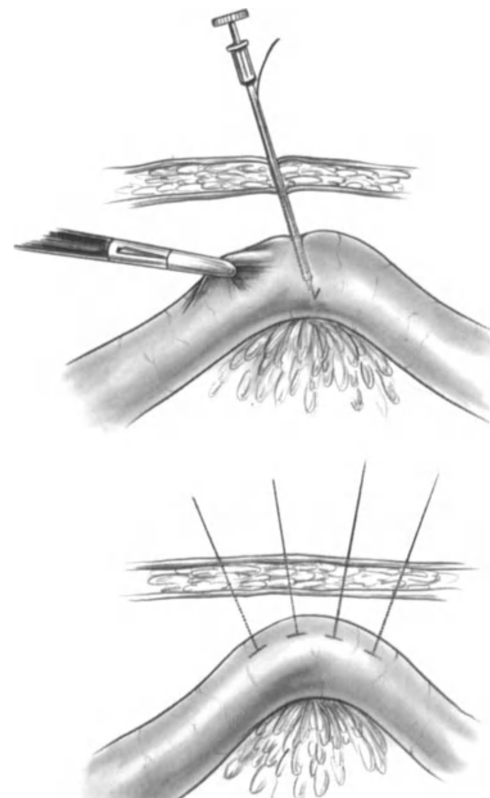

FIGURE 16.8. In a final step the bowel may be tacked to the anterior abdominal wall in the appropriate location with T-fasteners (Ross Laboratories, Columbus, OH) introduced percutaneously, and an 8F catheter is inserted through a peel-away introducer with the help of a J-wire.

vention may aid diagnosis and even therapy. Tagged red-cell scans or angiography may indicate the approximate location of bleeding if it is brisk enough, but visualizing the lesion with a conventional endoscope may allow it to be cauterized or a site of resection to be identified. A combined laparoscopic and endoscopic procedure can be beneficial in identifying sites of bleeding from lesions such as hemangiomas or arteriovenous malformations. A sterile flexible endoscope (pediatric or adult colonoscope) can be introduced through an enterotomy; and subsequently milked into the bowel, or the bowel can be telescoped over the endoscope with atraumatic bowel-grasping forceps. Sometimes a colonoscope introduced transorally can spare the patient an enterotomy; laparoscopic instrumentation is used to assist the colonoscope in traversing the length of the small intestine.[11] Reports of small-bowel resections combined with other laparoscopic procedures are rare at present, but recently there was a publication dealing with the laparoscopic treatment

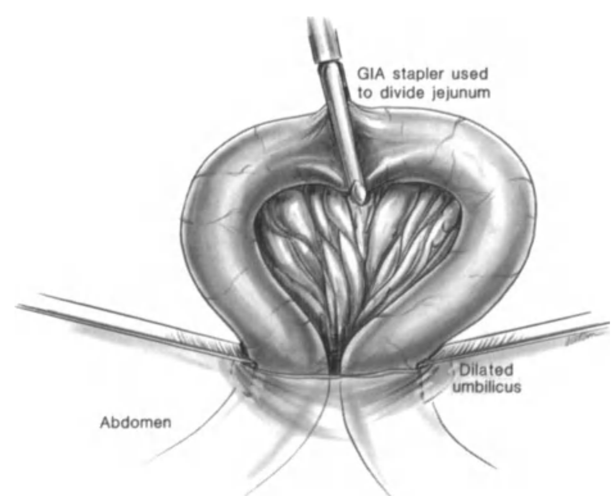

FIGURE 16.9. Roux-en-Y limb construction is accomplished by dividing the bowel with a stapling device and creating a 30-cm isoperistalic limb. Gastrointestinal continuity is re-established with a jejunojejunostomy.

of an incarcerated femoral hernia that included small-bowel resection of ischemic, entrapped intestine.[12] This would suggest that laparoscopy could be used to inspect the viscera following difficult hernia reductions where there was concern about the viability of the involved loops.

One area of great concern in today's healthcare climate is the allocation of resources and avoiding treatments perceived to provide low return on investment. Conceivably the laparoscope could be used to determine the cause of abdominal pain in patients with ischemic bowel disease, and perhaps even determine whether they are candidates for revascularization or resection. Laparoscopy may also have a place in the management of patients needing second-look procedures.

Laparoscopic Surgery in Small-Bowel Obstruction

Laparoscopy may be effective for the diagnosis and treatment of small-bowel obstruction, particularly in patients suffering from a single adhesive band. Whenever possible, we prefer to offer patients therapeutic resolution of the problem without the morbidity of a major laparotomy. As with any laparoscopic procedure, we do not consider conversion to laparotomy a technical failure or complication of any sort. With this in mind, we are often able to treat intestinal obstruction by carefully introducing the videolaparoscope into the peritoneal cavity under direct visualization. If a satisfactory exploration can be carried out, the cause of obstruction will frequently be identified and if the experience of the surgeon allows, adhesiolysis may be carried out laparoscopically. Embarking on laparoscopic exploration for small-bowel obstruction entails a slight increase in the risk of injury to the viscera, but using an open technique for initial cannula placement affords the patient minimal risk.

Conclusion

The mobility of the small bowel on its mesentery makes resection relatively straightforward. Additionally, manipulation can be carried out within the confines of the abdominal cavity, minimizing the potential for ileus.

A minimally invasive method of establishing gastrointestinal access for alimentary support is possible. The same techniques can be used for exploration of the abdomen in patients with small-bowel pathology, including obstruction or bleeding, with the understanding that conversion to laparotomy will be needed for many patients and should not be considered a technical failure.

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17
Laparoscopic Surgery for Adhesiolysis

Harry Reich

Introduction

In 1988 there were 281,982 hospitalizations during which adhesiolysis was performed, accounting for 948,727 days of inpatient care. Of these admissions, 54,100 were precipitated by adhesions. These hospitalizations were responsible for an estimated $1,179.9 million in expenditures.[1] Nor do these figures take into account outpatient surgical procedures for adhesiolysis.

Intra-abdominal adhesions are usually the sequelae of surgical or gynecologic operations, pelvic inflammatory disease (gonococcal or chlamydial), appendicitis, or endometriosis. Adhesions occur after abdominal surgery in over 60% of cases, although they are symptomatic in less than 30% of cases.

Adhesions may be responsible for chronic persistent abdominal pain without associated pelvic pathology. Clinically, adhesions present as chronic or acute abdominal or pelvic pain, partial or complete mechanical bowel obstruction, and infertility. Although adhesions probably cause pain by entrapment of expansile viscera, the relation of adhesions to abdominal pain is still controversial. In contrast, mechanical small-bowel obstruction after previous surgery is unequivocally due to adhesions.

Patients with chronic or recurrent abdominal pain and a history of abdominal surgical procedures are often denied treatment if they are not obstructed or do not have symptoms of intermittent bowel obstruction. While surgical therapy is withheld, multiple abdominal diagnostic procedures, including abdominal CT scan, are frequently ordered. These patients are then sent to chronic pain clinics for evaluation. Although few studies of unobstructed patients exist, a recent report suggests that women with severe, dense vascularized bowel adhesions have significant reduction of pain after adhesiolysis.[2]

Patients with symptomatic adhesions usually want minimally invasive therapy. If they are given the choice between a laparoscopic surgical procedure and laparotomy, they rarely choose laparotomy. Unfortunately they are rarely given the choice, even though most adhesiolysis laparotomy procedures can be done through the laparoscope. Laparoscopic enterolysis has not been rigorously compared with classical laparotomy, but laparoscopy obviously diminishes peritoneal mesothelial-cell ischemic damage from trauma, drying, talc, packs, and delayed bleeding. Laparoscopic surgery is also the preferable method of access for infertility surgery because it decreases the risk that new adhesions will form.[3,4] Surgical outcomes similar to those of laparotomy have been demonstrated in the management of endometriosis and extensive adhesions.[5,6] Laparoscopy affords panoramic pelvic visualization and magnification, lends itself to techniques similar to microsurgery, and allows hemostasis to be verified via underwater examination. The patient enjoys simultaneous diagnosis and treatment and all the advantages of minimally invasive surgery, such as a cosmetic incision and rapid recuperation. Finally, ileus is rare after laparoscopic surgery. Given these advances, the onus should be on the surgeon to prove that laparotomy results in better outcome than laparoscopy, not vice-versa.

This chapter discusses advanced laparoscopic equipment and techniques and their application to chronic adhesiolysis procedures, primarily omentolysis and enterolysis. Acute adhesiolysis, to prevent the formation of chronic adhesions, has been reviewed elsewhere.[7–9]

Equipment

A review of standard equipment such as light sources and video systems can be found in other chapters of this book. This chapter describes equipment useful for advanced procedures.

Laparoscopes

Four laparoscopes are used for adhesiolysis: a 10-mm 0° straight-viewing laparoscope; a 10-mm operative laparoscope with 5-mm operating or laser channel; a 5-mm straight-viewing laparoscope for introduction through 5-mm trocar sleeves; and an oblique-angled laparoscope (30 to 45°) for upper-abdominal procedures, especially those requiring the surgeon to operate directly beneath the umbilicus. A HydroLaparoscope (Circon-ACMI, Stamford, CT) is now available, which has a built-in lens-washing and irrigation system to clean the distal lens and rinse the operative site during surgery.

High-Flow CO_2 Insufflators

The ability to maintain a relatively constant intra-abdominal pressure between 10- and 15-mm Hg during long laparoscopic procedures is essential to successful laparoscopic surgery. High-flow CO_2 insufflation at rates as high as 15 L/min compensates for the rapid loss of CO_2 during suctioning.

Abdominal-Wall Retractors (Gasless Laparoscopy)

Abdominal-wall subcutaneous emphysema is frequently associated with anterior-abdominal-wall adhesiolysis because peritoneal defects result in free communication of the abdominal cavity with the rectus sheath. Emphysema compromises the peritoneal-cavity operating space. A useful technique is to insert a Laparolift anterior-abdominal-wall retractor (Origin Medical Systems, Menlo Park, CA) once the umbilicus has been cleared of adhesions.

Thirty-Degree Tiltable Table

For the past 16 years this author has used steep Trendelenburg position (20 to 40°), with shoulder braces. (The patient's arms are at his sides.) Operating-room tables capable of 30° Trendelenburg position are necessary for advanced laparoscopic surgical procedures, especially those involving the deep pelvis. Presently, the hand-controlled Champagne model 600 (Affiliated Table Company, Rochester, NY) is used; an electronically controlled table capable of this degree of body tilt is also available (Skytron Model 6500, Grand Rapids, MI).

Rectal and Vaginal Probes

A sponge on a ring forceps is inserted into the posterior vaginal fornix and a 81F rectal probe (Reznik Instruments, Skokie, IL) is placed in the rectum to define the posterior vagina and rectum in endometriosis or adhesion cases with some degree of cul-de-sac obliteration and to open the posterior vagina for culdotomy. Whenever rectal location is in doubt, it is identified by placing the probe.[5]

Trocar Sleeves

Trocar sleeves are available in many sizes and shapes. For most cases, 5.5-mm cannulae are adequate. Laparoscopic stapling is performed through 12- or 13-mm ports. US Surgical Corporation (Norwalk, CT) disposable 12.5-mm trocar sleeves with adjustable locking retention collars (Reich screw-grid design) hold their position well for stapling, but their trap makes extracorporeal suturing cumbersome.

Short trapless 5-, 10-, and 12-mm trocar sleeves with an external retention screw grid are used in most cases (Richard Wolf, Vernon Hills, IL; Apple Medical, Bolton, MA). Once placed, their exit portal stays fixed at the level of the anterior-abdominal-wall parietal peritoneum, providing more room for instrument manipulation than other trocar sleeves.[10] These trocar sleeves facilitate instrument exchanges and the evacuation of tissue and allow complete freedom during extracorporeal suture tying.

Techniques

The advanced laparoscopic surgical techniques used by this author include scissors dissection, aquadissection, electrosurgery, laser surgery, and suturing. Aquadissection and scissors dissection are preferred to thermal energy (laser and electrosurgery).

Scissors Dissection

Blunt- or rounded-tipped 5-mm scissors with one fixed and one moveable blade are used to divide thin and thick bowel adhesions sharply. Scissors that cut are new laparoscopic instruments. Sharp dissection is the technique primarily used for adhesiolysis because it diminishes the potential for adhesion formation; electrosurgery and laser surgery are usually reserved for hemostatic dissection of endometriosis or adhesions where anatomic planes are not evident or vascular adherences are anticipated. Blunt-tipped sawtooth scissors (Richard Wolf), Manhes scissors (Karl Storz, Culver City, CA), and Jaret curved scissors (Hawthorne, NY) all cut. US Surgical Corporation disposable scissors depend on electrification for cutting. Hook scissors are not useful for adhesiolysis.

Scissors are the best instrument to cut avascular or congenital adhesions and peritoneum. Loose fibrous or areolar tissue is separated by inserting a closed scissors and withdrawing it in the open position. Natural planes are developed by pushing tissue with the partially open blunt tip.

Surgeons should select a scissors that feels comfortable in their hands. To facilitate direction changes, it should not be too long or encumbered by an electrical cord. This author prefers to alternate between scissors and microbipolar forceps advanced through the same portal to control bleeding, instead of electrifying the scissors.

Aquadissection[11]

Aquadissection is the use of pressurized fluid to aid in the performance of surgical procedures. The force vector within the volume of expansion of the fluid is multidirectional; the force applied with a blunt probe is unidirectional. Instillation of fluid under pressure displaces tissue, clearing it along the least-resistant planes. Aquadissection into closed spaces behind peritoneum or adhesions produces edematous, distended tissue on tension with loss of elasticity, making further division using blunt dissection, scissors dissection, laser surgery, or electrosurgery easy and safe.

Aquadissectors (suction/irrigators with the ability to dissect using pressurized fluid) should have a single channel to maximize suctioning and irrigating pressure and a solid distal tip to perform atraumatic suction/traction/retraction, irrigate directly, and develop surgical planes (aquadissect). Small holes at the tip impede these actions and the surgical field is sprayed with water to no purpose. The shaft should be specially treated by bead blasting to provide a dull finish that prevents laser-beam reflection, allowing it to be used as a backstop.

The Aqua-Purator (WISAP, Sauerlach, Germany, or Tomball, TX) was the first of the aquadissection devices. It delivers fluid under 200-mm Hg pressure at a rate of 250 mL/10 s. One liter can be instilled in 35 seconds. The market is crowded with many aquadissection devices.

Electrosurgery

Monopolar electrosurgery should be avoided when working on the bowel unless the surgeon is well versed in this modality. The expert laparoscopic surgeon can use monopolar electrosurgery to safely cut or fulgurate tissue, but desiccation (coagulation) on bowel should be performed with a bipolar instrument.[12,13]

Monopolar *cutting* current is safe. *Cutting current* is used to both cut or coagulate (desiccate), depending on the portion or configuration of the electrode in contact with the tissue. The tip cuts, whereas the wide body tamponades and coagulates. The voltage is too low with pure cutting current to arc or spark a distance of 1 mm.

Monopolar *coagulation current* with conventional electrodes and electrosurgical generators can arc or spark a distance of approximately 1 to 2 mm. The electrode is used in close proximity to tissue but not in contact with it to fulgurate diffuse venous and arteriolar bleeders. It takes 30% more power to spark or arc in CO_2 than in room air; thus, at the same electrosurgical power setting, less arcing occurs during laparoscopy than during laparotomy. Coagulation current is modulated so that it is on only 6% of the time and uses voltages more than 10 times higher than that of cutting current.

The bowel beyond the surgeon's field of view can be injured during laparoscopic procedures if there are electrode insulation defects or capacitive coupling occurs. While the surgeon views the tip of the electrode, electrical discharge may occur from its body (insulation failure) or from metal trocar cannulae surrounding the electrode that are separated from the skin by plastic retention sleeves (capacitive coupling). These problems can be eliminated by using the Electroshield EM-1 monitor system (Electroscope, Boulder, CO) that consists of a reusable sheath for the laparoscopic electrode that shields against capacitive coupling and an electroshield monitor (EM-1) that detects any insulation faults and shields against capacitive coupling.

The *argon beam coagulator* uses argon gas (at 2 L/min) and high-voltage coagulation current to increase the spark or arc and yet penetrate the tissue very superficially. It is rarely used during adhesiolysis.

Bipolar desiccation for large-vessel hemostasis was first reported in 1985.[14,15] A cutting current is used to obtain a uniform bipolar desiccation process. Large blood vessels are compressed and bipolar *cutting* current passed until complete desiccation is achieved, that is, the current depletes tissue fluid and electrolytes to the extent that it ceases to flow between the forceps. The current is monitored by an ammeter or current flow meter (end-point monitor: Electroscope EPM-1, Boulder, CO). Coagulating current is not used as it might rapidly desiccate the outer layers of the tissue, producing superficial resistance that might prevent deeper penetration.

Finally, when discussing electrosurgery, it is important to emphasize that cautery, thermocoagulation, or endocoagulation refer to the passive transfer of heat from an instrument heated by electrical current to tissue. The temperature rises within the tissue until cell proteins begin to denature and coagulate, causing the cells to die. No electrical current goes through the patient's body! The term "cautery," when referring to electrosurgery, is a misnomer and should be abandoned.

Teamwork for Hemostasis

When active bleeding is encountered, the surgeon irrigates and suctions at the bleeding site until the source is identified. The suction/irrigator is replaced with bipolar forceps while the surgeon continues to watch the vessel on the video screen. The surgeon pulls the suction/irrigator out, and the assistant immediately inserts the bipolar forceps through the trapless trocar sleeve. The surgeon, without much arm movement, releases the suction/irrigator and grasps the bipolar forceps, never taking his eyes off the bleeding vessel on the video screen. Obviously this maneuver takes much practice and teamwork, but it markedly reduces the number and size of secondary sites needed to perform the procedure. With practice, a good laparoscopic surgical team makes fast instrument exchanges so that little pneumoperitoneum is lost. If a team cannot be assembled or cumbersome trocar sleeves are used, it is best to tamponade the vessel after locating it, usually with the tip of the suction/irrigator, and to introduce the bipolar forceps through a third lower-quadrant cannula, while using the second lower-quadrant cannula for retraction at the operative site.

Laser Dissection

Use of a CO_2 laser through the operating channel of the laser laparoscope allows the surgeon a panoramic field of view and the ability to cut or ablate tissue in the vertical plane that bisects this field. In addition, because this laser has a 0.1-mm depth of penetration and its energy is absorbed by water, it affords the surgeon a margin of safety when working around the bowel, ureter, and major vessels. Backstops are rarely necessary because of the laser's superficial depth of penetration and because the surgical field is wet, especially if the operator develops the skill of using the tissue to be vaporized as a backstop. When the surgeon is working around bowel, the CO_2 laser is set between 10 and 20 W in superpulse or ultrapulse mode to allow tissue cooling between pulses by reducing the amount of heat reaching adjacent tissues by thermal conduction.

Major problems encountered when using CO_2 lasers through the operating channel of an operating laparoscope are jumping, blooming, and loss of the beam. If the laser laparoscope coupler does not connect with the laparoscope at precisely 90°, the beam is off axis in the channel. The beam energy heats the CO_2 purge gas unevenly, causing it to act as an asymmetric lens that refracts the CO_2 laser energy to a different spot than the spot made by the aiming HeNe laser. New laser couplers correct this problem.

The passage of CO_2 gas through the laparoscope lumen, presently a necessity to purge this channel of debris, decreases both the power delivered to tissue and the power density at tissue because the 10.6-μm wavelength of the laser beam is absorbed by the purge gas, whose absorption wavelength is the same as the emission wavelength of the laser. Power to tissue is reduced 30 to 50% in the case of a 7.2-mm laparoscopic operating channel (12-mm scope) and by 60% in the case of a 5-mm operating channel (10-mm scope). Although it is desirable to operate at high power density for a short time to minimize damage to surrounding tissue, heating of the CO_2 gas in the laparoscope lumen increases the spot size and thus reduces the power density (the concentration of laser energy on the tissue) at all power settings. At high power settings (80 to 100 W), a large spot, 3 to 4 mm, is obtained, which is extremely coagulative and provides hemostatic cutting.[16]

The Coherent 5000L laser is a CO_2 laser that employs the C^{13} isotope of carbon to shift the emission wavelength to 11.1 μm, circumventing absorption of laser energy by the CO_2 purge gas in the operating channel of the laparoscope. A 6-mm beam enters the coupler from the end of the laser arm and emerges as a 1.5-mm spot 350 to 400 mm away. The 1.5-mm spot size is maintained at all power settings. At high power settings, the power density in the target is 10 times greater than that of a 10.6-μm beam.

Heraeus LaserSonics (Milpitas, CA) maintains a small spot size by suctioning the peritoneal cavity through the sleeve surrounding the laparoscope, which induces rapid inflow of gas through the operating channel of the laparoscope. The gas is exchanged faster than it can be heated, and smoke generated by the laser is evacuated as fast as it is produced.

Fiber lasers (KTP, argon, and YAG) are not used because they lack the versatility of electrosurgical electrodes, which can cut, coagulate, or fulgurate. The energy from these lasers is absorbed by the protein matrix in tissues and converted to heat. A large volume of tissue suffers thermal effects—coagulation initially and vaporization after the protein is heated to temperatures higher than 100°C. In contrast, the energy from the CO_2 laser is completely absorbed by water and rapidly converted to thermal energy. A much smaller volume of tissue suffers thermal effects.

Suturing

An excellent technique for laparoscopic suturing was developed in 1970 by Dr. H. Courtenay Clarke. He used a knot pusher (Marlow Surgical, Willoughby, OH) to tie sutures much as they are hand-tied at open laparotomy (Figure 17.1A).[17] The surgeon stitches the tissue, pulls the needle outside, and then, while holding both strands, makes a simple half hitch (Figure 17.1B). The Clarke knot pusher is put on the suture as it is stretched across the index finger, and the throw is pushed down to the tissue (Figure 17.1C). A square knot is made by pushing another half hitch down to the knot to secure it, while holding the suture taut from above (Figure 17.1D).

The difficulty of suturing with large curved needles is introducing the needle into the peritoneal cavity through a small incision, such as a 5-mm lower-quadrant incision.[18] To suture with a CT-1 needle, a trocar sleeve placed lateral to the rectus sheath is taken out of the abdomen and loaded by introducing a needle holder through the sleeve, grasping the distal end of the suture with the needle holder, pulling the suture through the trocar sleeve, reinserting the instrument into the sleeve,

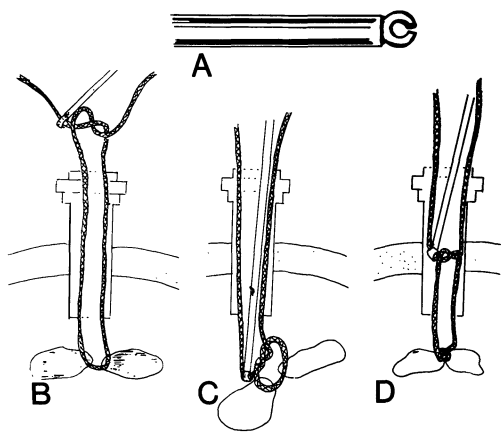

FIGURE 17.1. *A,* A Clarke-Reich knot pusher. *B,* After suture has been applied to the tissue, a half hitch is made just above the trocar sleeve. *C,* A Clarke knot pusher is used to push the half hitch to the tissue. *D,* Usually three more half hitches are used to secure the knot.

and grasping the suture with the instrument about 2 to 3 cm from the needle. The needle driver is inserted into the peritoneal cavity through the original tract; the needle follows the driver through the soft tissue and, thereafter, the trocar sleeve is reinserted. Even large needles can be pulled into the peritoneal cavity in this manner. At this stage, the Semm straight-needle holder (WISAP) is replaced with a Cook oblique curved-needle driver (Cook OB/GYN, Spencer, IN), and the needle pierces the tissue. Afterward, the needle is stored in the anterior-abdominal-wall parietal peritoneum for removal after the suture is tied. The needle is cut from the suture, the cut end of the suture pulled out of the peritoneal cavity through the trocar sleeve, and the knot tied with the Clarke knot pusher. To retrieve the needle, the trocar sleeve is unscrewed, and the needle holder inside it grasps the suture remnant attached to the needle and pulls the needle through the soft tissue. The trocar sleeve is then replaced with or without being loaded with another suture.

Underwater Surgery at the End of Each Procedure[19]

At the close of each operation, underwater examination documents complete intraperitoneal hemostasis as the intraperitoneal pressure is gradually decreased; this detects bleeding from vessels and viscera tamponaded during the procedure by the increased intraperitoneal pressure of the CO_2 pneumoperitoneum. The integrity of the colon is often checked at this time by instillation of dilute Betadine solution.

The CO_2 pneumoperitoneum is displaced with 2 to 5 L of Ringer's lactate solution, and the peritoneal cavity is vigorously irrigated and suctioned until the effluent is clear of blood products, which usually takes 10 to 20 L. Underwater inspection of the pelvis is performed to detect bleeding. Any bleeding is controlled by using microbipolar irrigating forceps to coagulate through the electrolyte solution. First, hemostasis is established with the patient in the Trendelenburg position, then, after underwater examination, with the patient supine and in reverse Trendelenburg position, and, finally, with all instruments removed, including the uterine manipulator.

To visualize the pelvis with the patient supine, the 10-mm straight laparoscope and the actively irrigating aquadissector tip are manipulated together into the deep cul-de-sac beneath the floating bowel and omentum. During this irrigation procedure, copious clear fluid is deposited into the pelvis and circulates into the upper abdomen, displacing upper-abdominal bloody fluid, which is suctioned after flowing back into the pelvis. An underwater examination is then performed to verify, in female patients, that the tubes and ovaries are completely separated and to confirm complete hemostasis.

A final copious lavage with Ringer's lactate solution is done, and all clot is aspirated; at least 2 L of lactated Ringer's solution is left in the peritoneal cavity to displace CO_2 and to prevent fibrin adherences from forming by separating raw surfaces during the initial stages of reperitonization. Displacement of the CO_2 with Ringer's lactate diminishes the incidence and severity of shoulder pain from CO_2 insufflation. No other antiadhesive agents are employed. Hyskon is not used as it pulls intravascular fluid into the peritoneal cavity. No drains, antibiotic solutions, or heparin are used.

Adhesion Prevention

The peritoneum regenerates after ischemic damage or denudation by mesothelial or reserve cell growth from the bottom of the defect or injured area.[20] Adhesion-prevention regimens that are more expensive than leaving Ringer's lactate solution in the peritoneal cavity should be used only at centers doing clinical research. The mechanism by which Ringer's solution prevents adhesions is simple; as Dr. Jaroslav Hulka said in 1988 that "Reich's solution to pollution is dilution." This author believes that adhesion reduction requires: minimal thermal damage to tissue, absolute hemostasis, clot evacuation, copious irrigation to dilute fibrin and prostaglandins released from operated surfaces and bacteria, and leaving 2 or 3 L of Ringer's lactate in the peritoneal cavity at the end of the operation to physically separate operated and unoperated tissues.

Many surgeons currently use intraperitoneal Ringer's lactate solution to prevent adhesions, but few prospective studies of this practice have been done. Rose determined by weighing patients that lactated Ringer's solution is absorbed in two or three days.[21] A recent study found that

Ringer's lactate was superior to Gore-Tex and Interceed in adhesion prevention.[22] Another research was unable to demonstrate that Interceed decreased postoperative adhesion formation in a rabbit model.[23]

The Gore-Tex Surgical Membrane (WL Gore, Flagstaff, AZ) is probably the best of the available surgical barriers. It is a nonabsorbable inert barrier of expanded polytetrafluoroethylene with a pore size smaller than 1 μm. It is used after division of severe adhesions, such as retroperitoneal ovary adhesion. A patch of membrane that allows margins of at least 1 cm is sutured over the defect. Oxidized regenerated cellulose (Interceed, Johnson & Johnson, New Brunswick, NJ) cannot be used in laparoscopic procedures because it requires absolute hemostasis at the site of application and it cannot be immersed. Bleeding from vessels and viscera tamponaded during the procedure by the intraperitoneal CO_2 pressure cannot be detected without an underwater examination. This author suspects that bleeding from a raw site after the pneumoperitoneum is expelled fills Interceed with blood, making it adhesiogenic.

Lastly, short-interval second-look laparoscopic adhesiolysis (two to four weeks) may be considered to diagnose and treat early adhesions. Second-look adhesiolysis is particularly appropriate following known adhesiogenic procedures, such as salpingo-ovariolysis, salpingostomy, myomectomy, and treatment of polycystic ovaries.

Many studies have documented the efficacy of second-look laparoscopy following pelvic reconstructive surgery.[24–26] Ideally it should be performed between the time of serosal healing (8 days) and that of established-adhesion fibrosis (21 days). This author performed second-look laparoscopy in 11 of 15 women after laparotomy salpingostomy for distal occlusion. Six of these 11 women conceived, and 5 had intrauterine pregnancies.[6]

Second-look laparoscopic adhesiolysis soon after surgical procedures for infertility is much easier than the original procedure. Aquadissection is ideal for this situation, and the aquadissector is often the only instrument needed. Adhesion interfaces are readily identifiable when seen through the laparoscope, and serosal cleavage planes can easily be created by aquadissection. In this manner, adnexal adherences to the uterus and pelvic sidewall are separated, and the fallopian tube detached from the ovary. Second-look laparoscopy after extensive laparoscopic adhesiolysis should also be considered, although patient acceptance of a second laparoscopic procedure is limited.

Laparoscopic Peritoneal Cavity Adhesiolysis

Both laparoscopic and laparotomy adhesiolysis can be time-consuming and technically difficult and are best performed by an expert surgeon. However, despite lengthy laparoscopic procedures (two to four hours), most women are discharged on the day of the procedure, avoid major abdominal incisions, experience minimal complications, and return to full activity within one week of surgery.

In this section, general adhesiolysis, pelvic adhesiolysis, ovariolysis, salpingo-ovariolysis, and salpingostomy are described. The laparoscopic treatment of acute adhesions has not been included. However, the best treatment for the adhesive sequelae of sexually transmitted diseases may be early laparoscopic diagnosis and treatment of the infection, including any abscesses; acute adhesiolysis will often prevent chronic adhesion formation.[7–9]

Classification

A classification system is needed that ranks extensive peritoneal-cavity adhesion procedures according to their degree of severity and the expertise necessary for adhesiolysis. The single best indicator of the degree of severity and of the expertise needed for adhesiolysis is the number of previous laparotomies. The frequency of the symptoms of small-bowel obstruction indicates the urgency of the surgery.

Peritoneal adhesiolysis procedures can be divided into enterolysis procedures, including omentolysis, and female reproductive-system reconstructive procedures (salpingo-ovariolysis and cul-de-sac dissection with excision of deep fibrotic endometriosis). Bowel adhesions can be upper abdominal, lower abdominal, pelvic, and a combination of these three. Adhesions surrounding the umbilicus are upper abdominal because they require an upper-abdominal laparoscopic view for division. The extent, thickness, and vascularity of adhesions varies widely. Intricate adhesive patterns exist with fusion to parietal peritoneum or various meshes.

Extensive small-bowel adhesions are not a frequent finding at laparoscopy for pelvic pain or infertility. In these cases, the tube is usually stuck to the ovary, the ovary adheres to the pelvic sidewall, and the rectosigmoid may cover both. Rarely, the omentum and small bowel are involved. Adhesions may be the result of an episode of pelvic inflammatory disease or endometriosis, but most commonly they are caused by previous surgery. Adhesions cause pain by entrapping the organs they surround. The management of extensive pelvic adhesions is one of the most difficult problems facing surgeons today.

Preoperative Preparation

Patients are informed preoperatively of the high risk of bowel injury if the surgeon suspects the cul-de-sac is extensively involved by endometriosis or adhesions. They are encouraged to drink fluids and eat lightly for 24 hours before admission. A mechanical bowel preparation (GoLytely or Colyte) is administered orally the afternoon before the surgery to induce brisk, self-limiting diarrhea that cleanses the bowel without disrupting the electrolyte balance.[27] The patient is usually admitted on the day of surgery. Lower-abdominal, pubic, and perineal hair is *not* shaved. Patients are encouraged to void on call to the operating room, and a Foley catheter is inserted only if the bladder is distended or a long operation is anticipated. A catheter is inserted near the end of the operation to prevent bladder distension and removed in the recovery room when the patient becomes aware of its presence. Antibiotics (usually cefoxitin) are administered in all cases where surgery lasts over two hours at the two-hour mark.

When extensive small-bowel adhesions are expected, 90 cc or six tablets of charcoal are administered the night before surgery. Should small-bowel enterotomy accidentally occur, identification and repair are simplified by the intraluminal charcoal.

Positioning of Patient

All laparoscopic surgical procedures are done under general anesthesia with endotracheal intubation and an *orogastric* tube. Routine use of an orogastric tube is recommended to diminish the possibility of a trocar injury to the stomach and to reduce small-bowel distension. The patient is flat (0°) during umbilical trocar-sleeve insertion and upper abdominal adhesiolysis, but the steep Trendelenburg position (20 to 30°), the reverse Trendelenburg position, and side-to-side rotation are used when necessary. The lithotomy position, with the hip extended (thigh parallel to abdomen), is obtained with Allen stirrups (Edgewater Medical Systems, Mayfield Heights, OH) or knee braces, which are adjusted for each patient before she is anesthetized. Anesthesia examination is performed before the patient is prepped for surgery.

Incisions

In most cases, the first incision is a vertical midline incision on the inferior wall of the umbilical fossa extending to or just beyond its lowest point is used. Carbon dioxide is insufflated until a pressure of 20 or 25 mm Hg is obtained, which usually requires 4 to 6 L CO_2. It is not necessary to lift the anterior abdominal wall when the trocar is inserted after establishment of pneumoperitoneum because the parietal peritoneum and skin move as one. The palmed trocar is positioned at a 90° angle to the skin and the tip is upturned approximately 30° in one continuous thrusting motion during which the wrist rotates nearly 90°. The result is a parietal peritoneal puncture directly beneath the umbilicus. High pressure is needed during initial insertion of the trocar, but the pressure is lowered thereafter to avoid vena-caval compression and subcutaneous emphysema. A relatively constant intra-abdominal pressure of between 10 and 15 mm Hg is maintained during long laparoscopic procedures.

Special entry techniques are necessary in patients who have undergone multiple laparotomies, have lower-abdominal incisions traversing the umbilicus, or who are thought to have extensive adhesions either on the basis of a clinical examination or another doctor's operative record. Open laparoscopy or microlaparotomy carry the same risk for bowel laceration if the bowel is fused to the umbilical undersurface.

If CO_2 insufflation cannot be done through the umbilicus, a Veress needle is used to puncture the left ninth intercostal space on the anterior axillary line. Adhesions are rare in this area, and the peritoneum is tethered to the undersurface of the ribs, making subcutaneous insufflation unusual. To puncture the peritoneum, a disposable pneumoperitoneum needle (US Surgical Corporation or Ethicon), is grasped near its tip between the thumb and forefinger like a dart. The needle tip is then inserted at right angles to the skin but at a 45° angle to the horizontal anterior abdominal wall between the ninth and tenth ribs. A single pop is felt upon penetration of the peritoneum. A pressure of 20- or 25-mm Hg is obtained (Figures 17.2–17.4). A 5- or 10-mm trocar is then inserted at the left costal margin in the midclavicular line, a location that allows a panoramic view of the entire peritoneal cavity.[27]

When there are extensive adhesions around the umbilical puncture, the surgeon should immediately seek a higher site. Later, the adhesions can be freed down to and just beneath the umbilicus; an umbilical portal can then be safely established and used for further work (Figure 17.5).

Other laparoscopic puncture sites are placed as needed, usually lateral to the rectus abdominis muscles and always under direct laparoscopic vision. When the parietal peritoneum is thick because of previous surgery

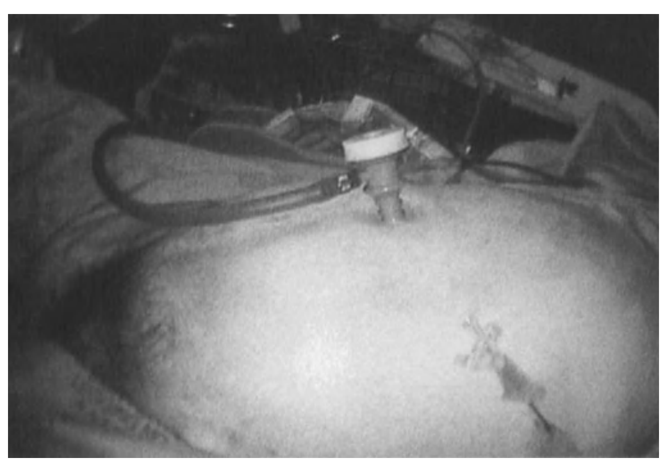

FIGURE 17.2. Veress needle in the ninth intercostal space and a 10-mm trocar in the umbilicus.

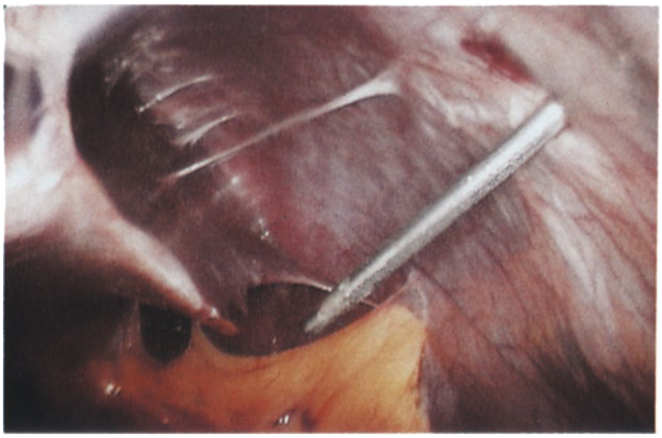

FIGURE 17.3. Veress needle penetrating the peritoneal cavity through the ninth intercostal space. Note the perihepatic adhesions.

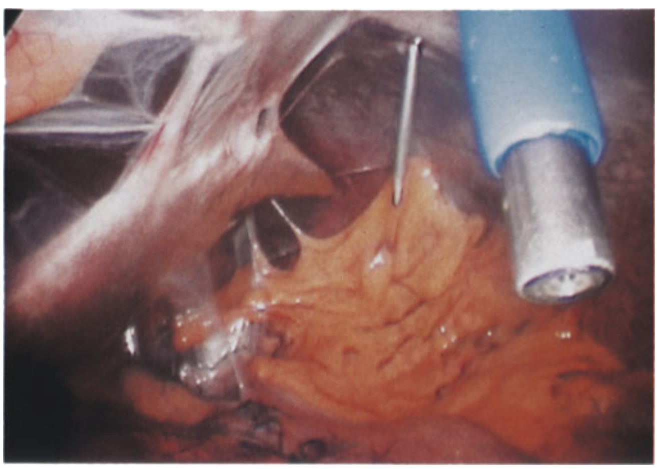

FIGURE 17.4. Veress needle and the 5-mm trocar at the subcostal margin.

or obesity, the position of the muscles is determined by palpating and depressing the anterior abdominal wall with the back of the scalpel; the wall will appear thicker where rectus muscle is enclosed, and the incision is made lateral to this area, near the anterior superior iliac spine.

If an umbilical insertion is possible but extensive adhesions are present close to and below the umbilicus, the first instrument to be used is the operating laparoscope with scissors in the operating channel. If a left-upper-quadrant incision is necessary, there is usually room for another lateral puncture site to do initial adhesiolysis with scissors.

Surgical Plan for Extensive Enterolysis

A well-defined strategy is important for small-bowel enterolysis. For simplicity, this strategy can be considered to have three parts:

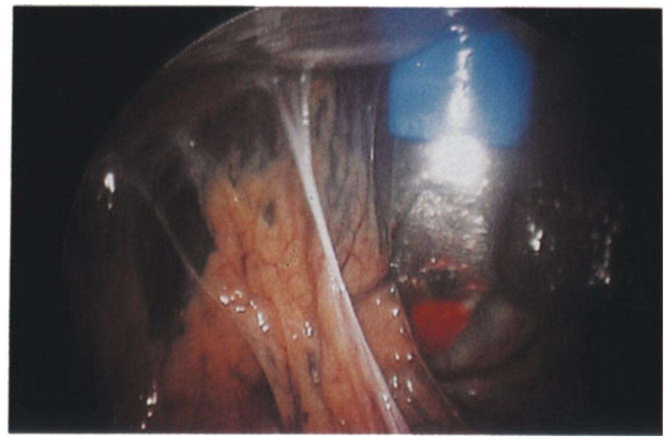

FIGURE 17.5. After adhesions are divided down to the umbilicus, a 10-mm umbilical trocar is inserted, and dissection proceeds into the lower abdomen, which is visualized through the 10-mm laparoscope.

1. *Division of all adhesions to the anterior-abdominal-wall parietal peritoneum.* Small-bowel loops encountered during this process are freed from each other, using their anterior attachment for countertraction.
2. *Division of all small-bowel and omental adhesions in the pelvis.* The rectosigmoid, cecum, and appendix often are freed during this part of the procedure.
3. *Running of the bowel.* Using atraumatic grasping forceps and a suction/irrigator for suction/traction, the bowel is run. Starting at the cecum and terminal ileum, and ending in the high upper abdomen at the ligament of Treitz, loops and significant kinks are freed.
4. *Finally, tubo-ovarian pathology is treated if indicated.*

Time frequently dictates that all adhesions cannot be lysed. From the history, the surgeon should deduce which adhesions are most likely to be causing the pain—that is, whether they are in upper or lower or the left or right abdomen—and clear these areas of adhesions.

General Adhesiolysis Including Enterolysis

The first adhesions that are encountered involve the anterior-abdominal-wall parietal peritoneum. These consist of omentum and small-bowel attachments with varying degrees of fibrosis and vascularity. Small-bowel adhesions to the anterior abdominal wall are released. If these adhesions extend above the level of the umbilicus, another incision is made above the highest adhesion, and the laparoscope is inserted there. Adhesions are much easier to divide from above than from below, because the angle between the omentum or bowel and the parietal peritoneum is usually acute, which means gravity can help delineate the plane of division.

Adhesions are cut with scissors, electrosurgery, and the

CO_2 laser. In most cases the initial adhesiolysis is performed with scissors (Figures 17.6 and 17.7). If the adhesions are close to a trocar, the CO_2 laser beam may reflect from the trocar and precision is lost. Electrosurgery (cutting current) through a knife, spatula, or scissors electrode is used only when the surgeon is certain that the adhesion does not involve the small bowel (Figures 17.8–17.10).

Initially, blunt-tipped or hooked scissors are inserted between the anterior-abdominal-wall parietal peritoneum and the omentum. Rotating the laparoscope so that the scissors exist at 12 o'clock instead of 3 o'clock facilitates adhesiolysis at this stage of the procedure. First, blunt dissection is done by inserting the scissors and then spreading and withdrawing them. This maneuver is repeated many times until all the thin avascular adhesions are dissected. Thicker vascular fibrotic attachments are

FIGURE 17.8. The spoon electrode and a cutting current of 100 W is used to divide vascular adhesions hemostatically.

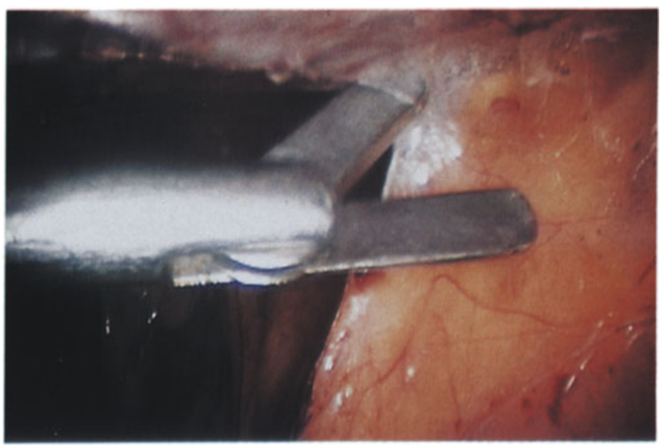

FIGURE 17.6. Scissors dissection is used to divide many of the adhesions at the interface between the omentum or small bowel and the parietal peritoneum.

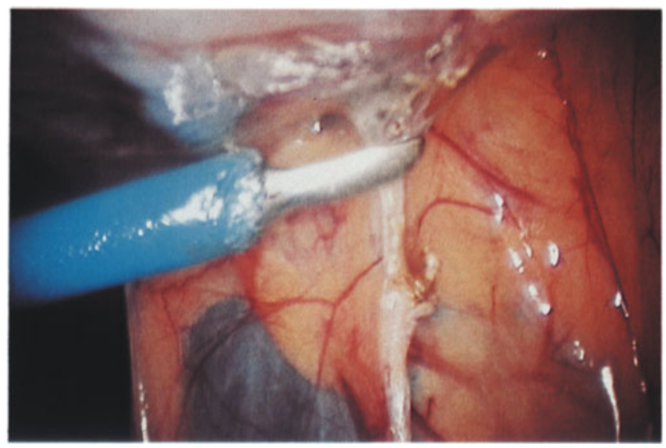

FIGURE 17.9. More vascular adhesions are divided.

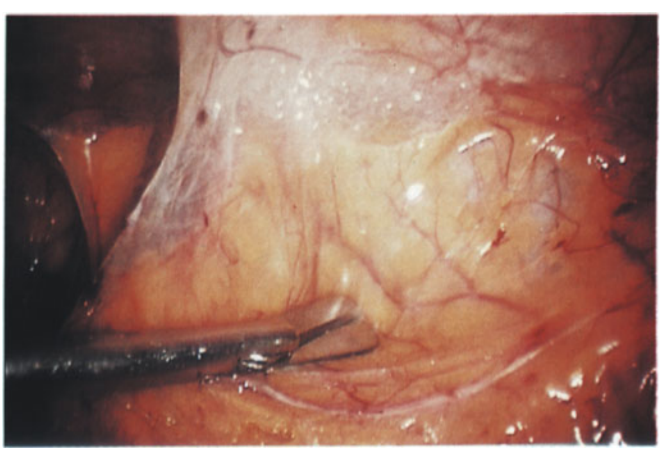

FIGURE 17.7. Blunt-tipped scissors are used to spread the adhesions. The bubbles are at the interface with the adhesions and the parietal peritoneum.

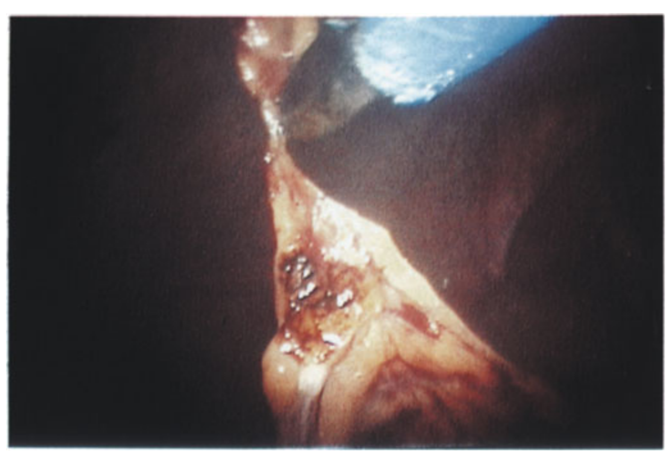

FIGURE 17.10. The omentum is finally completely freed from the anterior abdominal wall using the spoon electrode.

later individually coagulated and divided. Frequently, an adhesion can be bluntly divided by grasping it in the partially closed scissors and pushing.

Initial adhesiolysis creates space that allows better access for further adhesiolysis. Safe entry sites for secondary trocars become visible. After the trocars are inserted, an electrosurgical spoon or knife electrode is used to divide the remaining omental adhesions (see Figures 17.8–17.10). If the small bowel is involved or is intermingled with the omental adhesions, dissection proceeds with scissors through the second puncture site aided by traction on the small bowel from an oppositely placed puncture site. Rarely a CO_2 laser introduced through the operating channel of the operating laparoscope is used for this purpose. When a CO_2 laser is used, the interface between the peritoneum and the bowel is distended with fluid by aquadissection before individual layers of adhesions are vaporized. Aquadissection of adhesions may be necessary because it is often impossible to identify small-bowel serosa enmeshed in adhesions. After small-bowel segments are freed, denuded areas of bowel muscularis are closed with a transversely placed seromuscular suture of 3–0 polyglactin 910 (Vicryl) on a ST needle. With perseverance, all anterior-abdominal-wall parietal-peritoneum adhesions can be released.

It is best to control even slight bleeding immediately. The need for ongoing meticulous hemostasis is an advantage of the laparoscopic route, because it ensures that the next step will not be hindered by bleeding. Sources of bleeding are more difficult to locate at the end of the procedure. If a vessel is injured, the laparoscope is retracted, so that the pumping blood does not coat its optic during bipolar desiccation of the vessel. The suction/irrigator is used to clean the laparoscopic optic, which is then wiped on the bowel serosa before continuing.

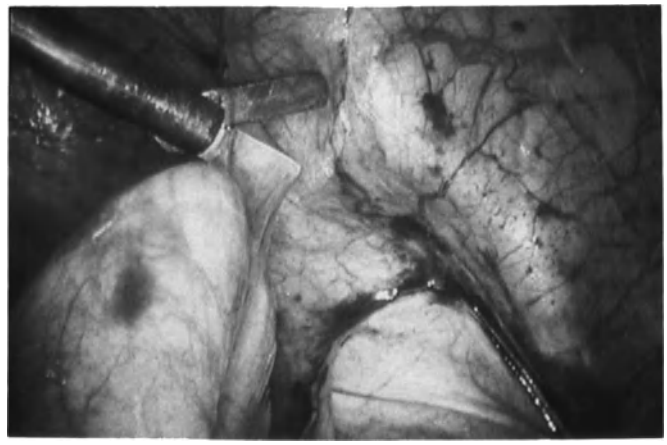

FIGURE 17.11. Adhesions between bowel segments are divided with scissors, usually after transillumination of the adhesion with the scissors.

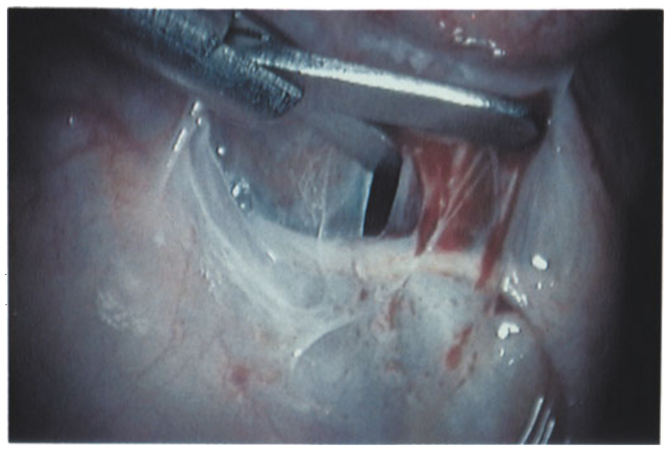

FIGURE 17.12. Magnification assists successful, safe small-bowel enterolysis with scissors.

Pelvic Adhesiolysis

The next step is to free all bowel loops in the pelvis. Small bowel attached to the vesicouterine peritoneal fold, the uterus or vaginal cuff, and the rectum is liberated. Deep pelvic dissection is done with scissors, aquadissection, suction/traction, electrosurgery, and the CO_2 laser. Small bowel is grasped with atraumatic grasping forceps or the suction tip of an aquadissector and put on traction. When adhesion interfaces are obvious, scissors are used (Figures 17.11 and 17.12). When these adhesions blend into one another, an initial superficial serosal incision is made with the laser, and aquadissection distends the layers of adhesions, facilitating identification of the involved structures. Division of adhesions continues with a laser in the pulsed mode and operating at a power of 10 to 20 W. The aquadissector and fluid injected behind bands of adhesions are used as a backstop for the CO_2 laser.

The rectosigmoid may be attached to the left pelvic sidewall obscuring the left adnexa. In this case, dissection starts well out of the pelvis in the left iliac fossa. Scissors are used to develop the space between the sigmoid colon and the psoas muscle to the iliac vessels, and the rectosigmoid is reflected toward the midline. With the rectosigmoid on traction, rectosigmoid and rectal adhesions to the left pelvic sidewall are divided starting cephalad and continuing caudad.

Cul-de-sac adhesions can cause partial or complete obliteration of the space between the anterior rectum, posterior vagina, cervix, and the uterosacral ligaments. The anterior rectum is freed from the posterior vagina to the loose areolar tissue of the rectovaginal septum before visible and palpable deep-fibrotic endometriosis is excised or vaporized.[5]

The anterior rectum is dissected throughout its area of involvement until the loose areolar tissue of the rectovaginal space is reached. Using the rectal probe as a guide, the rectal serosa is opened at its junction with the cul-de-sac lesion. Careful aquadissection, suction/traction, laser, or scissors dissection ensues, until the rectum is completely freed and identifiable below the lesion. Excision of fibrotic endometriosis is done only after rectal dissection is completed.

Deep fibrotic, often nodular, endometriotic lesions are excised from the uterosacral ligaments, the upper posterior vagina [the location of which is confirmed by means of the Valtchev retractor (Conkin Surgical Instruments, Toronto, ON) or a sponge in the posterior fornix], and the posterior cervix. Dissection proceeds on the outside of the vaginal wall using the laser, electrosurgical electrode, or scissors. Usually an endopelvic fascial layer infiltrated with endometriosis is identified. After this layer is excised, the soft pliable upper-posterior-vaginal wall is uncovered. It is frequently difficult to distinguish fibrotic endometriosis from the cervix at the cervicovaginal junction and above. Frequent rectovaginal examinations help identify occult lesions. When the lesion infiltrates the vaginal wall, an *en bloc* resection of the cul-de-sac and the posterior vaginal wall is done, and the vagina repaired laparoscopically with the pneumoperitoneum maintained by means of a 30-cc Foley balloon in the vagina.

Endometriotic nodules infiltrating the anterior rectal muscularis are excised, usually with the surgeon's or assistant's finger in the rectum just beneath the lesion. In some cases, the anterior rectum is reperitonized by pleating the uterosacral ligaments and lateral rectal peritoneum across the midline. Deep rectal-muscularis defects are always closed with suture. Full-thickness rectal-lesion excisions are suture-repaired laparoscopically.

When a ureter is close to the lesion, its course in the deep pelvis is traced by opening the overlying peritoneum with scissors or a laser. On the left, this often requires scissors reflection of the rectosigmoid, as previously described, starting at the pelvic brim. Bipolar forceps are used to control arterial and venous bleeding.

Ovariolysis

Ovarian adhesions to the pelvic sidewall can be filmy or fused. During ovariolysis, it is important to preserve as much peritoneum as possible while freeing the ovary. Dissection begins by using the aquadissector and suction/traction to develop spaces among the adhesions at the lowest ovarian attachment to the sidewall peritoneum or below the infundibulopelvic or utero-ovarian ligament. Thereafter, laparoscopic scissors are used to divide the adhesions, usually in very small bites. These blunt-tipped scissors can be used to place the ovarian cortex on tension (by lifting its most dependent portion) and to nibble at its stretched adherences. Dissection continues until the ovary is free to its hilum. On occasion, the CO_2 laser is used to aid this dissection, especially if the ureteral location is in doubt, because this laser causes minimal thermal damage deep to the operative site.

Salpingo-Ovariolysis Including Salpingostomy

The surgical procedures performed for tubal adhesions are salpingo-ovariolysis, fimbrioplasty, and salpingostomy.[28–30] Small- or large-bowel enterolysis often accompanies these procedures. Extrinsic tubal disease from previous surgery, endometriosis, or appendicitis can also be treated laparoscopically.

When both tubes are open and the fimbria of the tube are not involved by adhesions, the procedure is termed salpingo-ovariolysis. When the distal tube is completely blocked, as documented by transuterine tubal lavage, the surgical procedure is salpingostomy. When the fimbria are attached to the ovary or the distal tube is partially occluded, the procedure is termed fimbrioplasty. In actuality, there is much overlap between these procedures. If salpingo-ovariolysis is performed on a tube whose distal end is stuck to the ovary, freeing this end from the ovary frequently results in a salpingostomy. If the surgeon makes an incision in the most dilated portion of the end of the tube before dissecting the distal tube off the ovary, the opening will seal just as the incision made for ectopic-pregnancy surgery does. Linear incisions along the length of the tube seal; incisions at what was once the true tubal ostium stay open, if the opening is wide enough. Salpingo-ovariolysis for a retroperitoneal ovary or a fused tubo-ovarian complex, however, is more difficult than a terminal salpingostomy with a free ovary.

During adnexal surgery, scissors are generally used to cut and microbipolar forceps to coagulate. On the left side, the rectosigmoid must often be reflected from congenital adherences to the left iliac fossa to better visualize the left infundibulopelvic ligament and the cephalad portion of the left tube and ovary. The ovary is manipulated by grasping the utero-ovarian ligament with an ovarian forceps when possible. Twisting this forceps places the adhesions between the ovary and the pelvic sidewall on tension. Thereafter scissors and aquadissection are used to develop tissue planes and to preserve the pelvic-sidewall peritoneum and ovarian cortex at attachment sites.[6] In cases where adhesion bands are thicker, a well-tuned CO_2 laser can be considered.

Laparoscopic tubal surgery must be as meticulous as that performed by laparotomy. Tubo-ovarian adhesions are placed on traction and divided with scissors (Figures 17.13 and 17.14). Microbipolar forceps with irrigant are reserved for hemostasis after bleeding occurs. The laser is avoided during this dissection to prevent adhesions from thermal necrosis. The ability of laser to dissect with hemostasis makes it ideal for separating vascular fused tubo-ovarian complexes, however. In these cases, it is not easy to identify dissection planes by placing tissues under

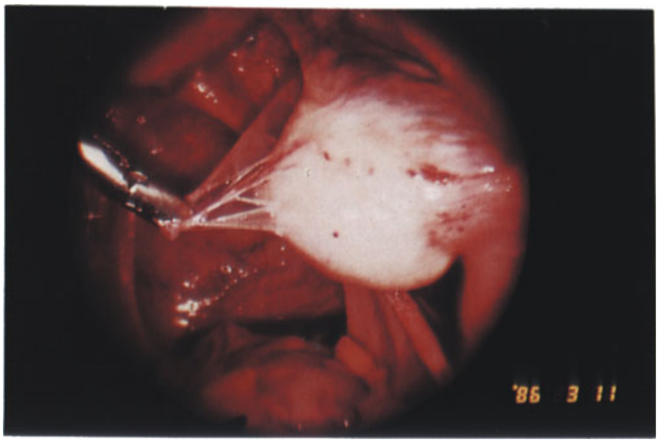

FIGURE 17.13. Tubal ovarian adhesions are put on traction and excised, usually with scissors but sometimes with a laser.

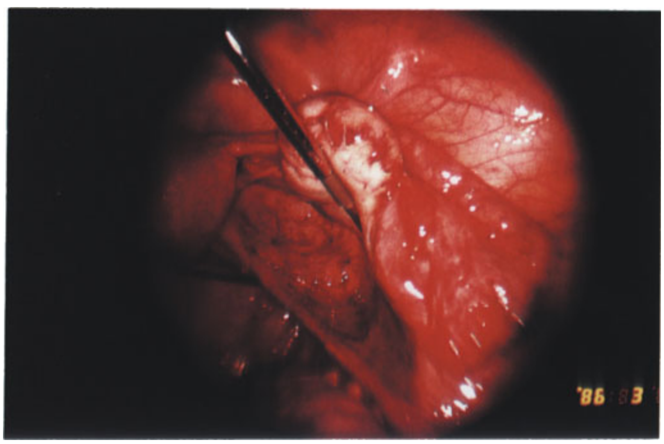

FIGURE 17.14. At the end of the procedure, the tube and ovary are free of all adhesions that connected them to each other and to the pelvic sidewall.

traction. Frequent tubal lavage distends the tube, making it easier to identify. An aquadissector and the CO_2 laser are used to complete the dissection.

Chronic pelvic inflammatory disease with hydrosalpinx can almost always be treated laparoscopically. It is helpful to do a preoperative hysterosalpingogram to evaluate the proximal tube for salpingitis isthmica nodosa. This portion of the tube also requires careful intraoperative inspection.

Scissors dissection should be attempted on the tube with the best prognosis and the laser or electrosurgery reserved for the other.[6] In cases of hydrosalpinx, the distal end of the tube is often fused to the ovary; the tube is opened by dividing all adhesions between distal tube and ovarian surface. Difficult surgical decisions must be made when dissecting the distal tube from the ovary because bleeding that can compromise the fimbrial ostial blood supply often ensues in the tubo-ovarian ligament of the fimbria ovarica. During mobilization of the distal tube, the hydrosalpinx often opens. Otherwise, the distal tube is opened with scissors. Microscissors are inserted into the phimotic ostium and spread. Avascular areas are divided. Then a 3-mm grasping forceps is inserted and spread to stretch the ostium. Avascular areas are again divided. Finally, a 5-mm smooth grasping forceps is inserted and spread, and again avascular areas divided. This procedure usually results in a wide-open ostium with fimbrial epithelium protruding from it.

Laser eversion should be avoided if possible, because thermal effects can cause phimosis or adhesions. More physiologic eversion can often be obtained by cutting bands of fibrous tissue surrounding the tubal ostium. On occasion, eversion should be accomplished with a suture made of 4–0 polydioxanone (PDS) or 5–0 Vicryl. In the case of a large sactosalpinx, laser eversion (Bruhat technique) at a power setting of 1 to 3 W is followed by placement of a suture that apposes ostial epithelium to tube serosa, effectively covering most of the thermally damaged serosa.[31]

The intussusception salpingostomy method of McComb[32] is a good technique in selected cases. It avoids thermal damage to the ciliated tubal epithelium such as can be caused by CO_2 laser or electrosurgery. All adhesions between the adnexa, rectosigmoid, and pelvic sidewall are divided with scissors. On occasion, when the tube is firmly fused to the ovary, the CO_2 laser is used instead of scissors. Dilute indigo/carmine dye is instilled transcervically to distend the distal tube and delineate the point of occlusion. Scissors are used to incise the thinned-out distal tubal serosa over this occlusion, which is usually the result of either external purulent fluid or a pyosalpinx. A relatively short incision is made along the axis of the fimbria ovarica toward the antimesenteric border of the tube. Both scissors and grasping forceps are then inserted into the lumen, which is gently stretched to increase its diameter to approximately 12 mm. The lateral margin of the ostium is grasped with forceps, and the blunt end of the scissors is used to slip the ampullary epithelium and serosa through the ostium as in intussusception. The borders of the incision act as a retaining collar, maintaining the mucosa in this newly everted configuration. In some cases, the ostial margin is sutured to the ampullary serosa with 6–0 polypropylene suture.

Postoperative Care

Same-day discharge is common even after long procedures. Motility of the bowel is encouraged by early ambulation and a clear liquid diet for two to four days. Patients are instructed to return gradually to their normal levels of activity during the week after surgery.

Partial small-bowel obstruction during the week after surgery is usually due to ileus and is treated by intravenous hydration and a nasogastric tube if vomiting is present. Surgical exploration should be avoided in these cases.

If peritonitis occurs in the days after the operation, it must be assumed that an injury to the bowel has gone unnoticed, and a laparotomy is indicated. If an abscess forms postoperatively, it can be drained percutaneously under sonographic guidance or possibly by means of laparoscopy. Adhesions may recur even if atraumatic techniques were used.

Bowel Complications of Adhesiolysis

Gastrointestinal injuries can occur during any laparoscopic procedure, but they are of particular concern during laparoscopic adhesiolysis surgery. The surgeon should be familiar with detection and management of these injuries, regardless of his specialty. In many cases, laparotomy is not required.

Clinical Experiences

This author has repaired small- and large-bowel injuries laparoscopically since July 1988. Between 1984 and 1992, a total of 364 laparoscopic enterolysis cases were performed; 236 were extensive. Concomitant pathology included severe endometriosis (94) and pelvic abscess (10). One of the 364 patients was a male undergoing pelvic lymphadenectomy for staging recurrent prostate cancer. Entry through the left ninth intercostal space was first done in 1991; since then it has been employed in over 50 cases without complications.

In this high-risk group there were 11 small-bowel perforations. These were managed by laparotomy (four cases) and laparoscopy (seven cases). All 11 patients had a significant laparotomy history (the average was 4; the range was 2 to 9). Eight had a history of bowel surgery. No large-bowel perforations occurred during adhesiolysis.[27,33]

Stomach

Routine use of an orogastric tube is recommended to reduce the possibility of a trocar injury to the stomach and to increase operating space by limiting gaseous distention of the stomach and small bowel. However, should such an injury occur, the inside of the stomach is usually evident; treatment consists of a purse-string or figure-eight suture laparoscopically placed in the seromuscular layer surrounding the defect, followed by nasogastric-tube drainage for two days.

Bowel

Trocar-Insertion Injury

Perforation of the intestine may occur either when the Veress needle or umbilical trocar is inserted or during surgery. Injury by Veress needle probably often goes unnoticed, especially when intestinal loops adhering to the anterior abdominal wall seal off the perforation promptly. Air insufflation of an intestinal loop occurred in 8 of 500 procedures in one series.[34,35] The emanation of foul-smelling gas through the pneumoperitoneum needle is a helpful diagnostic sign. In-hospital observation without laparotomy is recommended.

Injury during insertion of the first trocar (usually the umbilical trocar) may represent a diagnostic challenge, but recognition of this complication at the time of laparoscopy is crucial. When a segment of bowel (usually transverse colon) adheres to the abdominal wall, the trocar may pierce both walls of the bowel. The bowel remains fixed around the sleeve of the trocar during the entire procedure, so the accident may not be noticed unless the surgeon carefully examines the entire abdominal cavity. If perforation of the transverse colon is suspected, the trocar sleeve and the laparoscope inside it should be slowly retracted. The bowel is pierced, the bowel lumen will come into view during this maneuver. The recommended treatment is minilaparotomy for suture repair of the perforation or resection of the bowel segment. If an experienced laparoscopic surgeon is available, sutures can be placed laparoscopically or a laparoscopic stapler (Multi-Fire Endo GIA 30) can be used to close the defect. If the perforation has occurred in a bowel segment other than the transverse colon, it may be beneficial to leave the trocar in place until the affected segment is identified and clamped. Colostomy is rarely indicated.

In cases with extensive small-bowel adhesions small-bowel perforation during trocar insertion may not be recognized until later in the procedure, after the omental and small-bowel adhesions are freed from the anterior abdominal wall. If these adhesions are not freed, perforations may not be recognized. Thus, the surgeon who finds extensive adhesions surrounding the umbilical puncture should consider a higher primary puncture site that will allow him a view of the entire peritoneal cavity, such as the left costal margin in the midclavicular line. Thereafter, the adhesions can be freed down to and just beneath the umbilicus, allowing the umbilical portal to be established and used for further work.

A "safety" shield incorporated in some disposable trocars may become momentarily stuck at the level of the fascia. Its violent release can cause a crush injury to retroperitoneal vessels or the intestines located between it and the lumbosacral spine. Mutilation of the mesentery and gaping bowel rents can occur in this manner.

After a small-bowel perforation is recognized, it is repaired transversely with interrupted 3–0 Vicryl, silk, or PDS sutures made with a tapered SH needle and tied either externally or with intracorporeal instruments. Sterile milk is instilled into the bowel lumen prior to the closing of the last suture to detect leakage from the laceration and occult perforations within the small-bowel mesentery.

Bowel resection and primary enteroenterostomy is indicated if the length of an enterorrhaphy exceeds half the bowel diameter, there are multiple injuries near one another, or a segment of bowel is devascularized. The surgeon can best decide whether the single-layer, double-layer, or stapled method of repair should be used. Peritoneal drainage after small-bowel injury is counterproductive.

When intestinal injury has occurred antibiotics are routinely administered when the surgery begins and postoperatively for three doses. A nasogastric tube is rarely used after laparoscopic repair.

Injury During Surgery

Small-bowel perforation during surgery for pain from small-bowel adhesions that resulted from multiple previous surgeries is common, occurring in over 25% of these procedures. Even if adhesions are defined by traction and countertraction and carefully cut, some bowel punctures are inevitable. Repair is simple, as just described; a nasogastric tube is rarely indicated. Superficial thermal injuries to the bowel are treated with a purse-string suture placed laparoscopically outside the thermally affected tissue.

Large-bowel injury during surgery occurs most often at the level of the rectosigmoid or in the deep cul-de-sac. Again detection and careful inspection of the lesion is half the battle. Superficial lesions are managed by careful postoperative observation. Defects involving the full thickness of the wall require surgical repair by an experienced surgeon, either laparoscopically or by laparotomy. Resection with or without colostomy is rarely indicated.

In the bowel-prepped patient, injury to the anterior rectum can usually be repaired laparoscopically. Full-thickness penetration of the rectum may occur during the excision of rectal endometriosis nodules. After the nodule is excised and the rent in the rectum identified, a single- or double-layer transverse repair is done using 3–0 silk, Vicryl, PDS, a Multi-Fire Endo GIA 30, or circular stapler. Stay sutures are placed at the angles of the defect and brought out through a lower-quadrant trocar sleeve on each side. The sleeves are then replaced into the peritoneal cavity over the stay suture. After closure, dilute Betadine solution is injected into the rectum through a 26F Foley catheter with a 30-mL balloon, and an underwater examination is done to check for any leaks. This author has had no late sequelae following five such procedures.[33]

If the bowel is unprepared, whether the repair should be done laparoscopically depends on the amount of fecal spillage. If there is extensive fecal contamination, laparotomy followed by repair should be considered. Laparoscopic repair followed by copious irrigation until the effluent clears may be satisfactory.[36,37]

The practice of performing a colostomy during treatment of bowel injury began in 1944 when Ogilvie reported that colostomy significantly reduced the mortality from colon injuries during World War II.[38] In fact, in 1943, the Surgeon General of the United States issued an order that all colon injuries sustained in battle should be treated by a colostomy.[39] In 1951, Woodhall and Ochsner reported their experience with primary repair without colostomy: their mortality rate fell from 23 to 9% with primary repair.[40] In 1979, Stone and Fabian reported the first well-controlled perspective randomized study on primary closure of traumatic colon perforations.[41] The morbidity of the colostomy group was tenfold higher and the average hospital stay was six days longer. Similar results were obtained by George and colleagues and Burch and colleagues.[42,43]

Unrecognized or Delayed Perforation

Delayed bowel injury can result from traumatic perforation not recognized during the procedure (these injuries include Veress needle or trocar puncture and laceration or excision during adhesiolysis) or from thermal damage from any source. Rarely, delayed injuries are due to the perforation of mechanically devascularized bowel or to hemorrhagic ischemic necrosis after mesenteric venous thrombosis. Bowel perforation following thermal injury usually presents 4 to 10 days after the procedure. With traumatic perforation, symptoms of peritonitis usually occur within 24 to 48 hours, although their occurrence as many as 11 days later has been reported.[44]

The gross appearance of traumatic and electrical injuries is similar; the perforation is usually surrounded by a white area of necrosis. Histologic examination should include a Mallory trichrome stain that turns desiccated tissue blue. Microscopic examination of an electrical-burn lesion reveals the persistence of dead amorphous tissue without polymorphonuclear infiltrate or capillary ingrowth. With puncture injuries, there is rapid and abundant capillary ingrowth, white-cell infiltration, and fibrin deposition at the edge of the injury site.[45] Treatment in either case is bowel resection.

Dr. Richard Soderstrom reviewed 66 cases of bowel perforation that resulted in malpractice suits. In 58 of these cases, the major reason for the lawsuit was a bowel burn. There was evidence of a thermal injury from electricity in only six cases. Of the 60 bowel-trauma cases, a disposable trocar was used in 12 and an open technique in 3 cases. The small bowel was involved in 53 cases, and the large bowel in 13.

Conclusion

No longer can the surgeon ignore the benefits of minimally invasive surgery for adhesiolysis. While these techniques and procedures are not without risk, patients should not be denied their benefits. Astute clinicians must work together to define the most appropriate uses for this therapy.

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18
Colon and Rectum

18.1
Laparoscopic Surgery of the Colon and Rectum

Morris E. Franklin, Jr.

Introduction

The advantages of minimally invasive techniques for performing abdominal procedures have been well demonstrated by thousands of surgeons and enjoyed by hundreds of thousands of patients. Laparoscopic cholecystectomy has been accepted by even the most harsh critics, but acceptance of more advanced procedures has been much slower. Certainly removal of a solitary organ with a comparatively simple blood supply and drainage system can readily be accomplished. Reconstruction of organs, however, poses an entirely new set of problems, which continue to challenge even the most skilled laparoscopic surgeons. A few of the problems facing the would-be laparoscopic colon surgeon are: understanding anatomy viewed through a laparoscope at an unfamiliar angle, handling of bulky tissue with unfamiliar tools, retracting adjacent structures without the use of hands or packing, mobilizing difficult organs at unusual angles, handling multiple large and small blood vessels, removing bulky tissue, and handling tissue carefully enough to ensure proper healing. Laboratory investigations and early clinical trials have demonstrated that laparoscopic colonic procedures are practical and beneficial for the patient. Their efficiency, cost-effectiveness, and equivalence to open procedures will doubtless be debated for several years to come.

Historical Review

The first planned laparoscopic colon operations were performed by Fowler, Franklin, and Jacobs in 1990, and since that time innumerable procedures have been performed to control bleeding, relieve obstructions, remove tumors, cure infections, and aid defecation. More than 160,000 colonic procedures are performed in the United States each year and more than 300,000 in Europe. A significant number of these could be approached laparoscopically.

Important principles of colonic surgery include:

- Control infection
- Ensure continuity of function
- Minimize blood loss
- Avoid large wounds
- Obviate short- and long-term complications
- Minimize pain
- Alleviate the problem for which operation is being performed

Any new technique intended to substitute for an open procedure should fulfill these criteria at a minimum and should also offer distinct advantages.

Because of the quick recovery of patients after laparoscopic cholecystectomy, we began to study the feasibility of laparoscopic colonic procedures in early 1990. After learning how to properly clean the porcine colon and with the use of colonoscopic control, we performed a number of procedures (Table 18.1.1). We found not only that the procedures were feasible but also that the animals were active and taking fluids in 30 hours or less and had bowel function in 24 hours or less. Necropsy examination revealed that all repairs had healed, all anastomoses were open and intact, and there were few adhesions. Based on this work, the institutional review board at our hospital approved clinical trials, which began in 1990. Our initial experience with colectomy and polypectomy was encouraging and colon resections with anas-

TABLE 18.1.1. Animal Studies.

Procedure	Number
Colotomy	5
Transection of colon with hand-sewn repair	4
Segmental resection with hand-sewn anastomosis	4
Segmental resection with circular stapled anastomosis (purse string)	7
Segmental resection with circular anastomis (loop)	9
Extended procedure	1

tomosis soon followed, with equally good results. Since then our techniques for management of problems have substantially improved and we have defined more precisely the contraindications for these procedures.

The benefits of laparoscopic cholecystectomy do indeed spill over to laparoscopic colon resections: improved patient well-being; marked reduction in pain; and the absence of significant wound, pulmonary, or bleeding problems. The extra time and effort this type of surgery requires is rewarded by a more comfortable patient who recovers more quickly from major surgery.

Laparoscopic Techniques

Prior to attempting laparoscopic colonic procedures it is imperative that the surgeon become familiar with the specialized equipment needed to perform successful laparoscopic surgery. The surgeon should practice in the laboratory or, at the very least, with other less demanding laparoscopic procedures, before these much more difficult procedures are attempted. Accounts are beginning to appear in the literature of possible misadventures, including small-bowel perforation, small-bowel obstruction, urethral injury, excessive bleeding, and inordinately high rates of conversion to open surgery, which can probably be traced to the surgeon's lack of laparoscopic experience and skill. The surgeon who depends on new gadgets to overcome inexperience is destined to make the same mistakes over and over.

Laparoscopic colon surgery demands anal access, and we have found this to be most readily accomplished if the patient is positioned with the buttocks near the lower edge of the operating table and the legs in Lloyd-Davis stirrups. The operating table should be moveable because the procedure is definitely easier if the patient can be tilted left or right as well as placed in the Trendelenburg and reverse Trendelenburg positions. All exposed or bony prominences should be carefully padded in order to avoid nerve or pressure injury during these sometimes lengthy procedures. We routinely tape the padded shoulders quite firmly to prevent the patient from slipping when in the steep Trendelenburg position. Extra precautions should be taken to prevent body-core cooling, such as heating of insufflation gas, placing heating pads around the patient's body, heating inspired gases, wrapping the patient's legs in plastic sheets to prevent heat loss, and heating irrigation fluid. We have also found that placing the patient's arms at his sides allows the surgeon, assistant surgeon, and camera holder much better access. Monitor placement is crucial to efficient use of the laparoscope. We recommend the use of at least two monitors and, if possible, a third for the colonoscope. All personnel must be able to see clearly if a laparoscopic operation is to proceed efficiently. For sigmoid colon, low anterior, and abdominal perineal resections, the monitors should be at the caudad end of the operating table to avoid fatiguing the surgeons. If mobilization of the left colon or splenic flexure is anticipated, it should be possible to move the monitor on the patient's left to very near the patient's left shoulder. Although some surgeons have reported that they stand on the same side as the operated segment, we strongly advocate that the surgeon be on the side opposite the involved segment of colon. He may have to change positions during subtotal and total colectomy, or an assistant can perform parts of the procedure. For right-side lesions, the assistant should be between the patient's legs with the monitor at the level of the umbilicus. Surgeon and monitor placement are illustrated in Figures 18.1.1–18.1.3.

Many different methods of trocar placement have been suggested, but we do not advocate any particular pattern. Trocars 10 mm or larger should be used at every port site and the surgeon should move the laparoscope between port sites as needed. Generally speaking we try to place the laparoscope at the umbilicus regardless of the segment of colon on which we are operating. We then try to place ports outside of the rectus muscle and lateral

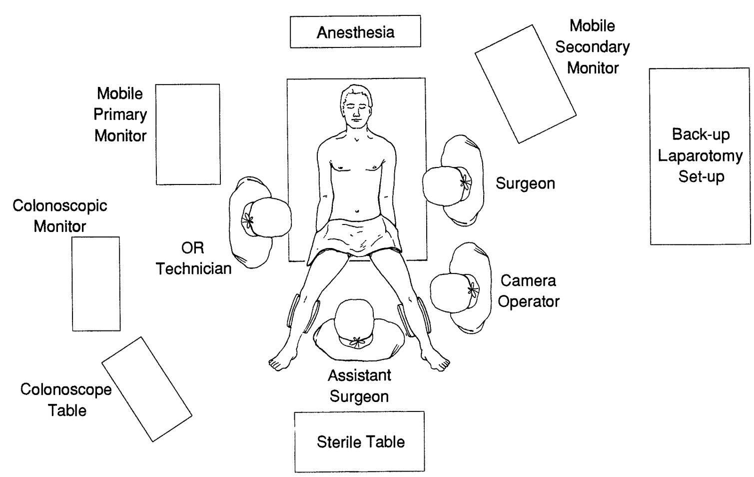

FIGURE 18.1.1. Operating room arrangement for right colon resection.

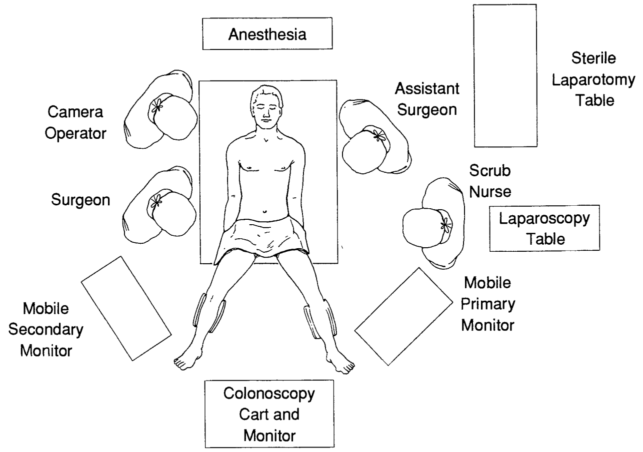

FIGURE 18.1.2. Operating room arrangement for sigmoid resection.

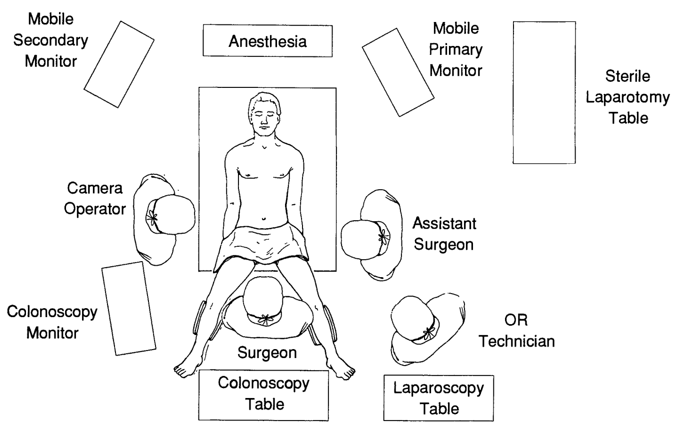

FIGURE 18.1.3. Operating room arrangement for splenic flexure mobilization.

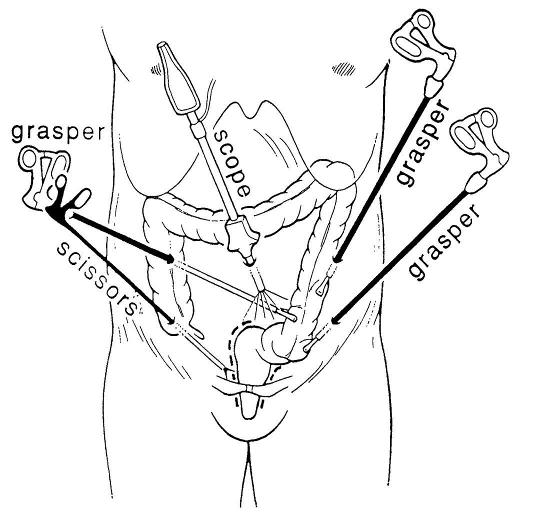

FIGURE 18.1.4. Trocar placement for low anterior and abdominal peritoneal resection.

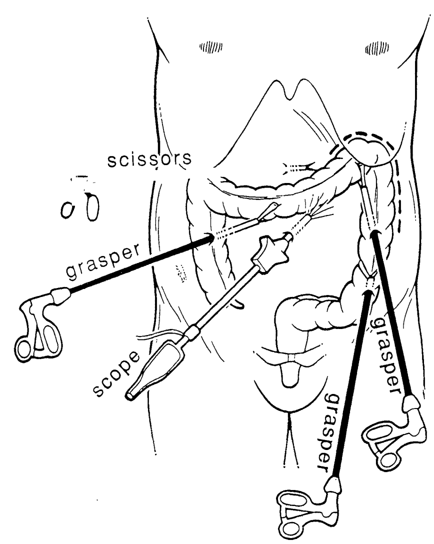

FIGURE 18.1.5. Trocar placement for splenic flexure and left colon.

enough to miss major vessels but still allow instruments to meet and to reach the lower or upper aspects of a given dissection. The typical trocar placement for low anterior and abdominal peritoneal resections is displayed in Figure 18.1.4. Trocar placement for splenic flexure and left colon resection is shown in Figure 18.1.5 and that for right colon resection is shown in Figure 18.1.6. We strongly urge the use of 10-mm trocars at all sites, primarily because they put fewer constraints on technique.

Operative details of sigmoid, low anterior, and abdominal perineal resections are similar and will be considered together. After standard insufflation to approximately 13 or 14 mm Hg with CO_2, the trocar sites are selected, taking body configuration and location of the lesion into account. We firmly believe the surgeon and his assistant should have both hands available and thus almost always employ a camera holder. The sigmoid colon should be displaced medially by Babcock graspers or, failing them, by blunt retractors. Avoidance of sharper instruments will result in much lower incidence of inadvertent bowel injury or perforation, which the surgeon may not immediately recognize. Sharp meticulous dissection should be utilized to aid in the mobilization of the colon, and the ureter on the left as well as that on the right should routinely be identified and referred to as needed during the dissection. The sigmoid colon should be mobilized medially well past the sarcal promitory and into the pelvis. Mobilization should include dissection and ligation of the middle hemorrhoidal vessels if the disease process is below the promontory. Vessels can be clipped, coagulated, or ligated, depending on their size and the experience of the surgeon. We prefer to coagulate vessels 2 mm in diameter or smaller, to clip or tie vessels 2 to 5 mm in di-

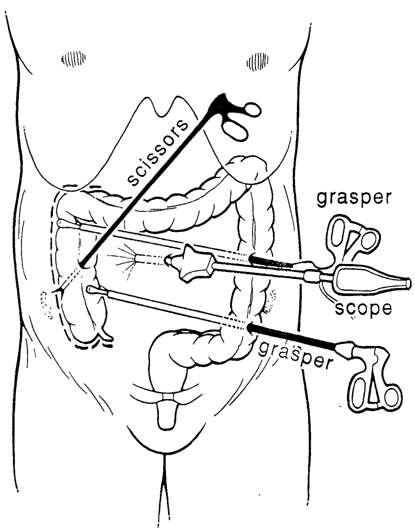

FIGURE 18.1.6. Trocar placement for right colon resection.

ameter, and to ligate vessels larger than 5 mm with an extracorporeal knot using a nonabsorbable suture. Stapling devices such as the Endo GIA (US Surgical Corporation, Norwalk, CT), or Endocutter (Ethicon, Cincinnati, OH) may be utilized, but we have found they add considerably to the cost of the procedure.

After medial mobilization of the sigmoid and mobilization of the left colon up to and including the splenic flexure, the right mesorectum and mesosigmoid are dissected and a window in the mesentery is developed. During cancer operations the iliac artery and vein as well as the bifurcation of the aorta and the take-off of the inferior mesenteric artery are quite easily identified as the dissection is continued from below upward and the window is expanded. The proximal extent of the dissection is then determined as well as the distal margin and both are marked with a clip or cautery. The mesenteric defect is extended to these areas, again by slow meticulous dissection of all vessels. Care should be taken at this point to routinely check the position of the left ureter with respect to the mesentery being divided.

After adequate mobilization has been completed, the proximal colon above the planned line of resection is clamped with a bowel-occluding atraumatic clamp, preferably a laparoscopic Glassman clamp or even a laparoscopic Glassman bulldog clamp, and the colon is examined with the colonoscope for cleanliness as well as to determine whether there are adequate margins for resection. We feel this step is extremely important to ensure a complete colonic preparation. We often irrigate with Betadine solution at the conclusion of the colonoscopy to further cleanse the colonic lumen.

Division of the colon can be accomplished with the KTP (potassium titanyl phosphate) laser, scissors, a finetip cautery, or with a variety of linear cutting/stapling devices. We prefer to divide the proximal segment first and the distal segment second in order to prevent CO_2 leakage in low resections. As the colon is divided, the proximal segment of the resected bowel is closed with a stapling device or a pre-tied loop. The distal end is closed after division as well. The specimen is then placed in a sterile bag for removal transabdominally at the conclusion of the procedure or transanally (if it is small enough). If the procedure is laparoscopically assisted, the specimen can be removed through the abdominal incision. We prefer totally intracorporeal anastomosis and remove the specimen through an extended subumbilical incision at the conclusion of the procedure if transanal removal is not feasible. It has been our observation that, as in laparoscopic cholecystectomy where large specimens are removed, little additional pain and virtually no morbidity are associated with this technique.

Because our experience with laparoscopic colon surgery began long before the introduction of laparoscopic staplers, we developed a technique utilizing PDS (polydioxanone suture) pre-tied loops. We have been pleased with this technique and continue to utilize it. A circular stapler is introduced transanally through the open end of the rectal segment. After full extension of the anvil shaft an Endoloop is immediately applied. The anvil is removed, the Endoloop is tightened over the end of the stapler, and excess cuff tissue is trimmed to allow good closure of the circular stapler. The anvil should be parked in a convenient place where it is unlikely to be dislodged between loops of bowel. The distal end of the proximal bowel is now identified, the anvil is introduced into it, and Endoloops are applied to this segment. Again excess tissue is removed and the stapler is reassembled. Care should be taken to avoid entrapping adjacent tissue, such as bowel, fallopian tube, or ureter, as the stapler is closed. Often this is best accomplished by moving the laparoscope to the lowermost lateral port site so that the anvil and head can be directly visualized as the stapler is closed.

After the surgeon checks to make sure there is an adequate thickness of tissue in the stapler (and no unintended tissue), the device is fired and removed. A lack of tension on the anastomosis should be verified. The proximal portion of the colon should then be cross-clamped with either a laparoscopic noncrushing clamp or, preferably, a laparoscopic bulldog noncrushing device, and the colon insufflated and anastomosis checked under water with the colonoscope for leaks. Should a leak be present, it should be pinpointed and simple sutures placed to close it. It is not uncommon to discover multiple leaks at the staple line site when the pressure is high. However, the majority of these minute leaks do not need to be closed. The mesenteric edges should be checked thoroughly for bleeding, after the abdominal pressure is reduced to 5 or 7 mm Hg and any excess fluid used for irrigation is removed. Pelvic drains for residual fluid (which is always present) can be left at the discretion of the surgeon.

Low anterior resections and abdominal perineal resections require extended dissection and bilateral ligation of the middle hemorrhoidal vessels. This can be accomplished with clips or sutures intra- or extracorporeally but these vessels are probably a little large for cautery alone. Again, meticulous identification of both ureters is mandatory.

Dissection of the lower aspect of the rectum can be particularly tedious but is made easier by early dissection of the presacial space as far as can be done. Often this space can be easily dissected to the levator ani muscle, and the muscle fibers visualized. We suggest beginning on the right side and completing the posterior lateral dissection from proximal to distal and then as far laterally as possible. The anterior peritoneum should also be incised. In the case of females, suspension of the uterus with transabdominal stay sutures is often helpful for anterior visualization. After completion of this initial dissection, dissection of the left pararectal space may be accomplished. In the case of abdominal perineal resections, the proximal sigmoid colon may now be divided and the perineal portion of the procedure completed. The colostomy may be brought out through a modified trocar incision lateral to the umbilicus. Residual dissection may be completed transperineally until the anus is free. The specimen is then removed, the pelvis irrigated and all potential bleeding sites checked, and persistent bleeding controlled with cautery, suture, or the argon-beam coagulator. The peritoneum may or may not be closed, depending upon the need for postoperative radiation or the preference of the surgeon. The perineal musculature may be closed from above or below. Closure from below is the most popular technique.

Right colon dissection requires a thorough understanding of the anatomic relations between the right ureter, second and third portions of the duodenum, the right colon, the stomach, and the pancreas. It is especially important to locate the somewhat inferiorly placed right colic artery and, in the case of malignancy, to perform a high ligation of this vessel. Mobilization of the right colon is best approached by starting at the readily recognizable cecum. It can be thought of as a continuation of the mobilization needed in the case of a retrocecally located appendix. Frequently this mobilization is quite easy, but it can be made easier by tilting the table to the right and placing the patient in the Trendelenburg and then in the reverse Trendelenburg position. This dissection is also easier if the monitors are on the right side of the patient, and we have found moveable monitors helpful as the dissection progresses. Hepatic flexure dissection is best completed by inferior medial traction on the colon and scissors or other dissecting instruments introduced through the subxiphoid trocar. The laparoscope should be frequently moved to a lateral or subcostal position to permit visualization of the right gutter and paraduodenal area. Superior placement and mobilization of the omentum will often assist division of the gastrocolic ligament and allow rapid identification of the right colic artery. This vessel may be divided by clipping, extra- or intracorporeal ligation, or division with a stapling/cutting device. Division of the right colic vessel allows very rapid mobilization of the remaining right colon mesentery, until the iliocolic artery is identified. This can be a very large vessel, and ligation is recommended for secure control. Laparoscopic vascular bulldog clamps make it much easier to apply Endoloops to the proximal and distal ends of the vessel, and this is rapidly becoming our preferred technique. The division site for the ileum is now selected, although in certain instances this decision may be made during the dissection. Division of the ileum is best accomplished with a stapler/cutting device such as the Endo GIA or the Endocutter although Endoloops or simple suturing techniques may also be used. The division site for the transverse colon is then selected, and the adjacent mesentery and omentum cleaned. The colon is divided with a stapling and cutting device, and the specimen is bagged. The mesentery is carefully inspected for bleeding under reduced pressure, and preparation for the anastomosis is completed. An extracorporeal anastomosis may be rapidly completed through a mini-lap incision in the right upper quadrant with hand sewing techniques or stapling techniques. The mesentery may be closed extracorporeally or intracorporeally with either hand sewing techniques or with a hernia-stapling device.

We prefer, however, intracorporeal anastomosis with the so-called triple-stapling technique, which allows an ileotransverse colostomy to be constructed and the enterostomy to be closed with a series of staple firings. We then inspect the anastomosis with the colonoscope and test it under pressure for leaks. The mesenteric defect may be closed by suturing or by stapling. The specimen in its bag can then be removed through an extended infraumbilical incision, as previously described.

Transverse and splenic flexure resections, in the opinion of the authors, should not be undertaken until the surgeon is thoroughly familiar with other techniques because these dissections are by far the most demanding of all laparoscopic colon procedures. The basic tenets of laparoscopic colon surgery, including mobilization, retraction, excellent visualization, precise dissection, and meticulous control of blood vessels and bleeding must be strictly followed or this type of procedure is doomed to failure. Intimate familiarity with the anatomy of this area, particularly with the relation between the pancreas, the stomach, the omentum, the spleen, and the mesentery of the transverse and left colon, and slow meticulous dissection through the mesentery will enable the surgeon to tackle this difficult area successfully. Identification of the left colic artery may be difficult in previously operated or obese patients and Doppler ultrasound can be of assistance. Generally speaking, it is helpful to dissect the omentum from the greater curvature of the stomach in the case of malignancy or from the colon itself in benign disease prior to division of the transverse colon mesentery. Anastomosis of the transverse colon or high in the left colon are among the most difficult laparoscopic procedures: they can be accomplished intracorporeally or extracorporeally with the hand sewing or stapling techniques previously described.

Total and subtotal colectomy, which have been performed in our institutions and elsewhere, require a combination of the previously discussed techniques. These procedures are quite time-consuming and obviously are not for the novice laparoscopic surgeon. They require precise planning and meticulous dissection, not to mention stamina. They can, however, be completed laparoscopically if laparoscopic surgical principles are practiced.

Clinical Results

Since mid- to late 1990, laparoscopic colonic surgery has been offered to patients in our institutions with a variety of disease processes. The surgery was initially offered to those patients with ideal lesions and what were perceived to be ideal anatomic situations. We now offer minimally invasive surgery to all patients with colonic disease except those with the following contraindications:

1. Morbid obesity
2. Large abdominal aortic aneurysm
3. Severe inflammatory bowel disease with friable bowel wall
4. Uncorrectable bleeding dyscrasia
5. Extensive neoplastic process involving one or more adjacent organs or frozen pelvis
6. Extensive previous surgery with known severe adhesions

This list is not intended to be all-inclusive. Certainly exceptions to these contraindications exist, but in most cases a laparoscopic approach is inadvisable or downright impossible when these indicators are present. With adequate preparation, careful monitoring, and thoughtful anesthesia, severe cardiac, vascular, and pulmonary disease have not been contraindications to laparoscopic colonic surgery. Rather, laparoscopy has resulted in a much smoother postoperative course for these high-risk patients.

Laparscopic colon surgery principles have been applied to a number of patients with a variety of disease processes in a distribution throughout the colon as outlined in Table 18.1.2. The patient profile data are outlined in Table 18.1.3.

A number of procedures other than resections have also been performed, as outlined in Tables 18.1.4–18.1.6.

Our patients have done relatively well, experiencing no more complications than those undergoing open proce-

TABLE 18.1.2. Locations and pathologic conditions for which surgery was performed.

	Disease process		
Procedure	Carcinoma	Benign	Total
Right hemicolectomy	15	0	15
Transverse colon resection	2	0	2
Subtotal and total colectomy	1	1	2
Left colon resection	8	0	8
Sigmoid colon resection	18	17	35
Low anterior resection	24	0	24
Abdominal perineal resection	17	0	17

TABLE 18.1.3. Patient profile data on 103 patients.

	Mean	Range
Age:	68 yr	22–96 yr
Weight:	178 lb	110–278 lb
Sex:	Female–50	
	Male–53	

TABLE 18.1.4. Laparoscopic polypectomy.

Location	Number
Right colon	8
Left colon	2
Sigmoid colon	3
Rectum	2
Total	15

TABLE 18.1.5. Laparoscopically monitored polypectomy (polypectomy performed with a colonoscope).

Location	Number
Right colon	4
Left colon	5
Transverse colon	2
Sigmoid colon	2
Total	13

TABLE 18.1.6. Miscellaneous procedures for complicated tiverticulitis.

Procedure	Number
Abscess drainage and lavage	6
Drainage and diversion	5
Division and drainage colovesical fistula	9
Division and drainage colovaginal fistula	4
Total	24

dures. The complications encountered in the first 146 colonic procedures are as shown in Table 18.1.7.

Return of bowel function has been more or less independent of the procedure and has averaged approximately 18 to 24 hours. The breakdown according to procedure is as shown in Table 18.1.8. Table 18.1.9 depicts operation time for various procedures.

The hospital discharge date has depended more on concurrent medical problems than the surgical procedure. Table 18.1.10 demonstrates that the average discharge time compares favorably with the nine days allowed by Medicare for most colonic procedures.

Our results from more than three years experience in laparoscopic colon resections utilizing exclusively intracorporeal techniques compare favorably with results reported by Fowler, Jacobs, Stitz, and Phillips, all of whom have found rapid return of bowel function, reduction in pain, and sparsity of significant complications to be distinct advantages of this new approach to colonic disease.

Whether colon resection is laparoscopically assisted or totally intracorporeal seems to have little bearing on the immediate outcome, although intracorporeal techniques require less analgesia. However, whether there is a difference in the long-term results, particularly in cases of carcinoma, remains unclear. A very real concern is that tumor cells might be implanted in the abdominal wall as well as possibly forced back into unresected segments of colon or the abdominal cavity when the affected segment is not isolated in a bag, but insufficient data are currently available for a realistic evaluation of this possibility. Reports of carcinomatous seeding with thoroscopic removal of cancer-containing tissue as well as of carcinomatous implants with laparoscopic cholecystectomy are disturbing and bear further study.

There is little doubt that equal operations are being performed laparoscopically for colon cancer as compared to open procedures. Several reports in the literature indicate comparable margins of resection with laparoscopic procedures and that equal or greater numbers of lymph nodes are retrieved. Studies are currently underway to assess other parameters, particularly the disease-free survival of comparable carcinoma patients. Initial results indicate that these patients have similar prognoses and survival rates.

The real difference between open and laparoscopic colon resection from the patient's point of view is patient tolerance of the procedure, the length of hospital stay, the length of convalescence, the interval before additional therapy can be instituted, and the ease with which older, sicker patients tolerate the procedure, with the balance being in favor of the laparoscopic procedure.

Table 18.1.11 shows the convalescence afer laparoscopic colon surgery as estimated by the patients.

Patients undergoing laparoscopic colon resection seem to experience greatly diminished pain, regardless of the procedure. The reduction in pain appears to correlate primarily with the lack of a significant abdominal incision rather than with the number of ports or the amount of intra-abdominal dissection and resection. Most patients

TABLE 18.1.7. Complications of laparoscopic colonic resections.

Complication	Number
Pneumonia	1
Death	3*
Anastomotic leak (suspected)	1
Thrombophlebitis	0
Blood transfusion	1
Wound infection	1**
Re-operation	2***
CVA	1

*Pneumonia 21 days postop; cerebovascular accident stroke (CVA) (preop anemia, refused transfusion); myocardial infarction 9 days postop.
**Specimen removed transanally.
***One bleeding ulcer; one loop ileostomy for anastomotic leak.

TABLE 18.1.8. Return of bowel function (tolerating oral intake with bowel movement).

Procedure	Average (hours)	Range (hours)
Right colon resection	24	12–36
Transverse colon resection	30	18–40
Left colon resection	24	16–36
Sigmoid colon resection	24	12–36
Low anterior resection	30	18–40
Abdominal perineal resection	18	6–30

TABLE 18.1.9. Duration of operation.

Procedure	Average (hours)	Range (hours)
Right colon resection	1.75	1.5–3.5
Transverse colon resection	2.8	2–3.5
Left colon resection	2.1	1.75–2.75
Sigmoid resection	2.2	1.5–3.5
Low anterior resection	2.6	1.8–4.0
Abdominal perineal resection	1.75	1.25–2.6

TABLE 18.1.10. Postoperative hospital stay.

Procedure	Average (days)	Range (days)
Right colon resection	3.5	3–6
Transverse colon resection	3.5	3–6
Left colon resection	2.5	2–5
Sigmoid resection	3.8	2–30*
Low anterior resection	3.6	2–13*
Abdominal perineal resection	2.8	1.5–21*

*Explanation of prolonged hospitalizations: postop bleeding secondary to gastric ulcer; ileostomy for suspected anastomostic leak; pneumonia developing 7 to 10 days postop.

TABLE 18.1.11. Postoperative return to full function.

Procedure	Average (days)	Range (days)
Right colon resection	6	4–10
Transverse colon resection	8	6–12
Left colon resection	6	1–12
Sigmoid resection	7	4–31
Low anterior resection	11	7–35
Abdominal perineal resection	5	2–15

require little or no postoperative analgesia, and those who do have pain respond to very small amounts of narcotics, usually less than one-third the customary dose given at less-frequent intervals. The consequence is that the patients are able to ambulate unassisted much sooner, which diminishes pulmonary complications. The early, more frequent, and more enthusiastic ambulation resulting from less pain and anticipation of pain has also eliminated deep vein thrombosis in our series.

The advantages of laparoscopic surgery from the patient's standpoint are a shorter hospital stay as well as a much more rapid convalescence. Savings accrue from shorter hospital stays, as well as from the more rapid return to work. Time off work can be 7 or 10 days for laparoscopic procedures, compared to six to eight weeks for open procedures. The hospital cost will be somewhat higher initially, because more disposable equipment is used. It is often falsely elevated by adding in the cost of video equipment, laparoscopes and laparoscopic equipment, and insufflators; most operating rooms already have this equipment for use in other procedures. There is additional expense for disposable staplers, clipping and ligating devices, and some specific instruments but this cost is more than offset by the overall savings. Additionally, as the operating laparoscopic surgeon becomes more sophisticated and realizes that lower-cost techniques are available to perform these procedures, the cost will undoubtedly drop. As equipment manufacturers produce nondisposable equipment in greater volume, the cost will drop as well.

There seems to be a general feeling that laparoscopic colonic procedures or perhaps even laparoscopy in general should not be performed in sick, older, or pulmonary/cardiac-compromised patients. Several recent series have shown, however, that these are the patients who benefit the most from procedures, provided hypercarbia and hypothermia are prevented and the procedures do not last more than about four hours. As with any type of surgery, there are complications, but these seem more related to the population requiring the procedures than the procedures themselves (see Table 18.1.7).

Nonetheless there are still a few situations where laparoscopic colon resection is less satisfactory than open resection. Spillage of colonic contents is not a problem given current stapling techniques and bowel occlusion clamps. Severe inflammatory bowel disease with extremely friable bowel walls prevents adequate retraction, lessening the chance of adequate mobilization of the colon. Large bulky segments of colon, such as occurs with severe diverticulitis or advanced carcinoma with obstruction, may not leave adequate space within the abdominal cavity to work. Many surgeons feel that the inability to palpate the periaortic space, the liver, and the location of a polyp limits laparoscopy. However, intraoperative ultrasound, preoperative CT scans, and meticulous dissection overcome this difficulty in all but the most unusual cases. Intraoperative colonoscopy allows localization of a polypoid lesion, adequate marking of margins, the verification of bowel preparation, and postoperative verification of the anastomosis as well as control of bleeding.

Discussion

Technological advances in laparoscopic equipment have allowed surgeons to perform almost every known colonic procedure in a laparoscopic manner. A significant number of these procedures have been laparoscopically assisted, but as familiarity with the techniques is gained, more and more surgeons are performing all steps of the procedures, save removal of the specimen, intracorporeally. Eventually as nuclear ploidy, nuclear count, and other techniques of determining the pathology of a specimen come into use, it may become less important to obtain an intact specimen. Specimens will be removed with marcellation or liquification techniques, and the entire procedure will be performed through 10- or 18-mm incisions, with larger incisions being viewed with disfavor by surgeons and patients alike.

Some surgeons will probably never abandon the open approach. However, tomorrow's technology will allow virtually all colonic procedures to be performed laparoscopically. The only exceptions will be those noted earlier or the patient with severe fecal contamination who requires cleaning and irrigation not possible with present techniques. Few effective arguments can be marshalled against treating colonic disease requiring resection laparoscopically and the number of indications for open procedures in our institution seems to be dropping rapidly.

Conclusion

As more and more surgeons become familiar with laparoscopic colonic procedures and the public becomes more aware of this type of surgery and its advantages, the number of laparoscopic colonic surgeries and the variety of procedures performed will undoubtedly rise. Reluctance to embrace colonic surgery will disappear, and laparoscopic colonic surgery will become commonplace. There is little doubt that the surgery is more difficult to perform and that the procedures take longer, but the undeniable benefits to the patient and the equivalence of the procedure on other points leave few cogent objections to this advance in the surgery of colon and rectal disease. Eventually, close to all colonic procedures will be approached laparoscopically with close to 90 or 95% possible with totally intracorporeal laparoscopic techniques, with untold benefit to the patients and to the great satisfaction of the surgeons.

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18.2 Rectal Lesions

G. Buess and U. Weiss

Introduction

The anatomy of the pelvis makes it difficult to perform local excisions of rectal tumors that are some distance from the dentate line and, thus, until now these excisions have required invasive surgical procedures. We recently developed a new technique called transanal endoscopic microsurgery (TEM) that offers several advantages over traditional procedures. First, the stereoscopic and magnified view of the gas-dilated rectum allows precise surgery in an operative field that is otherwise difficult to reach. Second, minimal postoperative discomfort and pain result in a short hospitalization. And finally, this method has good cosmetic results and low complication and recurrence rates.

Historical Review

In 1980 Buess, Theiss, and Hutterer started to develop this new technique at the department of surgery of the University Hospital of Cologne, FRG, in cooperation with the Richard Wolf Company, Knittlingen, FRG. Although snare resection of pedunculated polyps was already established, sessile adenomas and low-risk carcinomas of the rectum still required invasive procedures. Those tumors were excised by techniques developed by Parks, Mason, and Kraske or by anterior resection.

Transanal Approach (Parks)

The rectum is reached through the anus using various retractors. This technique is only feasible for tumors in the lower rectum.

Sacrococcygeal Approach (Kraske)

After resection of the coccyx, sparing the sphincter muscles, the rectum is accessed posteriorly. This technique is feasible for the middle and upper part of the rectum.

Trans-Sphincteric Approach (Mason)

After an oblique skin incision, the sphincter muscles—carefully identified—are divided, and the rectum is reached by a posterior approach. After excision of the tumor, exact reconstruction of the sphincter muscles is mandatory. This technique is especially suitable for tumors of the middle rectum.

The limited distance from the anal verge within which tumors are operable, the poor exposure of even operable tumors, and the invasiveness and complication rates of the Mason and Kraske procedures and anterior resection made development of a new technique attractive.[1–4] Transanal endoscopic microsurgery was introduced clinically in 1983.

Indications

Sessile Adenomas

All sessile adenomas no deeper than 25 cm in the rectum that can be clearly visualized by a rigid rectoscope and that do not exceed 8 cm in length are suitable for TEM.

Carcinomas

Four classes can be distinguished.[5–7]

1. Well- or moderately differentiated pT1 carcinomas (low-risk carcinoma according to Hermanek). These have a high probability of cure (infiltration of lymphatic system has occurred in fewer than 3% of cases).
2. pT2 carcinomas in old or high-risk patients. These have a limited probability of cure (infiltration of lymphatic vessels has occurred in up to 10%).
3. pT3 carcinomas with good mobility during digital examination and diameters less than 4 cm irrespective of differentiation in old or high-risk patients. These are only suitable for palliative treatment.

4. Unsuspected/previously unconfirmed cancers. In up to 20% of patients, large sessile adenomas containing areas of *in situ* or invasive carcinomas, mostly of the pT1 low-risk type, are not detected preoperatively. This is by far the most common localized-cancer operation. These cancers have a high probability of cure.

The full-thickness excision, which is mandatory in the surgical treatment of cancer, is only feasible in the extraperitoneal parts of the rectum, specifically: anteriorly up to 12 cm, laterally up to 15 cm, and posteriorly up to 20 cm from the dentate line. For T2 and T3 carcinomas the distal resection margin should be at least 2 cm from the dentate line, so that a rectoanal suture line can be made without major problems after the excision of the lesion.

Rectal Prolapse

We recommend the transanal endoscopic rectopexy (TER) only for high-risk patients or patients with a moderate and easily reducible rectal prolapse, since this surgical procedure is still at an early stage of evaluation. In case of extended prolapse and for young patients, we prefer the laparoscopic rectopexy.

Preoperative Diagnosis

For the selection of patients suitable for the TEM operation, digital rectal examination, rigid rectoscopy and, if available, endoluminal ultrasonography should be performed. The findings of the digital rectal examination can be classified according to Mason's system[3]:

CS0—soft in texture
CSI—freely mobile
CSII—mobile
CSIII—tethered mobility
CSIV—fixed

The findings of the rectoscopy can be classified as follows:

Pedunculated polyp
Broadly pedunculated polyp
Sessile polyp, typical for adenoma
Sessile polyp, typical for carcinoma
Ulcerated polyp, typical for carcinoma

Rigid rectoscopy is important in order to measure the distance between the tumor and the anal verge and to define the tumor's circumference. These findings guide patient positioning for TEM. If the tumor is on the posterior wall the patient is placed in the lithotomy position, if it is anterior the patient is placed in the prone position, and if it is on the lateral walls the patient is placed on his side. If a carcinoma is suspected, preoperative biopsy and histologic examination should be performed, and a total colonoscopy is mandatory.

Endoluminal endosonography improves the preoperative staging of rectal tumors. Today this is the most sensitive method for determining the depth of the tumor infiltration.[8]

Preparation of the Patient

Orthograde lavage of the colon with 10 L of Ringer's solution on the day before surgery should be performed. At the beginning of the operation a single dose of combined-antibiotic prophylaxis is administered.

Anesthesia

TEM can be performed under general or epidural anesthesia.

Technique of TEM[9–11]

Patient Positioning

Depending on the location of the tumor, the patient is placed in a lithotomy, prone, or lateral position.

Equipment Requirements

Operating Rectoscope

The rectoscope, developed in cooperation with the Richard Wolf Company, Knittlingen, FRG, has an outer diameter of 40 mm and a length of either 12 or 20 cm (Figure 18.2.1). It is introduced into the rectum using an atraumatic obturator. The obturator is then removed and

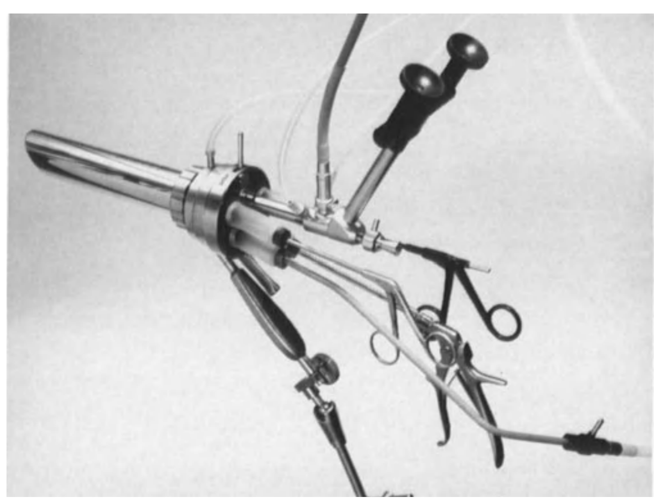

FIGURE 18.2.1. Operating rectoscope.

a glass window with a light source is inserted. The tumor is visualized by manual air insufflation, as in conventional rectoscopy. After the best view is obtained, the rectoscope is fixed to the operating table by the Martin arm (Figure 18.2.2), a double-ball-joint supporting instrument, which can be locked in any position by a screw. Now the glass window is replaced by the working insert. The working insert has four ports for the instruments, closed off by sealing sleeves and various sealing caps, and a fifth port with a locking device for the stereoscopic telescope.

Stereoscopic Telescope

The stereoscopic telescope provides a three-dimensional image magnified as much as sixfold. A third rigid eyepiece, which is angled to the bottom, can be connected to a single-view flexible teaching scope or a video camera. Channels for rinsing the front lens—important in case of spurting hemorrhage—and for CO_2 insufflation are integrated into the optics (Figure 18.2.3).

Surgical Instruments

The instrument set includes forceps and scissors angled to the right and to the left, a high-frequency knife, a suction device, a needle holder, and a clip applier. The forceps, the needle holder, the suction device, and the tip of the high-frequency knife are bent slightly downwards to better access the sacral cavity (Figure 18.2.4). The clip applier places a silver clip on the suture as a substitute for a surgical knot. After the resorption of the suture material (polydioxanone), the silver clips are passed with the feces.

Combined Endosurgical Unit

Optimal exposure of the operative field is achieved by automatic pressure-controlled gas insufflation. If the endoluminal pressure drops below the predetermined value, which is usually about 15 mm Hg, automatic insufflation commences at a maximum flow rate of 4 L/min. The use of the suction device especially may cause a rapid loss of rectal pressure and lead to a loss of visual control. For this reason a special roller pump is used that has a maximum suction capacity well below the maximum insufflation rate of the combined endosurgical unit, thus ensuring constant rectal wall dilatation even during maximal suction. A water rinse for the optic is also integrated (Figure 18.2.5). Because of the rectum's small lumen, conventional laparoscopic insufflators are not suitable for rectal operations.

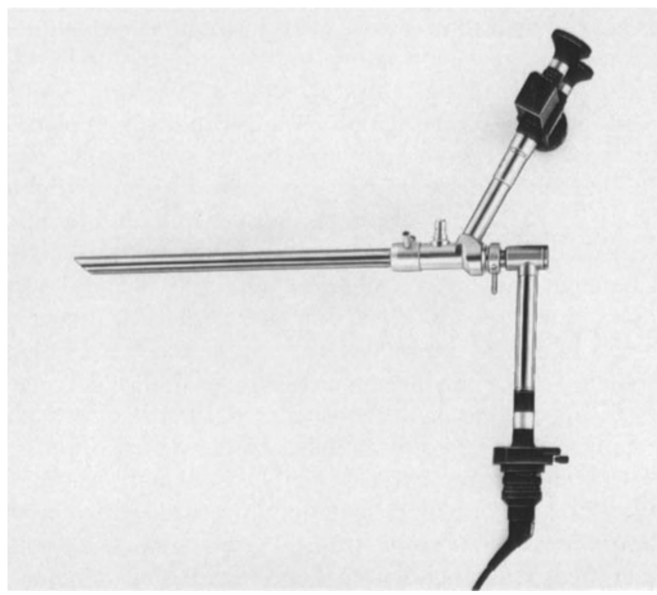

FIGURE 18.2.3. Stereoscopic telescope with a third eyepiece for the connection with the camera.

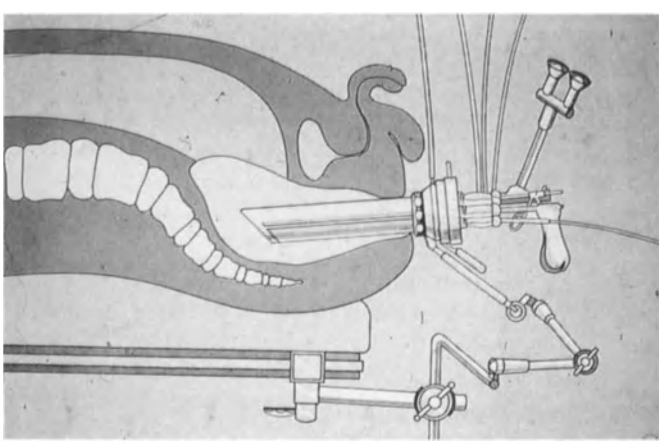

FIGURE 18.2.2. Rectoscope attached to the operating table by the Martin arm. Rectal cavity is dilated by constant CO_2 insufflation.

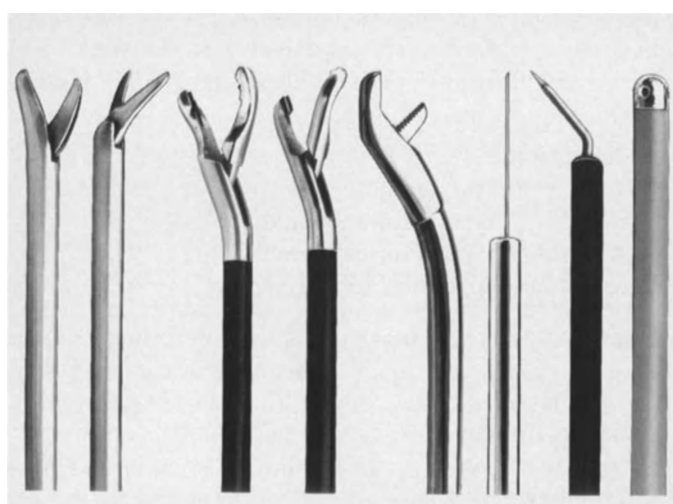

FIGURE 18.2.4. Instrument set.

FIGURE 18.2.5. Combined endosurgical unit. Besides channels for measuring intrarectal pressure and gas insufflation flow rate, there are channels for optic rinsing and suction.

Details of Technique

The patient is positioned on the operating table in such a way that the tumor is at the bottom of the operative field. The operating rectoscope is introduced with an obturator, the viewing window is placed, the area to be excised is exposed, and the rectoscope is fixed in a stable working position. Now the viewing window is replaced by the working insert and the stereoscopic telescope, and the instruments are introduced. If the surgeon is right-handed, the left upper port is reserved for the forceps, sealed with a red cap; the right upper port holds the high-frequency knife, also sealed with a red cap; the left lower port accommodates the suction probe, sealed with a gray cap; and finally, the right lower port is sealed off with a solid red cap. Then the connection tubes to the combined endosurgical unit are established, and the video system's camera is connected to the third eyepiece of the optic.

Resection begins by marking the safety margin around the rectal tumor with coagulation dots made with a high-frequency knife (Figure 18.2.6). We recommend a safety margin of 5 mm for adenomas and 10 mm for carcinomas. Different dissection techniques can then be used. The full thickness of all tumors located extraperitoneally is excised. This is also mandatory for all carcinomas. During the full-thickness operation for carcinomas, pararectal fatty tissue with lymph nodes can also be removed. TEM is not indicated for patients with carcinomas located higher than 12 cm on the anterior wall, higher than 15 cm on the lateral wall, and higher than 20 cm on the posterior wall, because of the gas loss into the opened peritoneal cavity following full-thickness excision. For the same reason, all adenomas of the intraperitoneal part of the rectum are resected by the mucosectomy or partial wall excision technique to prevent the opening of the peritoneum and the associated problems.

If the tumor is located on the anterior wall, caution is advised because of the proximity to the vagina (rectovaginal fistula) or the prostate (hemorrhage).

In cases of circumferential tumors, segmental resection can be performed, followed by end-to-end anastomosis.

After excision of the tumor, the defect is closed with 3–0 monofilament resorbable suture using the transverse continuous technique and beginning at the right edge of the wound. A silver clip substitutes for the conventional knot.

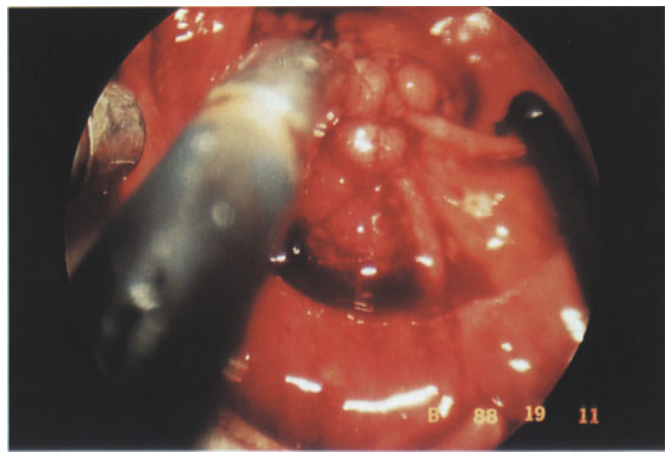

FIGURE 18.2.6. Marking of the resection line by coagulation dots. Forceps holding the adenoma on the left; suction device and a coagulation dot at three o'clock on the right.

The specimen is pinned to a cork plate with a 1-cm grid for documentation of its extent and its safety margins and to prepare it for the histologic work-up that allows it to be assigned a Hermanek classification (Figure 18.2.7).

Mucosectomy

In mucosectomy, the mucosa, including the polyp, is removed from the muscularis mucosae. This procedure must be performed with as much magnification as possible to prevent a too-deep excision. Mucosectomy should only be used for polyps smaller than 3 cm because malignant degeneration—not discovered preoperatively—can be expected in a high percentage of polyps larger than 3 cm (Figure 18.2.8A–D).

Partial Wall Excision

Partial wall excision is a modified mucosectomy, with additional resection of the superficial fibers of the muscularis propria. Partial wall excision is performed in the

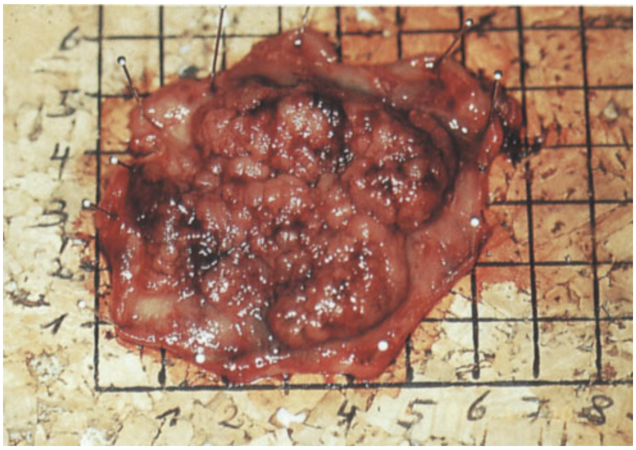

FIGURE 18.2.7. Specimen (villous adenoma) pinned to a cork plate.

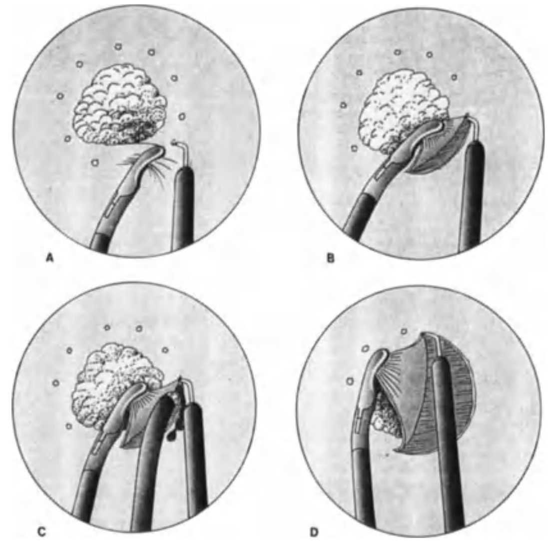

FIGURE 18.2.8. (A–D) Steps of a mucosectomy.

cases of large polyps located intraperitoneally or tumors that are close to the anal verge.

Full-Thickness Excision

When full-thickness excision is performed, pararectal tissue with lymph nodes can also be removed if a carcinoma was diagnosed preoperatively. We recommend that all extraperitoneal tumors be treated by full-thickness excision. Bleeding occurs particularly often during this procedure. After aspiration and detection of the source of bleeding, vessels smaller than about 1 mm are directly coagulated by the suction device, whereas larger vessels are grasped with the forceps and then coagulated (Figure 18.2.9A, B). If the peritoneum is inadvertently opened, the defect must be closed immediately to prevent further gas loss into the abdominal cavity and reduction of the pneumoperitoneum.

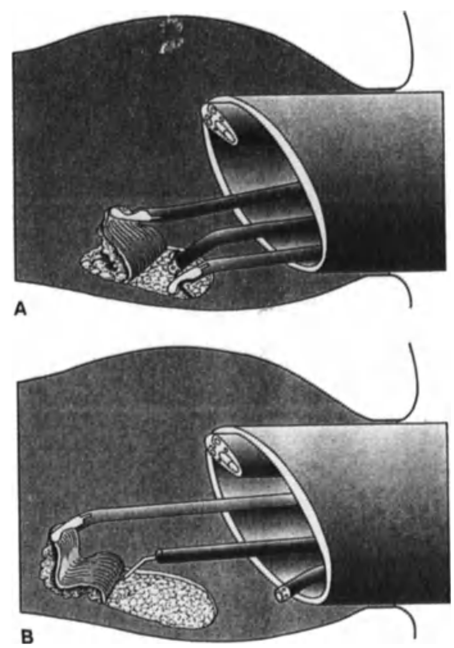

FIGURE 18.2.9. (A, B) Steps of a full-thickness excision.

Segmental Resection

Since the segmental resection, used for circumferential tumors in the middle third of the rectum, requires extreme upward angling of the rectoscope, it should only be performed by a very experienced endoscopic surgeon.

TER

In TER, the posterior wall of the middle third of the rectum is divided, about 5 cm of the presacral ligaments is exposed, and the posterior upper third of the rectum is attached to these structures with U-shaped sutures. After two or three stitches are placed in this manner, the rectal incision is again closed by the transverse continuous suturing technique (Figure 18.2.10A, B). We recommend TER only for moderate and easy reducible prolapses.

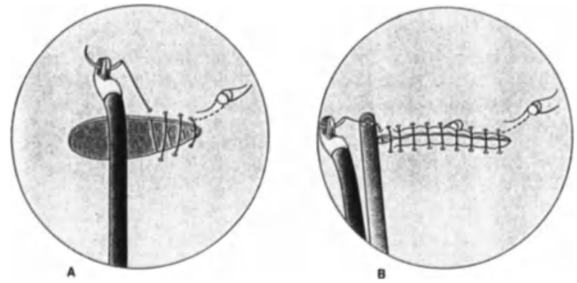

FIGURE 18.2.10. (A, B) Defect suturing in TEM.

Postoperative Care

After mucosectomy, patients are given clear liquids on the first postoperative day and regular meals on the second day; they can be discharged from the third on. After full-thickness excision, the patients are given IV fluids and clear liquids on the first and second postoperative days and on the third day progress from full liquids to normal diet; they may be discharged from the fourth day on.

Wound dehiscence must be strongly suspected if the temperature rises above 38.5°C or pyrexia continues for more than four days. If dehiscence is documented by rectoscopy or a water-soluble contrast enema, IV fluids and antibiotic therapy are started.

Adenomas are followed up annually by alternate rectoscopy and colonoscopy. Follow-up examinations after excision of carcinomas are performed every three months during the first two postoperative years, then every six months until the sixth year, and finally every year.

Clinical Results

Between July 1983 and September 1990 we performed 314 TEM operations at the university hospitals of Cologne, Mainz, and Tübingen, FRG. Histological work-up revealed 227 adenomas, 74 carcinomas, four carcinoids, three hyperplastic polyps, and one malignant lymphoma. Additionally, one rectal ulcer was excised and four rectal prolapses were corrected.

The data presented here come from a prospective study conducted at the university hospitals of Mainz and Cologne from 1983 to 1989.[12,13] During this period 137 adenomas and 49 carcinomas were treated by TEM.

Average Age

The average age of the patients with adenomas was 63.7 years, and of patients with carcinomas was 68.5 years.

Previous Operations

Of the patients with adenomas, 40% had undergone snare resection and 10% had undergone surgical removal. Of the patients with carcinomas, 29% had already been treated with electrosnare and 6% had been treated surgically.

Symptoms

Of the 137 patients with adenomas, 63 had rectal blood discharge and 24 had mucosal discharge. Diarrhea was present in 20 patients. In contrast, most of the patients with carcinoma complained of pain.

Location of Tumors

The majority of the tumors were located in the middle third of the rectum. The deepest was 24 cm from the anocutaneous line.

Excision Technique

Adenomas as well as carcinomas were mostly treated by full-thickness excision. In 13 of 49 carcinomas the retrorectal fat was removed with the specimen.

Duration of the Operation

The average operating time was 84 minutes. The time was related to the type of procedure. Adenomas 3 cm in diameter usually required less than 1 hour, whereas a segmental resection required twice as long.

Complications

Adenomas

The postoperative complication rate in 137 operations was 5% (see Table 18.2.1). Postoperative stenoses, which occurred in five patients, were successfully treated by bouginage. Micturation difficulties were encountered relatively often but usually disappeared after 24 hours. They may result from compression of the urethra by the operating rectoscope. In most cases a single catheterization was sufficient.

Carcinomas

Suture dehiscence was encountered in two carcinoma patients (see Table 18.2.2). One required temporary protective colostomy, and the other was treated conservatively.

TABLE 18.2.1. Intra- and postoperative complications of patients with adenomas (n = 137).

Complication	No. of patients	Therapy
Intraoperative:		
Extended peritoneal perforation	1	Anterior resection
Postoperative:		
Embolic lung (fatal)	1	—
Suture dehiscence	2	Conservative
Rectoileal fistula	1	Conservative
Perianal bleeding	3	Transfusion (1) Repair of suture under anesthesia (1) Rectoscopic coagulation (1)
Temporary retention of urine	5	Catheterization
Stenosis	5	Bouginage

Rectovaginal fistulas were also observed in two patients. One required a temporary colostomy, but the histologic studies of the other patient revealed a pT2 carcinoma necessitating abdominoperineal rectum extirpation.

Incontinence

Partial incontinence is frequent during the first few postoperative days. Usually it resolves after one week. However, in one patient stool incontinence persisted five months postoperatively.

Histology

Size of the Specimen

For adenomas the average specimen was 17.7 cm², and the mean tumor area was 11.7 cm². For carcinomas, the average specimen was 19.7 cm² and the mean tumor area was 10.4 cm². The larger difference between the specimen size and the tumor size in the case of carcinomas was due to larger safety margins.

Staging and Grading

G1-stage adenomas were found in 17, G2 in 96, and G3 in 24 cases. Of the 49 carcinomas, only 16 were diagnosed preoperatively. In all other cases the carcinomas were found incidently. In 40 out of 49 cases the tumor was restricted to the mucosal layer (pT1), in 37 out of these 40 cases it was graded G1 or G2 (pT1 low-risk), and in 3 cases it was graded G3 (pT1 high-risk). Seven patients had pT2 and two had pT3 tumors.

During the removal of retrorectal fatty tissue in five patients with carcinoma, a total of nine lymph nodes were removed. None of them contained metastasis.

In four cases it was histologically questionable whether the safety margins were free of tumor tissue. In three of these four cases no malignant cells were detected after a subsequent resection.

Re-Resection after Local Excision

One of the seven patients with pT2 and one of the patients with pT3 carcinoma were re-resected without finding lymph-node metastasis. The other patients refused a second operation or were high-risk patients who were not candidates for one.

TABLE 18.2.2. Postoperative complications in patients with carcinomas (n = 49).

Complication	No. of patients	Therapy
Incontinence	1	—
Apoplexy	1	—
Suture dehiscence	2	Temporary colostomy (1) Conservative (1)
Rectovaginal fistula	2	Temporary colostomy (1) Extirpation (T2 tumor)
Perianal bleeding	1	Rectoscopic coagulation
Stenosis	2	Bouginage

Recurrence Rate

Currently we have detected seven recurrences of adenomas and 10 new polyps in areas other than the operative ones. Surgical intervention was necessary in only three patients (2%). Of the 25 patients with pT1 low-risk carcinomas, only one has developed an extensive local recurrence and liver metastasis. When evaluation of the original specimen was repeated, it showed that the resection had not been complete. In two out of the three high-risk carcinomas, local recurrences were detected and treated by a radical re-operation. Of the seven pT2 carcinomas, one had a recurrence, also treated by a radical operation.

Comparison to Open Technique

The superiority of TEM to conventional techniques in terms of recurrence and complication and mortality rates has already been proved in the treatment of sessile adenomas and low-risk carcinomas (see Table 18.2.3).

Since the functional results had not been examined, we conducted a prospective study to assess pre- and postoperative anal-sphincter function in patients who had undergone TEM.[22] Between April 1991 and March 1992, 50 patients who underwent TEM at the University Hospital of Tübingen, FRG, were examined preoperatively and three months postoperatively by rectoanal perfusion manometry and a standardized interview regarding defecation and incontinence. Although the anal resting pressure and maximum squeeze pressure measured by rectoanal perfusion manometry were lower three months postoperatively, the standardized interview indicated that continence, in general, was restored to preoperative levels.

TABLE 18.2.3. Comparison of operation techniques.

Operation technique	Parks	Kraske	Mason	Anterior resection	TEM
Recurrence rate	17.3%[2]	5.5%[2]	3.3%[3]	2.6%[6]	5.0%[1]
Fistula	0%[5]	18.8%[3]	7.4%[3]	4.6%[4]	1.6%[1]
Infection	1.6%[5]	22.2%[3]	2.2%[3]	11.6%[4]	1.6%[1]
Mortality	0.4%[5]	1.7%[3]	1.3%[3]	4.8%[4]	0.3%[1]

[1]Buess et al.[16,17]
[2]Häring, Karavias, and Konradt.[15]
[3]Schildberg and Wenk.[14]
[4]Gall and Hermanek.[18]
[5]Wedell et al. and Galandiuk et al.[19,20]
[6]Heald and Ryall.[21]

Only incontinence for gas could be documented and then only in a few cases. The postoperatively higher incidence of urge incontinence and the increased frequency of bowel movements indicated diminished rectal capacity after TEM. The rectoanal inhibitory reflex, which leads to relaxation of the internal anal sphincter after distention of the rectal wall and is thus an important factor in continence and controlled defecation, was preserved in 54%. In contrast, after anterior resection this reflex was absent in 80 to 100%.

In conclusion, transanal endoscopic microsurgery temporarily alters anal-sphincter function in most patients, but the preoperative condition is restored three months postoperatively. This is a further respect in which TEM is superior to conventional techniques and confirms its status as the treatment of choice for sessile adenomas and low-risk carcinomas.

Discussion

Local resection for the treatment of sessile adenomas and pT1 carcinomas is now well accepted, because of the pathologic studies of Morson and Hermanek.[6,7] Access to the rectal cavity can be achieved transanally (Parks), posteriorly (Mason, Kraske), or anteriorly with anterior resection of the rectum. Anterior resection necessitates a large abdominal opening, but in the posterior approaches important functional structures must be divided before the tumor is accessible. All these techniques are restricted to special areas in the rectum. TEM, with its constant gas dilatation of the rectum and magnified stereoscopic view, allows precise dissection up to a depth of 25 cm.

TEM has the additional advantage over Parks's method of a low recurrence rate and, over other conventional methods, of lower complication rates and good functional results.[14–22]

The disadvantages of TEM are, first, that this advanced technology requires relatively expensive instruments and, second, this technique is more difficult than laparoscopic cholecystectomy because freedom of movement is limited and special training is therefore mandatory. We offer video-supported intensive training courses using phantom models at the University of Tübingen.[23] To maintain the skills of the surgeons and the nurses, a relatively heavy case load is advantageous, such as is provided by colorectal centers.

In the future, TEM will be optimized by bipolar techniques and combination instruments that we are developing together with The Erbe Electromedicine Company, Tübingen, FRG. The instruments combine suction, rinsing, coagulation, and cutting, reducing operating time and the time it takes to repair a spurting hemorrhage.[24,25]

Conclusion

TEM is the treatment of choice for sessile adenomas and pT1 low-risk carcinomas, because, as a minimally invasive technique, it avoids incisions and the division of vital structures and therefore results in minimal complication and recurrence rates, less postoperative pain, shorter hospitalization, and better cosmetic results than conventional techniques. In patients with pT2 or pT3 carcinomas, TEM should be restricted to old or high-risk patients.

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19
Laparoscopic Staging of Malignancies

Frederick L. Greene

Although laparoscopic techniques were first used for the treatment of abdominal malignancy in the late nineteenth and early twentieth centuries, it is only because of the excitement generated by therapeutic laparoscopy in the past 10 years that this endoscopic modality is once again being considered for the staging and management of patients with abdominal malignancy. Beginning in the 1920s and 1930s, a concerted effort was made by physicians throughout the world to develop a staging system that would allow a "world-wide dialogue" about the interpretation and classification of solid tumors. This work was crystallized by Pierre Denoix in the 1940s, who first advanced the concepts of the tumor, node, metastasis (TNM) system.[1] During the 1940s and 1950s, further work was done by committees throughout the world on both the clinical and the pathologic staging of cancer. Throughout the 1960s and 1970s, staging systems were in use (i.e., Dukes's system for colorectal cancer), but the language of cancer staging was not really delivered from the "land of Babel" until the 1980s when the decision was made by committees of the International Union Against Cancer (UICC) and the American Joint Committee on Cancer (AJCC) to adopt a system based on tumor status, nodal involvement, and metastatic findings (TNM).[2]

The development of the TNM system and the rebirth of laparoscopy occurred almost simultaneously. As a result of this rebirth, endoscopic staging can, in fact, complement other modalities, such as computerized tomography, ultrasound, nuclear medicine scanning, and magnetic resonance imaging. It is also important to realize that the goal of pathologic staging has generally been to determine the advisability of open surgical procedures on the major body cavities. It is becoming clear that many patients who may not benefit from major extirpative procedures may derive benefit from palliative nonoperative procedures. The laparoscope can be understood as a tool that will allow safe retrieval of pathologic material and the performance of palliative procedures in the management of cancer patients.

Historical Overview

The first documented examination of the abdominal cavity by laparoscopy was by Ott in 1901.[3] The work of this Russian gynecologist predated the work of Kelling of Dresden, who utilized a cystoscope to evaluate the abdominal cavity of dogs.[4] These early pioneers realized that the only way the abdominal cavity could be visualized was if techniques were developed to expand the abdominal wall, allowing the safe introduction of optical devices. During the early twentieth century, the concept of the pneumoperitoneum was developed, which led to the work of Jacobaeus, who introduced the term, "laparoscopy."[5] In addition, Jacobaeus first described the diagnosis of cirrhosis, metastatic tumors, and tuberculous peritonitis using the laparoscope. During the next two decades, laparoscopy was introduced into the United States by Bernheim.[6] Although the technique had potential, visualization was hampered by limited optics. Later, Ruddock advocated "peritoneoscopy" and demonstrated improvements in diagnostic accuracy.[7] The further application of laparoscopic techniques to abdominal cancer was reported by Benedict, who discovered that gastric and colonic neoplasms together with gynecologic disease were causes of ascites.[8] The safety of pneumoperitoneum was improved when Fervers advocated the use of oxygen or carbon dioxide rather than room air in the 1930s.[9] Greater safety in the instillation of gas was achieved by Veress who developed a spring-loaded needle that could safely be introduced into the peritoneal cavity in the late 1930s.[10]

Since then the application of laparoscopic techniques to routine cholecystectomy, appendectomy, and other classical operations of the abdominal cavity have led to the development of videoendoscopy and high-resolution television monitors. Today's outstanding optical resolution allows for safer inspection and biopsy in cancer patients and more complete interpretation of abdominal findings.

Patient Selection and Monitoring

Although diagnostic laparoscopy has an associated morbidity and mortality, problems can be limited by careful selection of patients. Several studies have documented adverse cardiopulmonary effects of pneumoperitoneum[11–13] and, therefore, it is important to carefully screen patients who have underlying pulmonary and cardiac disease. Since many older patients with potential neoplasms have associated chronic obstructive pulmonary disease and coronary artery disease a full work-up including appropriate laboratory and imaging studies should be done prior to diagnostic laparoscopy. Similarly, laboratory evaluation for coagulation defects is extremely important, especially in patients who may be nutritionally depleted or have underlying liver disease. Patients who have an elevated partial thromboplastin time or protime will require fresh frozen plasma or vitamin K to correct these defects. It is also important to assess the platelet count preoperatively and to achieve platelet levels of at least 20,000 to 30,000 per mm^3 prior to diagnostic laparoscopy.

Although abdominal assessment for cancer may be achieved without laparoscopy, this technique will be helpful when studies have been unrevealing or equivocal. Patients with unexplained ascites, abdominal pain, weight loss, or palpable masses would be better treated with early laparoscopy and directed biopsy than with multiple scans and blind biopsies.

Throughout the last several decades, there have been advocates for the use of local anesthesia during diagnostic laparoscopy.[14] This would certainly be appropriate in cooperative patients where limited inspection is anticipated. It is our view that general anesthesia is necessary to achieve proper abdominal relaxation, to create an adequate pneumoperitoneum, to permit appropriate monitoring of patients, and to allow the surgeon to undertake unhurried inspection and biopsy. Because of the use of general anesthesia, it is critical that patients undergo laboratory, cardiac, and pulmonary evaluation before surgery to avoid problems related to the additive effects of general anesthesia and creation of a pneumoperitoneum.

Monitoring during laparoscopy should include electrocardiographic monitoring, end-tidal CO_2 monitoring, blood-pressure evaluation using either a cuff or an indwelling arterial line, and bladder catheter that allows the urine output to be evaluated and decompression of the bladder for trocar insertion. A nasogastric or orogastric tube should routinely be passed, in order to facilitate gastric emptying during the procedure. If previous studies, such as computerized tomograms or ultrasound studies, have been obtained, these should be readily available in the operating room so that the surgeon can use them to determine the site of trocar insertion that will minimize potential injury and untoward results.

The surgeon endoscopist who undertakes laparoscopic examination should also have available accessories needed for biopsy or cytologic studies. Acquaintance with two-and three-trocar approaches will also be helpful, depending on the information to be obtained. A percutaneous core biopsy needle should be available if directed biopsy is anticipated. The primary accessory instruments required for diagnostic laparoscopy are: noncrushing biopsy forceps; atraumatic graspers for manipulation of bowel and omentum; intra-abdominal retractors for lifting hepatic lobes; or, if the retrogastric area is entered, the stomach, and the usual array of equipment for controlling bleeding resulting from biopsy. In addition, either elastic stockings, leg wraps, or sequential compression stockings should be applied to reduce the risk of venous stasis, especially when the patient is in the steep reverse Trendelenburg position. It is also important to position the feet at a 90° angle on a footboard to avoid neurologic injury during prolonged laparoscopic examination.

Techniques of Diagnostic Laparoscopy

The choice of an insertion site for the trocar to be used in the creation of the pneumoperitoneum depends on whether there are healed abdominal incisions, abdominal masses, organomegaly, or ascites. The Veress needle is used for most patients, but we prefer an open technique using the Hasson cannula, especially if the patient has had other operations. The periumbilical approach is usually selected, but evaluation of the abdomen with ultrasound may indicate the presence of intra-abdominal adhesions that make an alternative trocar site more attractive. If ascites is present, the classic Trendelenburg position for establishment of pneumoperitoneum must be avoided. It is suggested that the patient be placed in reverse Trendelenburg position; the gastrointestinal contents will float cephalad on the surface of the ascitic fluid, which will cushion them during the introduction of the needle into the pelvis. Carbon dioxide should be introduced above the level of ascitic fluid to avoid bubbles, which can be created when CO_2 is introduced directly into the ascitic collection. Drainage of ascitic fluid prior to the introduction of CO_2 is recommended.

Careful inspection is the first phase of a diagnostic laparoscopic exam for malignancy as of any laparoscopic procedure. This inspection may uncover small lesions on the surface of the intestinal serosa or other organs that the laparoscopist may wish to biopsy. By changing the position of the operating table, the small bowel may be repositioned to allow identification of the spleen. This maneuver is extremely helpful in the full evaluation of abdominal lymphoma. The patient may be placed in the right semilateral decubitus position, which allows for complete evaluation of the greater curvature of the stomach, the esophageal hiatus, and the spleen and also facilitates approach to the retroperitoneum through the gastrohepatic omentum.

It is vital to take the time to perform an adequate inspection of the entire abdominal cavity, including diaphragmatic surfaces, the hepatic surface, regions of the right and left colonic gutters, and the pelvic peritoneum, including the pouch of Douglas. Small collections of fluid should be aspirated and sent for routine cytologic identification. This is especially true in patients with pancreatic carcinoma, because small fluid collections will be positive in at least 40% of patients who have evidence of a localized pancreatic neoplasm.[15] Once the entire abdominal cavity is inspected, and the small bowel mobilized so that the mesenteric surfaces can be evaluated, the patient may be placed in various positions that allow gravity to assist in the mobilization of the intra-abdominal contents for better inspection. Repositioning is especially helpful in the inspection and eventual dissection of the retroperitoneum. Tilting the table right-side down facilitates the approach to the left lobe of the liver, the greater curvature of the stomach, the peripancreatic area, and the spleen. Repositioning may also facilitate biopsy and aspiration of the ascitic fluid.

In the absence of ascites, peritoneal washing may help to retrieve malignant cells that will provide additional information about metastatic disease in the peritoneal cavity. A solution of normal saline (500 to 1,000 mL) is instilled into the peritoneal cavity, and the patient is moved to direct flow into all areas of the abdomen. Aliquots of this fluid may be removed from several locations in the peritoneal cavity and sent for cytologic study.

It is important for the surgeon laparoscopist to be prepared to approach the retrogastric area as well as to sample nodes from the retroperitoneum if this is appropriate. Placement of two or three additional trocars may be necessary to facilitate retraction of both the stomach and the transverse colon to allow safe entrance into the gastrohepatic omentum and inspection of the body and tail of the pancreas and the hilum of the spleen. Utilizing this approach, the celiac axis may be inspected. Biopsy or entire nodal dissection can be achieved through a retrogastric approach.

Laparoscopic Staging of Gastrointestinal Tumors

Laparoscopy may be useful either prior to a definitive diagnosis of cancer or following the discovery of a specific gastrointestinal tumor. Currently, debate centers on whether laparoscopy should be a routine part of the preoperative staging of patients with esophageal, gastric, hepatic, or pancreatic carcinoma. There is ample evidence to suggest that the sensitivity and specificity of laparoscopic examination of the abdomen surpasses that of the usual imaging technologies, such as computerized tomography and abdominal ultrasound.[16] It is our view, however, that laparoscopic diagnosis and evaluation should be done only if this procedure will, in fact, influence the management of the disease. If diffuse disease is identified, for example, a palliative nonoperative approach might be more appropriate than open extirpative surgery.

It has become evident that five-year survivals are unobtainable for most patients with esophageal carcinoma, especially if periesophageal nodal disease is present. The use of radiation and chemotherapy to palliate disease, together with endoscopic techniques to relieve esophageal obstruction, have become important in the management of patients with esophageal cancer and have reduced the number of patients undergoing palliative esophagectomy.[17] It is important, however, to continue to identify patients with early esophageal cancer. Diagnostic laparoscopy should be done to identify that subset of patients without evidence of diffuse disease who will, in fact, benefit from major esophageal resection and reconstruction. When evaluating patients with esophageal carcinoma, it is important to remember that although patients with primary tumors of the proximal or middle third of the esophagus may appear to have localized disease, because of the rich plexus of lymphatics and blood vessels, nodal draining areas surrounding the celiac axis and gastroesophageal junction are frequently involved at the time that patients present. In addition, the number of patients presenting with adenocarcinoma of the esophagus, especially of the lower one-third and the area of the gastroesophageal junction is increasing.[18] These patients will manifest early nodal disease, especially in the perigastric and peripancreatic areas.

Some have advocated routine diagnostic laparoscopy for evaluation of gastric carcinoma,[19] but the best palliation for patients with neoplasia of the stomach may, in fact, be resection with appropriate reconstruction of the upper gastrointestinal tract. Patients in Western countries usually present late in the course of gastric cancer, which condemns most of them to poor survival because both metastatic and nodal disease are present at the time of initial evaluation. Occasionally, there are patients with vague abdominal complaints and small gastric tumors who may benefit from chemotherapy and local resection, especially when diffuse peritoneal disease is found laparoscopically. This approach also allows for enteral feeding tubes to be placed when open procedures are not anticipated.

Primary pancreatobiliary cancer is an ideal opportunity for diagnostic laparoscopy, especially in light of the possibility that adequate palliation can be achieved by other endoscopic means (e.g., endoscopic retrograde cholangiopancreatography (ERCP) and stent placement), thereby avoiding open procedures and large transabdominal incisions.[20] The goal of laparoscopic diagnosis is to identify patients who have small cancer implants that are remote from the primary tumor, which indicates that resection of the tumor would not be curative. As has been mentioned, small collections of fluid may provide evidence that cancer cells are in fact present throughout the abdominal cavity. Lavage studies have indicated that as many as 40% of patients with pancreatic carcinoma already have diffuse peritoneal disease at the time of presentation.[15] Diagnostic laparoscopy, while not suitable for definitive diagnosis of pancreatic carcinoma, may indirectly lead to a correct assessment when biopsy of metastatic implants suggests that a pancreatic primary is present. Attempts to mobilize the duodenum may give indirect evidence of a mass in the paraduodenal or retrocaval area. A CT scan may then confirm the mass has major vascular involvement and is inoperable. Careful evaluation of the entire liver is also mandatory when staging pancreatic carcinoma. Biopsies should be performed utilizing cupped forceps and core needles when hepatic lesions are found.

The main indication for laparoscopic intervention may be that histologic specimens are needed. If liver specimens are needed, the entire liver must be examined carefully, and the left lateral lobe of the liver must be mobilized to ensure that the region of the triangular ligament is free of lesions. Biopsy may be routinely performed through alternative trocar sites or by direct puncture of the abdominal wall with a biopsy needle. The "guillotine-type" needles, which are very effective for biopsy of liver and other solid organs, may be passed directly through the abdominal wall over the organ, providing a safe and targeted biopsy. In a similar fashion, specimens for cytology may be taken from nodal tissue or solid organs with a needle and syringe. In patients with cirrhosis, careful assessment of the liver surface is necessary to allow for safe biopsy. Many patients with cirrhosis have surface varices that, when inappropriately biopsied, could lead to significant hemorrhage.

Cupped forceps allow larger specimens to be removed without causing a crush artifact. Peritoneal implants may be directly biopsied using sharp dissection techniques, and portions of tissue removed for pathologic investigation. It is important not to overuse electrocautery in dissecting these implants, because cautery artifact may interfere with full evaluation.

Currently there is no absolute indication for diagnostic laparoscopy in the evaluation of colonic or rectal malignancy. The technique may be used to select patients for extirpative operations and to differentiate them from those with small rectal tumors that could be treated by localized excism. A finding of peritoneal implants during diagnostic laparoscopy would also be an argument against extirpative surgery. It would be inappropriate to subject a patient to a large midline incision for abdominoperineal resection if diffuse hepatic metastases and peritoneal implants are present. Such a patient could be much better treated by either fulguration or local excision of the primary rectal tumor, if appropriate. The techniques are now being developed for removing portions of the stomach utilizing the laparoscope. Prior to performing any extirpative or bypass procedure, the laparoscopic surgeon must perform an adequate examination of the entire peritoneal cavity. Laparoscopy may also play a greater role in the follow-up of patients with colorectal malignancy in the future. Follow-up laparoscopy would be attended by recognized benefits of the second-look evaluation. Despite resectioning, approximately one-half of all colorectal carcinomas will recur, most within two years of operation.[21] The pattern of recurrence depends on the initial area of tumor involvement and that of colon carcinomas differs significantly from that of rectal carcinomas. Once cancer recurs, it is unlikely that a cure will be achieved, but patients with small recurrences may still benefit from early re-operation. Utilizing tumor markers, such as carcinoembryonic antigen (CEA), and conventional imaging studies, laparoscopic evaluation in patients who have had previous abdominal surgery can be safely and efficiently performed.

Second-look laparoscopy has been reported in the gynecologic literature, especially in the evaluation of women with ovarian carcinoma. In one study of 44 second-look and 28 third-look laparoscopic examinations in 52 women with ovarian carcinoma in clinical remission nearly 50% of those studied demonstrated recurrent tumor.[22] Laparotomy showed that laparoscopic examination had a 31% false-negative rate. This certainly supports the hypothesis that small areas of tumor may, in fact, be missed in patients who have already undergone significant abdominal procedures. Currently the indications and opportunities for second-look laparoscopy, especially in colorectal cancer, are limited. A rising CEA level or clinical findings suggesting recurrence should be evaluated with routine imaging studies, including computed tomography, ultrasound, or magnetic resonance imaging (MRI). Newer imaging studies, utilizing monoclonal-antibody labels are still in the experimental phase.[23] It may be possible to develop techniques in which intra-abdominal metastases are labeled with monoclonal antibodies and then identified laparoscopically. This exciting concept will await the future development of technology and clinical trials.

Laparoscopy in the Diagnosis and Staging of Abdominal Lymphoma

Until recently, the surgeon was intimately involved in the staging of Hodgkin's disease and, to a lesser extent, non-Hodgkin's lymphoma. With the advent of high-quality computerized tomography, lymphangiography, and other imaging techniques, the surgeon has been less involved in the management of this disease process. Biopsy of peripheral nodes is still appropriate, however, and it is important to precisely stage lymphomas in order to plan appropriate radiation or chemotherapy. Asymptomatic lymphadenopathy is usually the most common presentation of both Hodgkin's and non-Hodgkin's lymphoma. Although peripheral nodes may show the presence of lymphoma, abdominal exploration has been recommended for at least 85% of patients diagnosed as having Hodgkin's disease.[24] The approach to patients with Hodgkin's disease should include serum chemistries, complete blood count, chest x-ray, and a complete computerized tomogram of the abdomen and chest. Bone-marrow biopsy is also recommended to assess the systemic presence of disease and, if present, obviates the need for aggressive abdominal staging because it makes systemic chemotherapy mandatory.

Although imaging studies have a high accuracy rate, small nodes with lymphomatous involvement are often not identified. It is reported that approximately 25 to 50% of patients who are labeled as stage I to stage IIIA (in the Ann Arbor staging system) will be reclassified based on findings at celiotomy.[25] The traditional abdominal approach includes a full exploration of the abdomen, wedge and needle biopsy of the liver, splenectomy, biopsy of periaortic nodes, and generally a bone-marrow biopsy at the time of exploration. It required a generous midline incision that had an associated morbidity. Laparoscopy together with routine imaging techniques can obviate the need for traditional celiotomy. The staging procedure is done under general anesthesia and should include careful assessment of the surface of the diaphragm as well as the pelvis. The spleen is identified and is generally better visualized with the patient right-side-down in the reverse Trendelenburg position. Although we do not favor routine splenic biopsy, this is frequently undertaken by the group at the National Tumor Institute in Milan.[26] These investigators have reported minimal complications, although there is significant likelihood of understaging disease in the spleen when doing needle biopsy. Partial splenectomy, itself, will miss the diagnosis of splenic involvement in a proportion of patients and has generally been abandoned. Although traditionally, splenectomy was recommended during celiotomy to reduce the radiation ports, especially at the level of the left kidney and lower left lung,[24] with good radiation technique, this is less of a problem today.

Percutaneous laparoscopically guided biopsy or wedge biopsy of the liver may be undertaken safely and will give valuable information about hepatic involvement in Hodgkin's disease. We generally favor needle biopsy in the right and left lobes of the liver and routinely do wedge biopsy at the edge of the right lobe of the liver. Any bleeding from the wedge biopsy may be safely contained by electrocautery or placement of sutures through the laparoscopy port. The most difficult portion of the laparoscopic staging procedure is the approach to the retroperitoneum, but this can be safely undertaken with careful dissection at the root of the mesentery or by approaching through the gastrocolic omentum, using the lesser omental bursa to approach the periaortic region. It is important to identify abnormal nodes; the entire node can then be excised or, in the case of matted nodes, a percutaneous needle biopsy or wedge excision done. It is important to have electrocautery at hand, both to avoid bleeding complications and to reduce the likelihood of lymphocele formation following biopsy. The most important consideration is to obtain adequate tissue to allow the pathologist to make an appropriate diagnosis and to classify the lymphoma. Crush artifact is to be avoided, which is why whole-node excision or wedge excision is recommended.

Conclusion

The laparoscope should play a prominent role in the diagnosis and staging of abdominal malignancy, whether it affects a solid organ, the gastrointestinal tract, or is a lymphoma. More importantly, the laparoscope should be the "access tool" for future therapeutic modalities, such as radiation therapy or chemotherapy, which could be delivered by this means precisely to the areas encompassed by tumor. Further development of appropriate biopsy forceps, core biopsy needles, and other accessories will no doubt make laparoscopic approaches easier and safer for the surgeon treating abdominal cancer.

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20
Management of Pancreatic Disease

20.1 Laparoscopic Management of Pancreatic Disease

D. Litwin and L. Rossi

Introduction

Minimal-access techniques for the diagnosis and treatment of pancreatic diseases are in a state of infancy. However, beneficial effects of this approach might include improved cosmetics, diminished pain, shorter hospitalization, and earlier return to activities of daily living—in short, the benefits demonstrated by laparoscopic cholecystectomy.[1,2] In addition, since the conventional approach to pancreatic disease is major surgery, less atelectasis and pneumonia may also be benefits of the minimal-access techniques.[3]

Laparoscopic Pancreatic Surgery

Laparoscopic procedures for pancreatic disease fall into one of three categories. They are: pancreatic resection; bilioenteric or gastroenteric anastomosis for pancreatic malignancy; and internal pseudocyst drainage.

It has become clear that virtually all intra-abdominal operative procedures can be carried out laparoscopically and operations for pancreatic disease are no exception. However, whether these operations will be routinely carried out laparoscopically has yet to be determined.

Ultimately the acceptance of many laparoscopic operations will be determined by their degree of difficulty, the operating time, the costs (both hospital and societal), and patient outcomes. At present, the experience with laparoscopic techniques for the management of pancreatic disease is too scant to draw firm conclusions.

Anatomic Considerations

The pancreas lies in a retroperitoneal position in the upper abdomen and forms part of the posterior wall of the lesser sac. For this reason the pancreas gland is not immediately visualized with the laparoscope. However, exposure of the body and tail of the pancreas through the gastrocolic omentum is relatively easy. An oblique angle (30 or 45°) telescope at the umbilicus is used for this procedure. With the patient positioned head-up and with anterior traction on the stomach, electrocautery (mono- or bipolar) can be used to divide the gastrocolic omentum and is usually adequate for the size of vessels encountered. Kocherization of the duodenum can also be carried out by dividing the peritoneum lateral to the duodenum and using a combination of sharp and blunt dissection to free the duodenum posteriorly. Angled telescopes are absolutely essential for this maneuver. It must be remembered that adequate exposure of the pancreas for complete evaluation can be exhausting even for the most experienced laparoscopic surgeon, especially in the obese patient. Also, the inability to palpate in this region may make complete assessment of the pancreas impossible. It is likely that endoscopic ultrasound will eventually play a large role in the detection of pancreatic tumors and the location of tumor margins, metastases, and pseudocysts. Ultrasound may ultimately prove to be more accurate than palpation.

Pancreatic Resection

Indications for pancreatic resection include adenocarcinoma[4] and chronic pancreatitis.[5] Whipple first described pancreaticoduodenectomy in 1935[6] and reported 41 cases in 1941.[7] Despite a mortality rate of 27% in his series of 41 patients, pancreaticoduodenectomy became accepted for the treatment of carcinoma of the head of the pancreas and carcinoma of the bile duct, ampulla of Vater, and duodenum.[4] Less commonly, pancreaticoduodenectomy is carried out for the treatment of chronic pancreatitis.[8]

Controversy exists as to whether pancreatoduodenectomy should be used for treating pancreatic adenocarcinoma. Gudjonsson found only 145 (3.5%) five-year survivors among 4,100 pancreatic resections in a comprehensive review of the literature dating back to Whipple's resections.[9] The dismal five-year survival rate following resection was coupled with a very high operative mortality rate of 18%. Recent data suggest a more favorable five-year survival rate following resection, ranging from 19 to 24%[10,11] and some subgroups fared better than others. Patients with small tumors (< 2 cm),[12] those that had no tumor encroachment on major vessels,[10] and those that had no lymph-node metastasis[11] had five-year survival rates of 30, 36, and 57%, respectively. In addition, in many specialized centers the high mortality rate historically associated with pancreaticoduodenectomy has been reduced in recent years to < 5%, and there have been corresponding decreases in morbidity.[10,13–17] Therefore, pancreaticoduodenectomy should still be considered for patients with adenocarcinoma of the pancreas and also for those with more favorable tumors.[17]

Laparoscopic techniques might also significantly reduce the morbidity and mortality associated with pancreatic resections. There is less pulmonary physiologic derangement following laparoscopic cholecystectomy than following open surgery.[2,18,19] Many studies demonstrate that acute-phase immunologic, metabolic, or hormonal responses are less severe after laparoscopic surgery.[20–22] Warshaw, in a recent review of pancreatic carcinoma, speculates that the trauma of surgery "may depress the immune response and therefore the barrier to tumor dissemination."[23] However, the reality is that although laparoscopic pancreatic resection may hold great promise, it has been incompletely evaluated.

The first laparoscopic pancreaticoduodenal resection was carried out in 1992 by M. Gagner and his colleagues at the Hotel Dieu Hospital in Montreal, Canada.[24] The procedure was carried out in a 33-year-old woman with pancreas divisum and resultant chronic pancreatitis affecting mainly the head of the pancreas. The operation took approximately 12 hours, and the patient was hospitalized for 30 days postoperatively because of a delay in gastric emptying. Subsequently two additional pancreaticoduodenectomies were carried out. The underlying pathologies in these cases were carcinoma of the ampulla of Vater and adenocarcinoma of the pancreas. Both operations took 10 to 12 hours, and the patients were hospitalized for 62 and 14 days, respectively. The second pancreaticoduodenectomy patient developed a pancreatic fistula, which closed spontaneously on total parenteral nutrition, and the final patient required laparotomy 24 hours after resection because of bleeding from the splenic hilum. Pylorus-preserving pancreaticoduodenectomy was carried out in all three patients.

The initial experience of Gagner and his colleagues indicates that laparoscopic pancreaticoduodenectomy is technically feasible. The complications experienced by Gagner are no different than those associated with conventional pancreaticoduodenectomy. Nonetheless, one may conclude that the routine performance of this operation is not desirable at the present time because of its length and complexity, which may ultimately put the patient at risk for complications. Whether this procedure is, on balance, beneficial will not be determined until more experience is obtained, and, therefore, it must be considered investigational.

Distal pancreatic resections may be considered for a variety of conditions, including chronic pancreatitis,[26] and benign and malignant tumors. Unfortunately, in the majority of cases adenocarcinoma of the body or tail of the pancreas will be unresectable at the time of diagnosis[23] and therefore distal resections are uncommon.

Distal pancreatic resection via laparoscopy is relatively straightforward. The operation was carried out without difficulty in the porcine model by Soper.[27] Gagner and his associates performed distal pancreatectomy in four patients for cystadenocarcinoma (one), insulinoma (two), and pseudocyst of the tail (one).[28] The spleen was preserved in all instances, and the operating time ranged from 2.5 to 5 hours. One patient had both distal pancreatectomy and left adrenalectomy. All cases were done with the patient in the lateral position with the left side up. The pancreas was divided with a 60-mm linear cutter. There were no significant complications.

Local excision of the ampulla of Vater was carried out laparoscopically by our group (Litwin and Rossi). Local excision has been advocated for carcinoma of the ampulla of Vater in patients who are not candidates for more extensive resections, such as pancreaticoduodenectomy.[29,30] In our patient the duodenum was mobilized, duodenotomy performed, and excision of the ampulla of Vater carried out. Sphincteroplasty of both the common bile duct and the pancreatic duct with interrupted sutures of 4–0 Vicryl was performed. The duodenotomy was then closed with the endoscopic linear cutter (Endo GIA).

The initial experience of Gagner and Litwin with complicated resections for pancreatic or ampullary malignancy suggests that these operations are technically feasible. However, at the present time the advisability of this type of surgery is debatable. As surgeons gain technical skill and adjunctive instruments become available, complex resections may yet be done routinely. Then comparisons between laparoscopic and conventional procedures will become a major issue. At the present time it is imperative that all surgeons who are expanding the frontiers of laparoscopic surgery critically appraise the impact of laparoscopy in efficiency, cost, and patient well-being.

Bilioenteric or Gastroenteric Anastomosis for Pancreatic Malignancy

Since the advent of laparoscopic cholecystectomy, the laparoscope has been used with increasing frequency by the general surgeon. This is especially true in the evaluation of intra-abdominal malignancy. Easter and Cuschieri found that laparoscopy affected the management of all 25 patients with suspected intra-abdominal malignancy they evaluated,[31] allowing them to make a firm diagnosis of cancer, to exclude cancer, to assess resectability or to document metastasis. They concluded that laparoscopy was a safe and useful diagnostic tool that should be utilized more often in the diagnosis and staging of cancer. Preoperative diagnosis and staging with laparoscopy was more thoroughly studied by Warshaw, who routinely performed diagnostic laparoscopy to assess the resectability of pancreatic adenocarcinoma.[32] In his study, 88 consecutive patients with pancreatic or ampullary adenocarcinoma were prospectively evaluated for resectability by four modalities: CT scanning, MRI, angiography, and laparoscopy. Laparoscopy and biopsy proved to be essential for the diagnosis of small liver and peritoneal metastasis and provided the evidence for the diagnosis in 22 out of 23 cases (96%). All but two of these lesions were missed by CT scans, and MRI was no better than CT. It is clear that the routine use of laparoscopy in staging pancreatic and ampullary malignancy will spare many patients the pain and prolonged hospitalization associated with unnecessary laparotomy and allow a wider range of therapeutic options to be employed, such as biliary endoprosthesis placement or laparoscopic palliative bypass (bilioenteric or gastroenteric anastomosis).

At present most patients with obstructive jaundice are managed by placing an endoscopic or percutaneous stent. The success rate is high (85%) and a low mortality is associated with this procedure (1 to 2%).[33,34] Both prospective and retrospective trials suggest that there is no difference in survival between patients who have endoscopic stent placement and patients who undergo surgical bypass for obstructive jaundice due to malignancy.[35,36] However, patients with stents have more frequent readmissions to hospital (for stent occlusion, recurrent jaundice, and cholangitis). For this reason, there is appeal to performing surgical bypass by laparoscopy. Patients who undergo laparoscopic bypass should have shorter hospitalizations than those who undergo conventional surgical bypass and may have fewer of the late complications of occlusion, jaundice, and cholangitis than patients with endoscopically placed stents. The morbidity of open surgical bypass is substantial (19%),[37] and relatively few patients are candidates for this procedure. At present it is not certain if the laparoscopic approach will change this.

Cholecystojejunostomy is an acceptable procedure in patients with pancreatic adenocarcinoma, who have a dismal prognosis and an average life expectancy of less than one year.[37] Cholecystojejunostomy may be carried out if the gallbladder is suitable for anastomosis, the cystic duct is patent, and the junction of the cystic duct and the common bile duct is far from the tumor.[38,39] Nowadays preoperative imaging by percutaneous transhepatic cholangiography or endoscopic retrograde cholangiopancreatography is usual and, therefore, this information is available prior to surgery. If it is not, cholangiography can be performed intraoperatively by placing a Veress needle into the gallbladder, aspirating a small amount of bile, and injecting contrast.[38]

Laparoscopic cholecystojejunostomy has been reported by Shimi and colleagues in five patients.[38] Hand sewn anastomosis was carried out between the gallbladder and a jejunal loop in four instances, and a combined hand sewn/stapled anastomosis was carried out in one patient. In all cases, cholangiography was done to demonstrate cystic-duct patency. Relief of jaundice occurred immediately in four patients. One patient developed cholangitis secondary to obstruction of the cholecystojejunostomy by debris. After cholecystostomy with evacuation of the debris, the jaundice resolved.

Our approach has been to perform cholecystoenterostomy utilizing the 30-mm endoscopic linear cutter (Endo GIA) to create the entire anastomosis (Figures 20.1.1–20.1.4). This was carried out in four patients with obstructive jaundice secondary to adenocarcinoma of the pancreas. The cholecystoenterostomy took less than an hour in all cases. In two patients gastrojejunostomy was also performed. The cholecystojejunostomies functioned successfully until death (longest survival was six months).

Gagner has approached the problem of jaundice associated with malignant obstruction in an innovative way.[41] His team has carried out hepaticogastrostomy from a segment-II or a segment-III hepatic duct to the stomach with the aid of a PEG tube. In this procedure percutaneous access to the biliary tree is established by the radiologist, and a guidewire is placed in the segment-II or III duct. The patient is transferred to the operating room, where staging laparoscopy is carried out. The wire is exchanged for a needle, which is used to perforate the

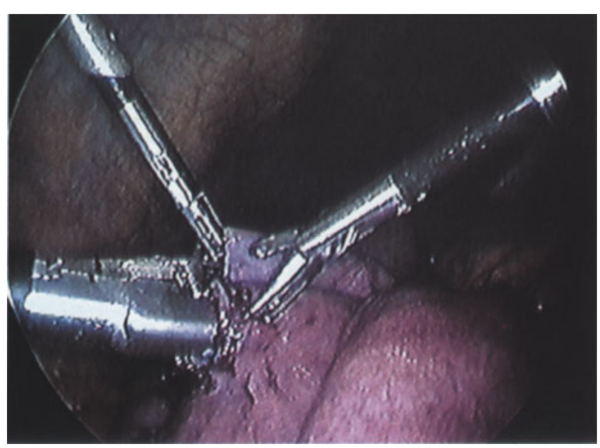

FIGURE 20.1.1. Laparoscopic cholecystojejunostomy. A small hole is made in the gallbladder and small intestine, the blades of the Endo GIA are advanced into the two lumens from the patient's right, and it is fired.

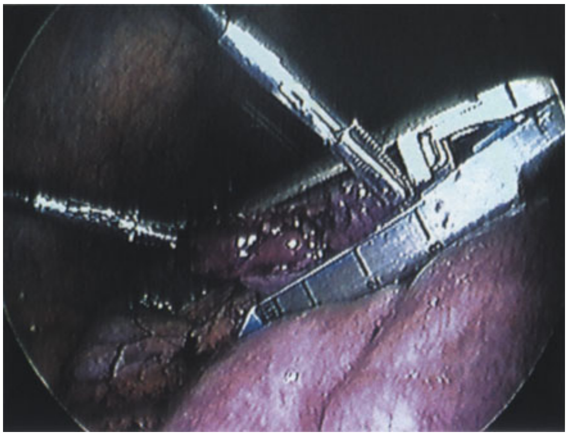

FIGURE 20.1.2. Laparoscopic cholecystojejunostomy. The Endo GIA is passed from the patient's left to close the opening.

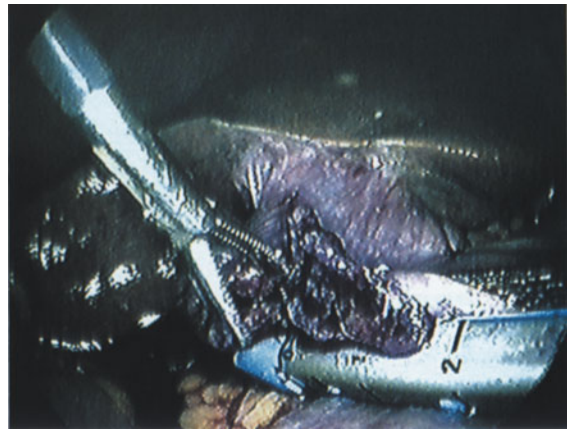

FIGURE 20.1.3. Laparoscopic cholecystojejunostomy. The Endo GIA is fired.

capsule of the inferior part of segment II or III. The needle is guided into the stomach through the lesser curvature and then exchanged for a guidewire. The guidewire is grasped by a snare and brought out through the mouth, where it is attached to a PEG tube. The tube is then pulled down into the stomach, through the liver, and out the patient's side until the stomach and the liver are apposed. The tube is left in place for 14 days, then snared and removed.

Gagner has carried out hepaticogastrostomy in 10 patients. No loss of patency of the anastomosis has occurred in any of the patients, one of whom lived for nine months. Histologic examination of the anastomoses revealed epithelialization.

Although gastrojejunostomy often does not adequately palliate many patients with gastric-outlet obstruction from pancreatic adenocarcinoma,[42] we would carry out this procedure laparoscopically in a patient with significant gastric-outlet obstruction. We have performed gastrojejunostomy in five patients for this reason. The anastomosis was carried entirely with the Endo GIA, and therefore operating times ranged from 40 to 72 minutes (Figures 20.1.5–20.1.7). No significant complications occurred, although two patients continued to have symptoms of nausea and vomiting despite anastomotic patency.

Internal Pseudocyst Drainage

Nonresolving pseudocysts have traditionally been treated by internal drainage into the stomach, duodenum, or jejunum, depending on the cyst location.[43] More recently percutaneous transgastric drainage has been described under ultrasound guidance with fluoroscopy.[44,45] Success rates of 60 to 80% are reported, but prolonged tube drainage is required for complete resolution of the pseudocyst (4 to 12 weeks).

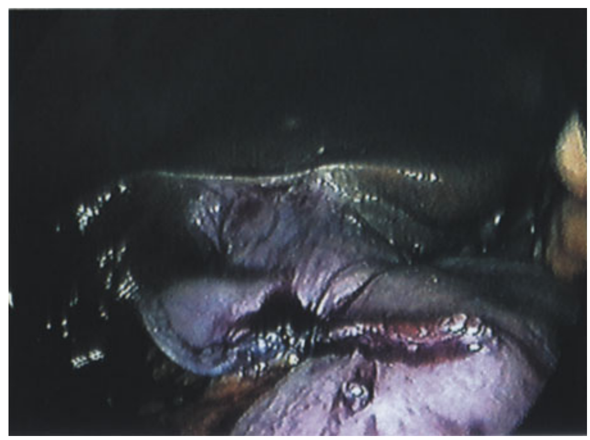

FIGURE 20.1.4. Laparoscopic cholecystojejunostomy. The anastomosis is complete.

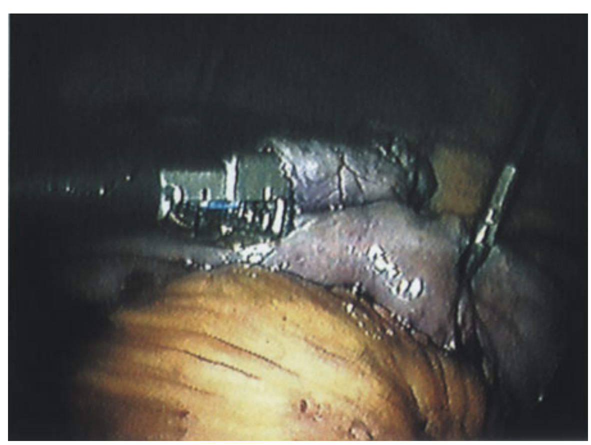

FIGURE 20.1.5. Laparoscopic gastrojejunostomy. Small holes are made in the stomach and jejunum, and the blades of the Endo GIA are introduced from the patient's right.

The advantage of laparoscopic pseudocyst drainage is that an adequate surgical anastomosis can be carried out with a minimal incision and no need for drainage. The first laparoscopic cystgastrostomy was done by J. Petelin in 1991.[46] He performed an anterior gastrotomy, created a window between the pseudocyst and the stomach, and hand sutured the margins with interrupted sutures. This proved to be time-consuming and laborious, but the patient did extremely well.

We (Litwin and Rossi) have performed laparoscopic cystgastrostomy in which we opened the stomach anteriorly, located the pseudocyst, entered it with electrocautery, and then created a window between the posterior wall of the stomach and the pseudocyst with two firings of the Endo GIA 30 instrument. No complications occurred, and the patient progressed to a regular diet within two days.

More recently we have utilized a technique of cystgastrostomy introduced by L. Way.[47] In this technique, the stomach is inflated with CO_2 via the nasogastric tube and trocars are introduced via the stomach. The stomach is then used as the operating chamber (Figures 20.1.8–20.1.12).

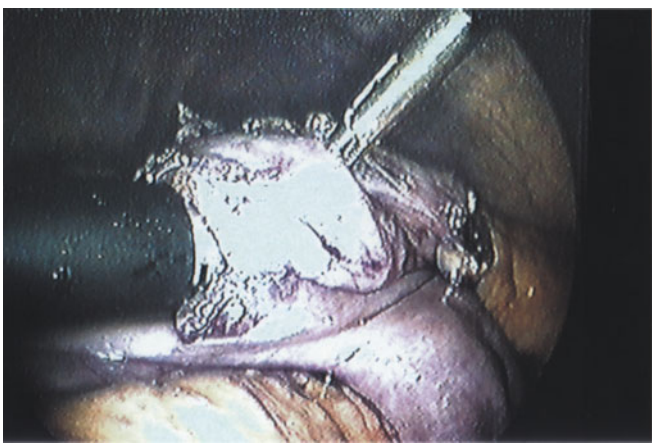

FIGURE 20.1.6. Laparoscopic gastrojejunostomy. Two firings of the Endo GIA 30 are required to make an anastomosis of adequate size.

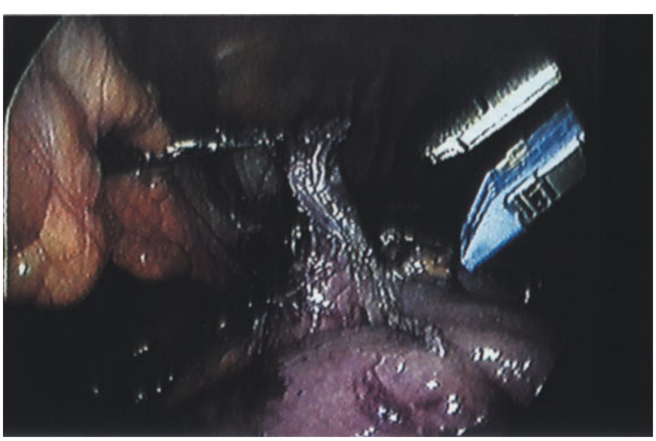

FIGURE 20.1.7. Laparoscopic gastrojejunostomy. The opening is closed by introducing the Endo GIA from the left.

Conclusion

At present, experience with laparoscopic pancreatic surgery is very rudimentary. Nonetheless, we believe that laparoscopy will make an impact on the surgical approach

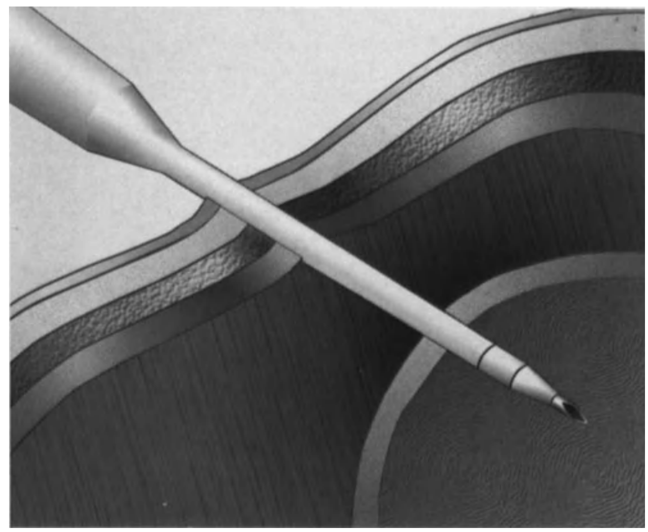

FIGURE 20.1.8.

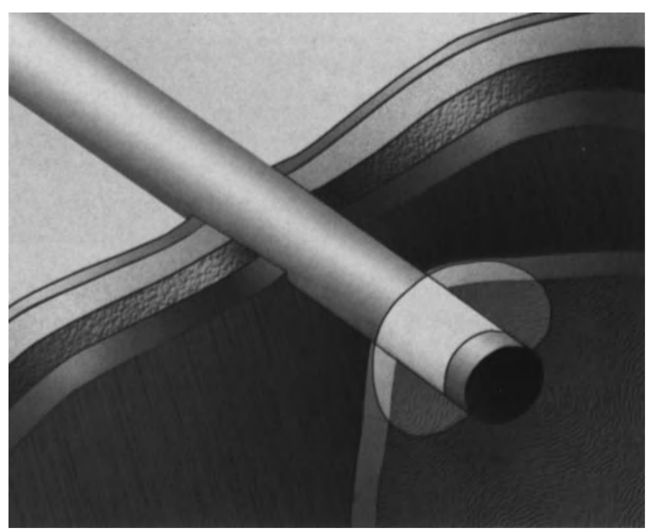

FIGURE 20.1.9.

FIGURES 20.1.8 and 20.1.9. Cystgastrostomy. Under laparoscopic guidance, the inflated stomach is pierced with the needle of the radially expanding trocar (RED), which is then introduced into the stomach.

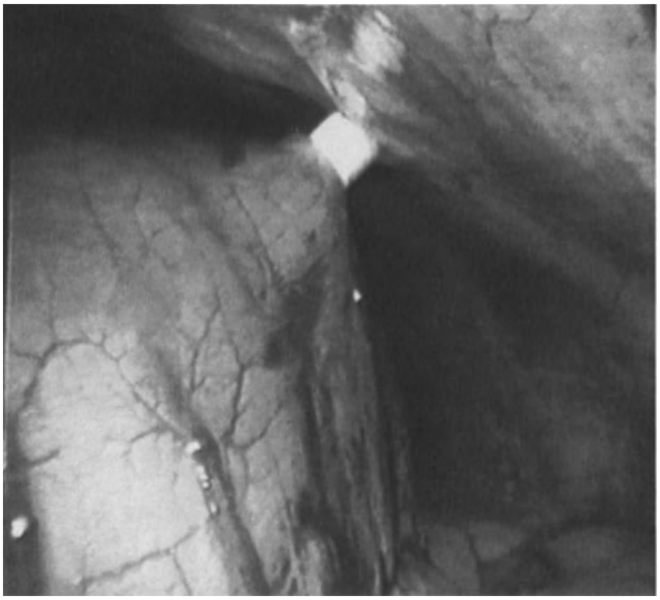

FIGURE 20.1.10. Cystgastrostomy. RED placed in stomach.

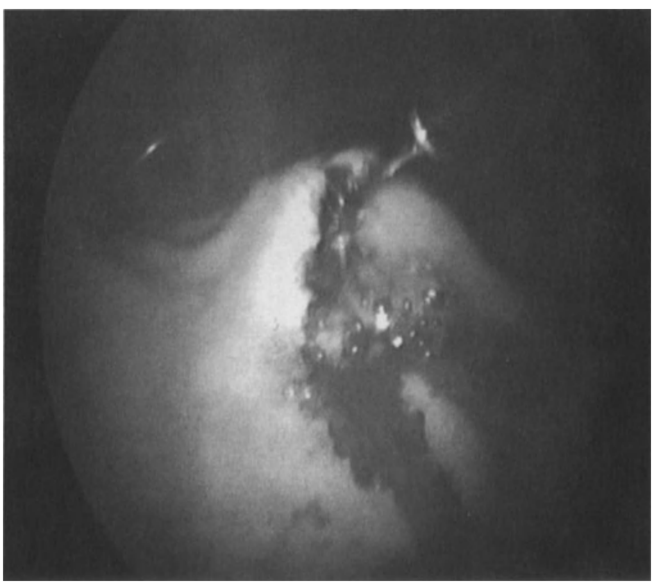

FIGURE 20.1.11. Cystgastrostomy. With the 5-mm telescope in the stomach, the hook is used to cut a hole in the posterior wall of the stomach.

to pancreatic disease. This is particularly true for palliative bypass procedures for terminal pancreatic disease, which are relatively easy to carry out laparoscopically. Also, the minimally invasive approach to pancreatic pseudocysts will likely offer our patients substantial benefits. However, each surgeon is his own best quality-control officer, and he must assess his own ability to carry out these surgical procedures and determine whether his short-term and long-term results meet accepted standards.

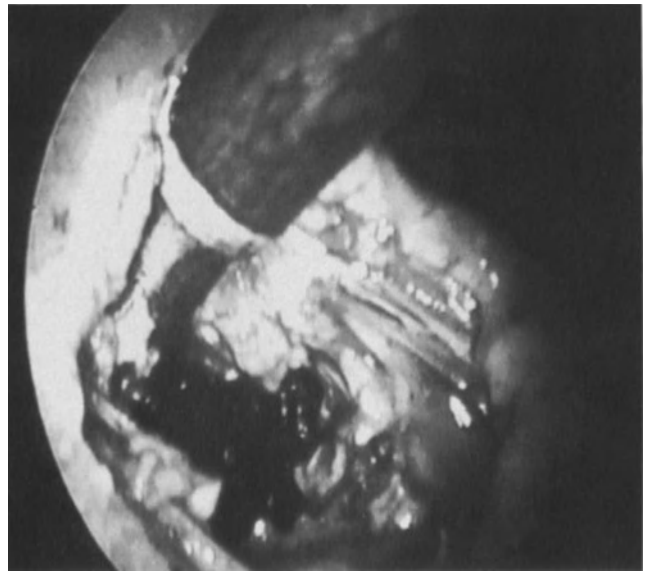

FIGURE 20.1.12. Cystgastrostomy. A hole of suitable size has been cut into the posterior wall of the stomach with electrocautery. The cyst is evacuated. The transgastric trocars are removed, and the punctures are sutured with a single stitch.

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20.2 Endoscopic Therapy of Benign Pancreatic Disease

Gregory B. Haber and Isaac Raijman

In 1642, C. Wirsung became the first anatomist to dissect and describe the pancreatic duct in humans.[1] Over the next century much attention was given to the variant anatomy, particularly pancreas divisum, which was originally described by Johan Rhode in 1646 and published in 1661.[2] Investigation of the pancreas was limited to anatomic dissection, and little more was available for the next 300 years. The era of modern imaging and fiberoptics has allowed access to the living pancreas, making it possible to correlate structure with function.

The endoscopic approach to pancreatic disease is largely based on surgical experience; obstruction to flow, fistula, or pseudocyst are treated principally by a variety of drainage procedures. The therapeutic endoscopist, for the most part, has been able to achieve results similar to those of invasive procedures with endoscopic noninvasive approaches. The reduced morbidity and mortality of endoscopic procedures makes endoscopy appropriate for a broader range of indications and facilitates clinical trials and evaluation of therapy. Endoscopic techniques are currently limited only by a lack of appropriate material and devices and the relative lack of experience with these novel approaches. However, there is sufficient experience to firmly establish the validity of this therapy for many pancreatic problems.

This chapter addresses the endoscopic therapy of benign pancreatic disease, including pancreatic sphincterotomy, stone removal, stenting, pseudocyst drainage, and pancreatoscopy.

Pancreatic Sphincterotomy

Technique

Major Papilla

The principles of pancreatic sphincterotomy follow those established for biliary sphincterotomy. A bow-string papillotome and cutting current is most commonly used; coagulation current may lead to thermal injury and acute pancreatitis. Prior to pancreatic sphincterotomy, we prefer to do a biliary sphincterotomy. This allows for better visualization of the pancreatic orifice, the septum between the pancreatic and bile ducts, and the cutting direction. In addition, it prevents biliary occlusion if a pancreatic stent is placed. The pancreatic sphincter should be cut in the biliary direction, and the cut should be just long enough to open the duct, usually 3 to 5 mm (Figure 20.2.1). A longer cut is occasionally employed for larger pancreatic ducts or in case of extensive fibrosis. Pancreatic sphincterotomy is clearly associated with a higher risk of complication than biliary sphincterotomy and must be undertaken only by experienced endoscopists. The risk of ensuing procedure-related pancreatitis dimin-

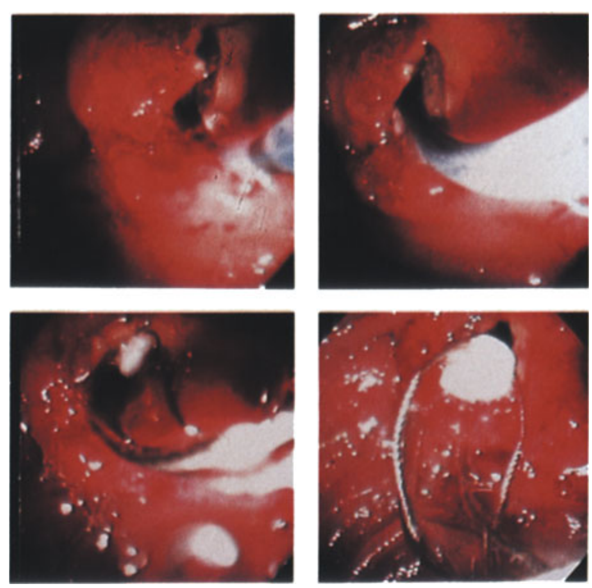

FIGURE 20.2.1. *Top,* Pancreatic sphincterotomy in a 14-year-old girl with idiopathic pancreatitis and intraductal stones. *Bottom,* Retrieval of stones.

ishes with the degree of chronic pancreatitis, and, somewhat surprisingly, has not been a major concern.

Minor Papilla

The smaller intramural segment of the dorsal duct in the minor papilla and the associated difficulty of cannulation limits the usefulness of standard sphincterotomy techniques. The preferred method for the minor papilla is to insert a short straight stent into the dorsal duct to serve as a guide for needle-knife cautery. The needle sphincterotome is passed in slow short sweeps from the edge of the minor papillary orifice in a nine o'clock direction over the top of the stent (Figure 20.2.2). Estimating the length of the cut is difficult, but it should be limited to the intramural segment of the duct.

Complications

In a recent series of 61 patients with pancreatic disorders, we performed pancreatic sphincterotomy of the major papilla in 17 and of the minor papilla in 8. There were no perforations or bleeding episodes and only 2 of the 25 patients developed pancreatitis. In both cases the pancreatitis was mild. Cremer and colleagues performed biliary and pancreatic sphincterotomies in 76 patients with only three cases of cholangitis, one of hemobilia, and none of pancreatitis.[3] Huibregtse performed pancreatic sphincterotomy in 22 patients, 2 of whom developed mild pancreatitis and 1 a fatal duodenal perforation.[4]

Indications and Results

Pancreatic sphincterotomy is performed to provide access to the pancreatic duct in order to remove stones, place stents, perform pancreatoscopy, or to perform balloon dilation, as well as to correct functional or structural obstruction at the level of the papilla.

Pancreas Divisum

Pancreas divisum (PD) is an anatomic variation with pancreatic drainage occurring in 6 to 8% of the population that is not correlated with gender, geographic origin, or ethnic origin. It is characterized by pancreatic drainage predominantly through the minor papilla via the dorsal duct (the duct of Santorini) as a result of malfusion of the dorsal and ventral pancreatic anlages at six to eight weeks of embryonic development. In 80% of cases, noncommunicating dorsal and ventral ducts are identified; in 15% the ventral duct is atretic and cannot be identified; and in 5% there is partial communication between the dorsal and ventral ducts via a small filamentous duct.

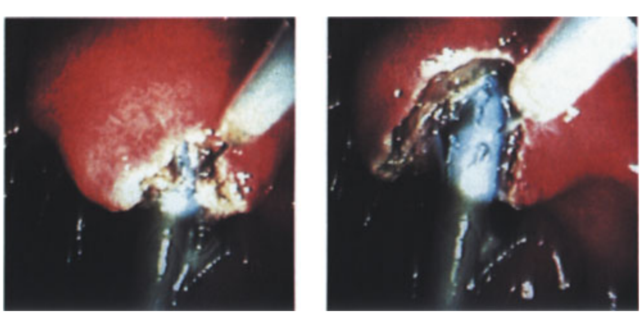

FIGURE 20.2.2. Needle-knife sphincterotomy of the minor papilla over a stent.

Whether this anatomic variant is an independent risk factor for pancreatitis is controversial. The arguments which would support an association have been summarized by Carr-Locke,[5] as follows:

1. Higher prevalence of PD in patients with idiopathic acute relapsing pancreatitis than in those with a known cause for acute relapsing pancreatitis;
2. Evidence of outflow obstruction in patients with PD;
3. Presence of morphologic, pathologic, and functional changes of the dorsal duct in patients with PD;
4. Improvement of these patients after endoscopic or surgical drainage procedures.

The empirical association of PD and pancreatitis is the subject of several recent articles. Cremer's group retrospectively reviewed 6,324 patients undergoing endoscopic retrograde cholangiopancreatography (ERCP) between 1971 and 1983, which included 304 patients (5.7%) with PD.[6] Among the 741 patients with pancreatitis, 6.9% had PD, an incidence not significantly different from the overall incidence of 5.7%. However, the incidence of PD among alcoholics was significantly higher at 15%, compared to an incidence of 6.7% in the idiopathic pancreatitis group and 5.7% in the overall group. Boyer's group in Angers, France, reported on 1,049 retrograde pancreatographies performed between 1978 and 1988.[7] The overall incidence of PD was 5.9%, and the incidence in those with biliary-tract diseases was 6.0%. They subdivided their patients into those studied retrospectively (series 1) and those studied prospectively (series 2). In series-2 patients, the incidence of PD was higher among those with acute pancreatitis (7.8%) and chronic pancreatitis (11.1%), although the differences were not statistically significant. Sahel's group from Marseilles did find a statistically significant difference between the incidence of PD in those with acute pancreatitis (27.8%) and especially in those with idiopathic pancreatitis (50%) when compared with the incidence in the overall group (7.5%) or those with biliary disease (6.2%).[8] Although there is no consensus, there appears to be a trend in favor of an association. Given the relatively small number of patients with PD and idiopathic pancreatitis, however, a confirmation of an association will likely depend upon a meta-analysis conducted by a jury of statisticians.

The proposed mechanism for the development of pancreatitis in PD is relative outflow obstruction, presumably due to the small caliber of the minor papillary orifice. Widdison and colleagues have shown in a cat model that during active secretion, increased ductal pressure is transmitted to the interstitium, and when the gland is less compliant, as it is in chronic pancreatitis, the increased interstitial pressure impairs blood flow, causing hypoxic injury.[9] Hypoxic injury may be one of the underlying mechanisms of pancreatic injury with outflow obstruction.

Staritz documented increased ductal pressure in the isolated dorsal duct of patients with PD when compared to the ventral-duct pressure of the same patients.[10] In patients with PD, the dorsal-duct pressure was 23.7 mm Hg and the ventral-duct pressure was 10.8. The pressures were 10.0 and 10.5 mm Hg, respectively, in a group of normal subjects. Further support for the impaired-outflow hypothesis comes from Warshaw's secretin/ultrasound studies in which the duration of dorsal-duct dilation following secretin infusion was monitored ultrasonographically.[11] Prolonged dilation was strongly correlated with a surgical assessment of minor papillary stenosis.

Pathologic studies on surgically resected pancreases reported by Cotton showed that the changes of chronic pancreatitis were limited to the dorsal-duct system in 9 out of 13 cases. Similarly, endoscopic pancreatography has shown morphologic changes isolated to the dorsal duct.[12]

Perhaps the strongest argument for an association between pancreatitis and PD is that surgical and endoscopic drainage procedures generally have positive results. The largest surgical series has been reported by Warshaw, who performed pancreatic sphincteroplasty on 88 patients.[11] Among 66 patients with a stenotic sphincter assessed preoperatively by an ultrasound/secretin study and operatively by lacrimal-probe calibration, 70% improved. The response was only 27% in the remaining 22 patients without a stenotic sphincter.

Early reports of endoscopic stenting of the dorsal duct in PD patients with acute relapsing pancreatitis were highly successful. Seventeen out of 19 patients responded in a study by the Racine, WI, group.[13] This same group later reported a study in which 19 patients with idiopathic acute recurrent pancreatitis were randomly assigned to receive either a stent for one year or a sham procedure.[14] During the first year 9 out of 10 treated patients had improvement in symptoms, compared to only 1 out of 9 of the controls. At 31.5 months seven of those in the control group had had episodes of pancreatitis whereas at 28.6 months only one patient in the treated group had had an episode. If these dramatic differences persist over a longer term, they will justify an aggressive endoscopic approach for this subset of patients.

Lehman and colleagues reported on a series of 52 patients with PD who underwent minor papilla sphincterotomy using a needle-knife over a short stent, which was left in place a mean of 24.2 days.[15] There were three groups of patients: 24 with chronic disabling pain and normal amylase; 17 with acute recurrent pancreatitis; and 11 with morphologic evidence of chronic pancreatitis, 4 with chronic pain only and 7 with recurrent pancreatitis. Patients were assessed for equal periods before and after treatment, using a symptom scoring system and days of hospitalization as indices of their condition. Improvement occurred significantly more often in those with acute recurrent pancreatitis (76.5%) than in those with chronic pain (26.1%) or chronic pancreatitis (27.3%), although the three patients with chronic pancreatitis who improved all had chronic recurrent pancreatitis, giving this subgroup a response of 43%.

Siegel and colleagues reported on a combined endoscopic/surgical approach in 31 patients, 23 of whom had acute relapsing pancreatitis and the remainder of whom had significant symptoms attributed to the pancreas.[16] Stent placement was successful in all patients and 83.8% showed improvement in symptoms. Among the 26 patients who improved, 12 subsequently underwent surgery, as did the 5 who failed to respond to stenting. These 17 patients underwent a total of 25 operations. Symptoms were completely resolved in 10, partially in 5, and not at all in 2. None of the five who failed stenting had long-term relief of symptoms with surgery. Response to stenting, therefore, may be an indicator of the benefit of a definitive surgical procedure.

Whether or not PD is associated with an increased risk of acute pancreatitis, there is sufficient evidence to support endoscopic or surgical drainage procedures. The evidence to date suggests that those patients with documented acute relapsing pancreatitis associated with dorsal duct dilation or a minor papilla stricture will have good short-term relief of symptoms with minor papilla sphincterotomy or pancreatic stenting. In those with the changes of chronic pancreatitis or a ductal stricture, although stenting may provide temporary relief, it is not clear whether the patient does better in the long term with ongoing stenting (plastic or expandable metal) or a definitive surgical procedure.

Pancreatic Sphincter Dysfunction

Although the classic work of Boyden suggested that comparatively few individuals have true sphincter pancreaticus, manometric studies after biliary sphincterotomy and simultaneous biliary and pancreatic sphincter recording in undisrupted sphincters clearly establish a functioning pancreatic sphincter segment.[17–19]

The Milwaukee/Racine group compared biliary and pancreatic sphincter pressures in three groups of patients: patients with functional pain (15); patients with partial biliary obstruction (19); and patients with idiopathic acute recurrent pancreatitis (24).[19] In the acute pancreatitis group, the basal pancreatic sphincter pressure was 33.3 mm Hg, significantly higher than the corresponding biliary-sphincter pressure of 21.1 mm Hg. Seven of the 24 idiopathic pancreatitis patients had elevated (> 40 mm Hg) basal pancreatic sphincter pressures. In five of the seven, the elevated pressures were confined to the pancreatic-duct segment of the sphincter of Oddi.

Trials of pancreatic sphincter ablation with combined biliary and pancreatic sphincterotomy are ongoing, and the results are not yet available.

Pancreatic Calculi

Calcification noted within the pancreas has been shown to be within the ductal system, with the distribution occurring in either the smaller branch ducts or the main pancreatic duct.[20] The deposition of calcium by saponification in acute necrosis does not result in formation of inorganic calcium salts, and the calcium is usually resorbed during the resolution of the acute process. There is controversy about the clinical benefit of stone removal, namely, whether it alters the progression of chronic pancreatitis, or relieves the principal symptoms of pain and steatorrhea. A recent review states that: "management of pancreatic calculi independent of chronic pancreatitis seems unwarranted."[21] This recommendation is supported by evidence that pancreatic calcification may regress in approximately 30% of patients in long-term studies of chronic calcific pancreatitis.[22] However, the evidence is largely based on radiographic plain films of small branch duct calculi. In addition, a number of the patients with regression had undergone a surgical drainage procedure. On the other hand, substantial evidence has recently been reported that in subsets of chronic pancreatitis patients, removal of main pancreatic duct stones has a measurable clinical benefit.[23–27]

Technique

Endoscopic stone removal is suitable for stones in the main pancreatic duct. The difficulties of stone removal peculiar to the pancreas include: the tortuosity of the duct, the lack of compliance of fibrotic parenchyma, and the relative hardness of the calcium carbonate stones. Radiolucent amorphous filling defects may also be found. They are usually composed of precipitated pancreatic stone protein as well as desquamated epithelial cells and leucocytes. Most amenable to extraction are nonimpacted stones and amorphous casts or debris.

Sphincterotomy of the pancreatic duct, described above, is performed to allow instrument access and stone removal. Our current practice is to perform a biliary sphincterotomy followed by a pancreatic sphincterotomy or septotomy in the major papilla and to insert a short stent for needle-knife sphincterotomy over the stent in the minor papilla. A dormia basket is passed along the duct past the stone and then withdrawn, entrapping the stone. A soft hydrophilic guidewire is often helpful in negotiating sharp angles. A catheter is then advanced over the wire, the wire is withdrawn, and a basket is advanced through the catheter to the stone. A wire-guided balloon catheter may be used in a similar manner. Miniaturized baskets or balloons may be needed for nondilated ducts. Because most pancreatic stones are hard, mechanical lithotripsy using through-the-scope or outside-the-scope specialized coil-spring stainless-steel sleeves may be required; the basketed stone is cracked by pulling it against the sleeve. Mechanical lithotripsy can be done only if the stone can be entrapped in a basket. Thus, impacted stones or stones behind a stricture may require other modalities of fragmentation. The available nonmechanical modalities include intracorporeal electrohydraulic or pulsed-laser lithotripsy, and extracorporeal shock wave lithotripsy (ESWL). The intracorporeal modalities require a mother-daughter scope system that allows the pancreatic duct to be directly visualized (see pancreatoscopy, below). The appropriate waveguide or probe can then be applied to the stone.

ESWL can be performed if the stone can be visualized and accurately targeted. Most difficult pancreatic stones are radio-opaque, allowing for radiologic targeting, but in other cases a nasopancreatic catheter may have to be inserted so that contrast can be infused to outline the stone. If the stone is located near the mouth of the pancreatic duct, insertion of a pancreatic stent to decompress the duct prior to lithotripsy may alleviate symptoms and prevent impaction of fragments in the papillary orifice postlithotripsy (Figure 20.2.3). Follow-up ERCP is always necessary to remove fragments (Figures 20.2.4 and 20.2.5).

Indications and Results

We recently published the largest series of endoscopic pancreatic stone removal ever reported.[27] This was a retrospective review of 32 patients who underwent endoscopic pancreatic duct stone removal for pancreatic symptoms. The patients were divided according to their clinical history into two groups. The chronic-pain group had chronic continuous abdominal pain with or without acute exacerbations but with serum amylase or lipase levels less than four times the normal levels. The chronic relapsing pancreatitis group had discrete attacks of abdominal pain with serum amylase or lipase levels more than four times the normal levels. The etiology and duration of symptoms are listed in Table 20.2.1.

Among 14 chronic-pain patients, stone removal was complete in 10, partial in 1, and unsuccessful in 3. After

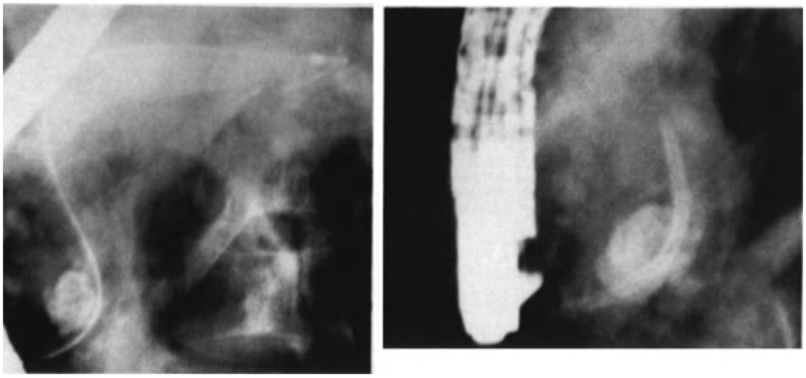

FIGURE 20.2.3. Insertion of a short stent to prevent impaction of a pancreatic stone, before extracorporeal shock wave lithotripsy.

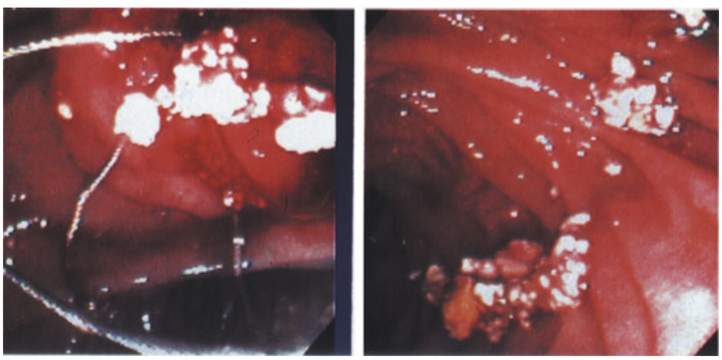

FIGURE 20.2.4. Fragments of a pancreatic stone extracted after extracorporeal shock wave lithotripsy

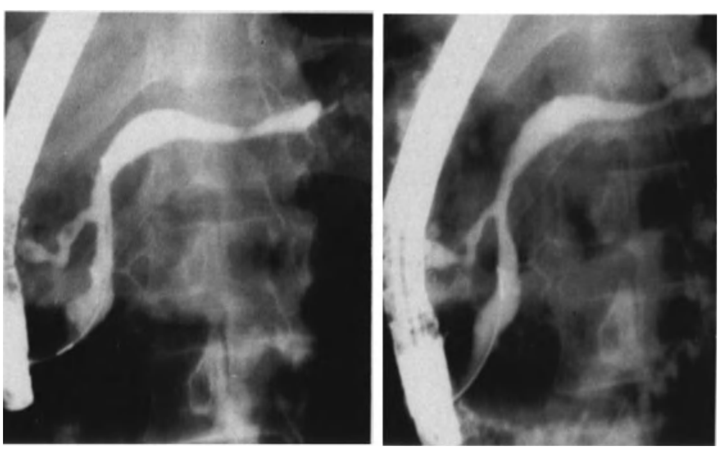

FIGURE 20.2.5. Duct after stone removal by extracorporeal shock wave lithotripsy.

a mean of 1.6 years, 44% of 13 patients had complete symptom resolution, including 4 of the 9 with complete stone removal. In the chronic relapsing group, stone removal was complete in nine, partial in three, and unsuccessful in six. All patients were followed for a mean of 2.3 years, and among the nine with complete stone clearance, eight were without symptoms. Factors favoring stone removal included:

1. Fewer than four stones
2. No impacted stones
3. Stone diameter < 10 mm
4. Stone located in the head or body of the pancreas
5. No stricture downstream of the stone

TABLE 20.2.1. Etiology of chronic pancreatitis and factors contributing to recurrent pain or pancreatitis.

Alcohol	8	
Pancreas divisum	8	
Sphincter of Oddi dysfunction	2	
Gallstones	2	
Hyperparathyroidism	1	
Hyperlipidemia	1	
Idiopathic	10	
	Chronic pain (N = 14)	CRP (N = 18)
Duration of symptoms (yr)	5.3 (0.5–10)	3.1 (0.5–10)
Duration of follow-up (yr)	1.6 (0.5–4)	2.3 (0.5–7.6)

When the patients were discriminated according to presenting symptoms, patients in the chronic relapsing group had much better results than the comparable patients in the chronic-pain group.

It should be noted that the patients on the study had been selected from a much larger group of pancreatic stone patients. They were selected on the basis of morphologic changes at ERCP that favored removal and on clinical grounds that excluded patients with ongoing alcohol consumption. These results are encouraging, but the study had a relatively short follow-up, and our conclusions can only be considered preliminary.

ESWL

Pancreatic stones are particularly amenable to shock wave fragmentation because they are usually homogeneous and relatively immobile, as it is the impacted stones that usually necessitate nonendoscopic fragmentation. This modality has been highly successful; a Brussels group reports a successful disintegration rate of 99% in 123 patients, although success was liberally defined.[28] For example, one criterion was simply the ability to deeply cannulate the pancreatic duct after ESWL. In 38 patients cannulation was attempted only after ESWL therapy; whether it would have been possible beforehand is unknown. Nevertheless, this large study clearly justifies a role for ESWL in the treatment of pancreatic stones. Among 122 patients with stone disintegration, complete duct clearance was achieved in 72 by means of immediate, post-ESWL pancreatic sphincterotomy and endoscopic fragment extraction. Pain relief was complete in 45 patients followed for a mean of 14 months and roughly as many experienced partial relief. Univariate analysis showed that the variables correlating with pain relief were the ability to place a nasopancreatic catheter pretreatment and reduction in the main duct diameter posttreatment. The patients were followed for a relatively short time, but other factors, such as increased body weight in 71% of those who had lost weight and in 46% of those with a prior stable weight, are encouraging. Although enthusiasm for biliary lithotripsy has been dampened by minimally invasive surgery, if symptoms continue to be relieved by pancreatic stone removal, many of the underutilized lithotriptors may be called back into service.

Pancreatic Stents

In the endoscopic era, pancreatography is used to determine ductal anatomy, so that the usefulness of a drainage procedure can be assessed. The indications for pancreatic stenting include:

1. Ductal obstruction by stricture or stone
2. Impaired papillary drainage
3. A ductal disruption that can be bridged
4. A cyst or abscess that should be drained

Technique

Although pancreatic stents are inserted in much the same way as biliary stents, the tortuosity of the pancreatic duct, the narrow caliber of the duct, and the smaller ductal orifice, especially in cases of PD, demand some changes in our approach.

A preliminary plain film in the region of the pancreas is often helpful in identifying parenchymal calcification and radio-opaque duct stones. Pancreatography should then be carried out with a dense contrast material so that overfilling or acinarization, which should be avoided to minimize the risk of pancreatitis, will be recognized early.

For pancreatic stenting, a hydrophilic polymer-coated guidewire with a diameter of 0.021 to 0.035 in. should be used. The flexibility of this wire reduces trauma to the duct and permits passage through strictured or angulated areas. Once the wire is positioned, either a small-caliber (5 to 7F) stent can be inserted, or a dilating 6F catheter can be advanced and larger (10 to 12F) stents inserted over the catheter (Figure 20.2.6). The stent size is determined primarily by the duct diameter. Pancreatic stents have a slight arc and flaps to prevent migration. Multiple side-holes along the length of the stent body allow branch duct drainage.

Biliary sphincterotomy may be performed prior to stent insertion. Pancreatic sphincterotomy is necessary when there is a very narrow orifice or stenosis of the pancreatic sphincter segment or when larger stents are inserted.

The minor papilla poses special problems because of its tiny orifice and often-tortuous duct take-off. Access often demands a specialized tiny 0.018- to 0.025-inch guidewire. Once access is achieved, a hydrophilic wire can be substituted for the guidewire.

The optimum duration of stenting is unknown. Theoretically, the dense fibrosis that accompanies chronic pancreatitis makes dilation a difficult task, and more than one year of stenting is usually necessary. However, if the problem is a relative outflow obstruction, the orifice may be dilated with increasingly larger stents more quickly. Replacing the stent at regular intervals of three to four months may help to avoid the complications of relapsing pancreatitis or sepsis associated with stent occlusion.

Complications

The complications encountered with the present stent designs include the following:

Insertion pancreatitis
Clogging
De novo pancreatic stones

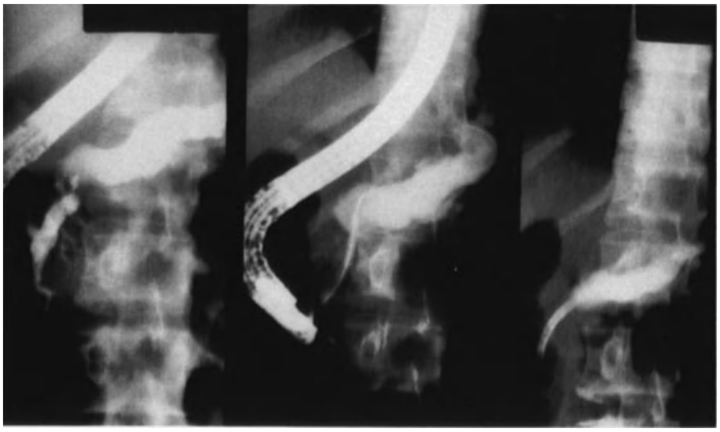

FIGURE 20.2.6. *Left,* Stricture at genu of pancreas in a patient with hereditary pancreatitis. *Center,* Insertion of guide catheter with hydrophilic wire. *Right,* Pancreatic stent in place.

Ductal changes
Migration
Pancreatic pseudocyst or abscess
Duodenal-wall erosion

Insertion pancreatitis is surprisingly infrequent and usually mild. Among a group of 50 consecutive patients undergoing stent insertion in our unit, 5 developed pancreatitis and none had any serious sequelae.

Clogging of the stent is noted more frequently if simple flow tests are done following stent removal. The usual finding is that there is a chalky white debris (calcium carbonate) along the length of the stent (Figure 20.2.7). Given that pancreatic juice is saturated with calcium salts, it is likely that the free reflux of duodenal contents into the stent precipitates the soluble calcium because it decreases the pH, leads to bacterial contamination, or interferes with the stabilizing action of pancreatic stone protein or citrate. An analysis of the clogging material has revealed that it consists of aggregates with an organic matrix and inclusions of calcium salts. The organic part is composed of proteolysed pancreatic-juice proteins, the insoluble fraction of pancreatic stone protein, and bacterial colonies.[29] Clogging was noted in 22% of our 50 cases, and in 47.4% of 52 patients in another study who underwent stenting of the minor papilla with a mean duration of stent placement of only 24 days.[15] Symptom recurrence has not been associated with clogged stents, which raises the issue of how and why the stent works. One hypothesis is that due to a wick effect, juice continues to flow around a clogged stent.

De novo pancreatic stone formation has been addressed in a recent study from our unit.[30] New stones formed in 12 of our 50 stent patients who had a total or 24 stents placed for a mean total stenting time of 22.8 weeks. Crystal analysis of the stones in two patients confirmed that they were of calcium carbonate (calcite) composition. The new stones could be easily cleared in 10 of the 12 patients. The explanation for stone formation is the same as for stent clogging.

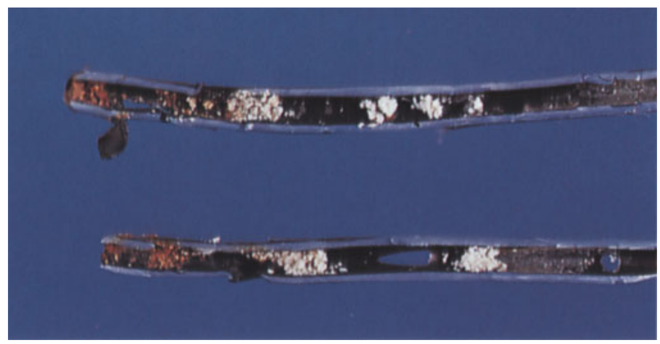

FIGURE 20.2.7. Longitudinal section of a pancreatic stent clogged with calcium carbonate and bilirubinate precipitates in the pancreatic and duodenal segments, respectively.

Ductal changes have been found in the majority of patients after stent insertion (Figure 20.2.8). A retrospective review of 34 stented patients showed that, among 17 whose ducts had been normal, 3 developed ductal stenosis, 4 developed ductal dilation, and 2 had pseudocyst complications, for a total of 9 cases of ductal change (53%).[31] Most of these changes were reversed with either a stent change or, in the case of the duct stenosis, by removing the stent. Spontaneous resolution occurred in two of three patients.

The direct adaptation of the plastic biliary stent to pancreatic applications is probably not ideal. An ideal pancreatic stent would be soft, pliable, without barbs (likely the most injurious characteristic of the device), and have an antireflux valve. Migration of the stent up the duct as well as stent fall-out into the bowel have been reported. After inward migration, retrieval is usually possible with a basket or forceps (Figure 20.2.9). We have one patient with a stent piece that broke off upstream of the stricture being treated. The patient has remained well for 31 months. Inward migration has been postulated to be due to a ratchet-like action of the stent barb, which allows inward movement but prevents outward sliding. A recent

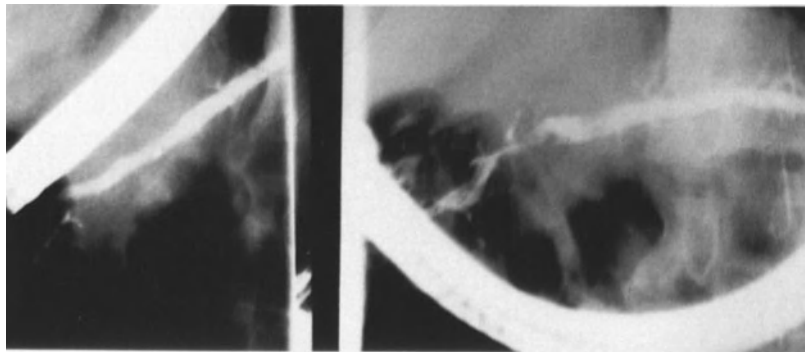

FIGURE 20.2.8. *Left,* Pre-stent dilated dorsal duct. *Right,* Post-stent edema and stricture ("ductitis").

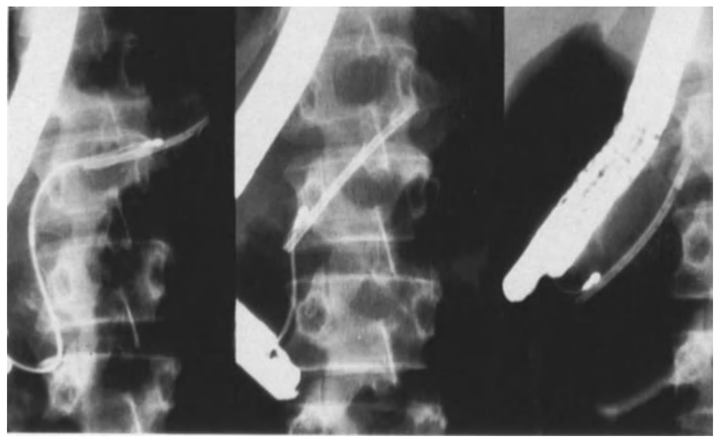

FIGURE 20.2.9. Retrieval of inwardly migrated pancreatic stent with dormia basket.

design change has eliminated the barb on the pancreatic end of the stent, which may resolve this particular problem.

There are a few case reports of abscess and pseudocyst due to duct disruption complicating the intrapancreatic end of the stent and of duodenal ulceration at the other end.

Indications and Results

Most reports on stenting in pancreatic disease are retrospective analyses of a heterogeneous group of pancreatic disorders treated with stenting alone or with stenting in combination with pancreatic sphincterotomy, balloon dilation, stone extraction, or extracorporeal fragmentation. Conclusions must be based on the consensus of the involved investigators rather than through critical analysis of well-designed trials, which have not yet been done.

Pancreatic Duct Strictures

Huibregtse and colleagues reported on endoscopic therapy of 30 patients, all of whom had anatomic abnormalities.[4] Stent insertion was achieved in 8 out of 11 with a stricture alone, and in 6 out of 10 with a stricture and stones. Among the 14 stent patients, all 7 with relapsing pancreatitis all improved, and only 5 of 7 with chronic pain improved.

McCarthy, Geenan, and Hogan reported on 35 patients with stent placement, 22 with PD whose stents were in the minor papilla, and 15 with other pancreatic disorders whose stents were in the major papilla.[13] Among the 15 patients in the nondivisum group, 14 had successful insertions: 5 had a localized stricture, 7 had supposed papillary stenosis, and 2 had idiopathic pancreatitis. Improvement occurred in four, three, and one patient, respectively.

Grimm and Soehendra reported on successful stent insertion or stone removal in 61 of 70 patients.[32] Forty-one of these had stent insertions. Of the 61 patients treated, 35 (57%) had good medium-term results.

Cremer and colleagues have the most extensive experience and provide the best data on stenting of patients with main duct strictures.[3] They report on 76 patients, all with a main duct stricture and upstream dilation, who underwent stent insertion. Placement was successful in 75; 54 were placed through the major papilla and 21 were placed through the minor papilla. Improvement was noted in 71 out of 75 (94%) patients, with concomitant reduction in duct diameter assessed ultrasonographically.

Most of these publications have shortcomings. The frequency and severity of patient symptoms before, during, and after stent placement is rarely noted. Neither is the role of alcohol or abstinence from alcohol well documented, undoubtedly in part because of the retrospective nature of these studies and the inherent unreliability of alcohol-consumption histories. The definition of ampullary dysfunction or stenosis is murky at best, and this putative cause of pancreatitis is rather too freely assigned since most studies lack data on morphologic changes, sphincter manometry, or drainage kinetics. Given these shortcomings, what can we conclude from these studies?

There is a consensus that impaired drainage is an etiological factor in pancreatic pain. This consensus is based on surgical studies of pancreatic duct pressures, manometric studies demonstrating a hypertensive sphincter pancreaticus, the experience with operative drainage procedures, and the observed diminution of duct caliber in patients who improve with stent placement.[33] It is not surprising, then, that there is enthusiasm for endoscopic therapy, but which patients are the most suitable candidates? As is true of most therapies, late intervention after end-stage damage to the organ is not as likely to be beneficial. Thus those with dense parenchymal calcification, multiple strictures, and, especially, continued alcohol insult do not benefit. In contrast, nonalcoholic patients with a dominant duct stricture and upstream dilation respond the best. Moreover, those with discrete episodes of relapsing pancreatitis have better results than those with a chronic-pain syndrome only.

Pancreatic Duct Disruption

A persistent fluid collection in or around the pancreas often signals spillover of pancreatic secretions from a disrupted duct. This is usually a sequela of acute pancreatitis, but it may also be related to trauma, or chronic pancreatitis. Bridging the disrupted duct with a stent shuts off the leaking and, in conjunction with transpapillary, transgastric, transduodenal, or percutaneous drainage, allows the cystic cavity to close (Figures 20.2.10–20.2.12).

Kozarek and colleagues reported on 18 patients with ductal disruptions identified on ERCP.[34] Fourteen of these had been hospitalized for several weeks and had failed refeeding attempts; eight were reliant on parenteral nutrition. Twelve patients had undergone a previous percutaneous or surgical drainage procedure, eight had chronic fistulous tracts, and nine were receiving octreotide therapy. At ERCP, in nine patients the disruption was within 2 cm of the genu, and in eight it was in the tail. Endoscopic therapy consisted of placement of 5 to 7F nasopancreatic catheters or indwelling stents. Control of the duct disruption was initially gained in 16 patients, with 12 of 14 fluid collections resolving within six weeks. At a median follow-up of 16 months, seven patients came to surgery, three for persistent pain and four for recurring fluid collections. These are remarkable results for this difficult and complex pancreatic problem.

Transgastric or Transduodenal Cyst Drainage

Most cysts complicating acute or chronic pancreatitis develop behind a duct segment obstructed by a stone, edema, or fibrosis. Others may form around a necrotic cavity. Small cysts 2 to 3 cm in diameter often resolve spontaneously, but larger ones, and those communicating with a disrupted duct system, often persist, necessitating drainage. Candidates for endoscopic drainage are symptomatic patients with mature cysts (present for four weeks) that are retrogastric or paraduodenal and clearly visible as a well-demarcated bulge of the mucosal wall. The apposition of the cyst to the gut wall (the absence of interposed tissue) should be confirmed with CT scanning or, more appropriately, with endosonography or Doppler probes where available.

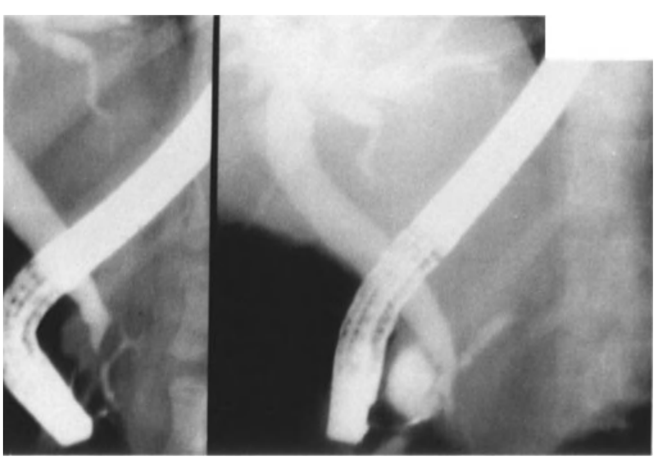

FIGURE 20.2.10. *Left,* Filling of ventral duct via major papilla. *Right,* Filling of obstructed dorsal duct via minor papilla.

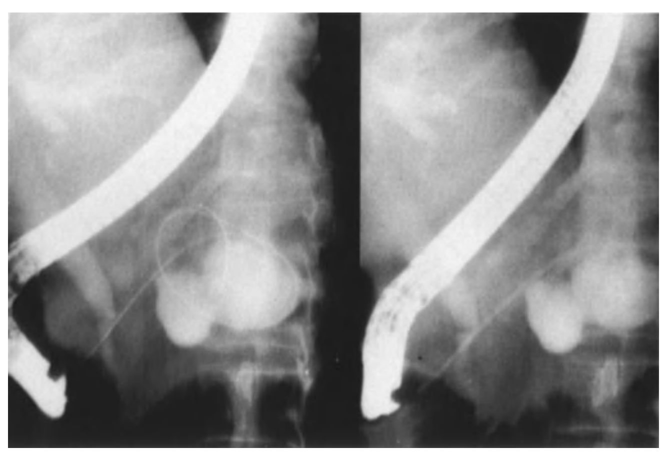

FIGURE 20.2.11. Filling of cystic cavity guidewire was advanced past duct disruption.

Technique

Needle aspiration should be performed to help assess the depth of the cyst and to sample the cyst contents. Fluid can be cultured and, if it is bloody, endoscopic drainage should be deferred. After aspiration, contrast is injected to define the size and the contour of the cyst and to determine whether it communicates with the duct (Figure 20.2.13). Needle diathermy is used to burn a hole in the cyst. If this is done with a double-lumen catheter, a guidewire can be introduced down the second channel and through the fistula. The guidewire can be used to advance a papillotome to extend the fistulotomy or to insert a nasocystic tube or a double-pigtailed stent (Figures 20.2.14 and 20.2.15). A cystoenterostome has been designed that consists of an outer 10F sheath with a diathermic ring through which a diathermic needle can be passed for initial puncture, followed by guidewire. The fistula can be further extended with the larger diathermic ring.[35]

The time needed for nasocystic or stent drainage depends on the size of the cyst. Smaller, noncommunicating cysts are substantially resolved within one week, whereas larger cysts require much longer stent drainage, preferably with a 10 to 12F double-pigtailed catheter to ensure patency of the fistulotomy.

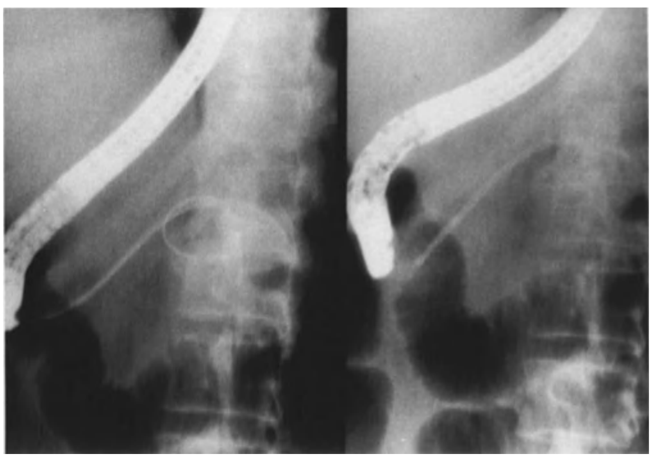

FIGURE 20.2.12. Placement of a pancreatic stent to allow cyst drainage.

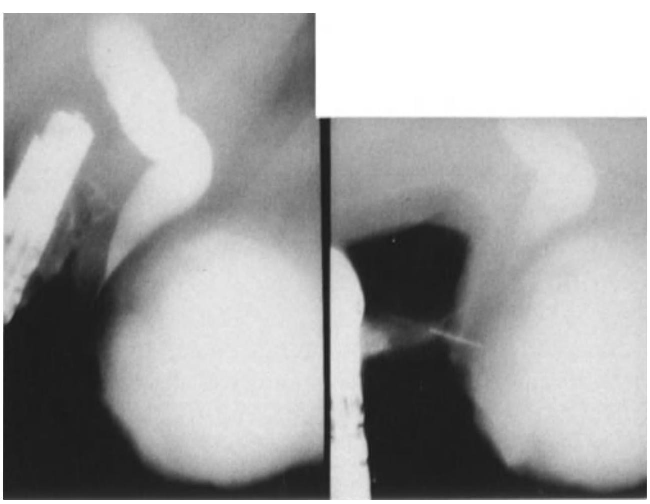

FIGURE 20.2.13. Opacification of pancreatic pseudocyst obstructing the bile duct and duodenum.

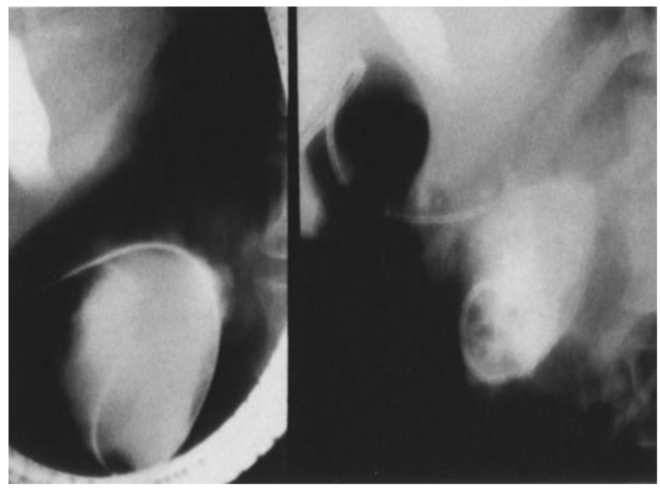

FIGURE 20.2.14. Placement of a double-pigtailed, 10F stent in cyst.

FIGURE 20.2.15. Shrunken cyst after endoscopic drainage.

Indications and Results

The experience of several centers was summarized by Sahel.[36] There were 97 patients from five centers; cyst-gastrostomy (ECG) was successfully performed in 16 of 18 patients and cyst-duodenostomy (ECD) in 69 of 72. The morbidity was 11% and the mortality 3.3%. One cirrhotic patient died and one alcoholic with chronic pancreatitis, both due to bleeding. A third patient died of a pulmonary embolus following surgery for an infected cyst. Another article reports long-term results in 33 patients.[37] Among 22 undergoing ECD, 16 of those available for follow-up were without clinical problems a mean of 35 months after treatment. All underwent follow-up ultrasound and nine underwent ERCP. In six of nine patients checked, the cyst-duodenostomy fistula remained patent. The relapse rate was 9% after ECD. Among 11 patients with ECG, the relapse rate was 19%. The higher relapse rate was related to the size of the cysts, the low pressure of the fluid in the retrogastric compartment, and the tendency for the cyst-gastrostomy fistula to close rapidly after stent removal.

Given the difficulties of transcutaneous access for paraduodenal cysts, endoscopic drainage is preferable to percutaneous drainage. Retrogastric cysts may be managed either way; the choice depends on the cyst topography.

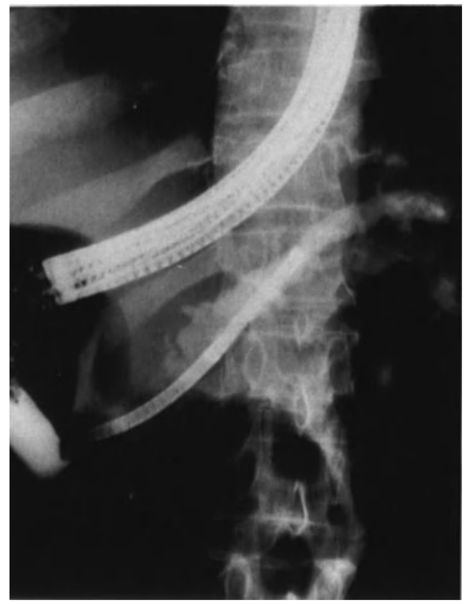

FIGURE 20.2.16. Pancreatoscopy with a "mother-daughter" scope system to target a stone for laser or mechanical lithotripsy.

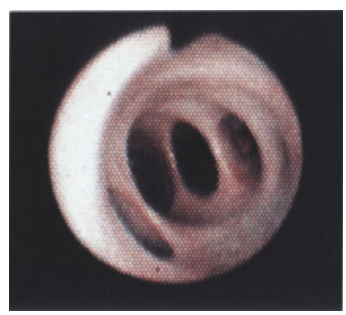

FIGURE 20.2.17. Pancreatic duct seen at pancreatoscopy.

Pancreatoscopy

Direct visualization of the pancreas is possible using a mother-baby scope system. A 4.5-mm miniscope in a large mother scope can only be maneuvered in a dilated pancreatic duct, and the operating channel provides access for lithotripsy fibers and biopsy forceps or snares (Figures 20.2.16 and 20.2.17). The major drawback is the size both of the miniscope and the cumbersome "mother" scope. At the other end of the spectrum is an ultrathin miniscope, 0.8 mm in diameter, which can be passed even through a catheter but has a limited field of view and no operating channel. This has recently been improved with the use of a sequential video converter to magnify the image.[38]

Riemann and Kohler used 3.1-mm and 0.8-mm miniscopes in 18 and 20 cases, respectively, and found that they improved diagnosis of protein plugs and segmental stenoses, and allowed verification of ductal tumors.[39] Neuhaus and colleagues used a 3.4-mm prototype miniscope, which could be inserted through a standard duodenoscope. An operating channel diameter of 1.2 mm allowed passage of a laser fiber and simultaneous coaxial irrigation during lithotripsy of a pancreatic duct stone (Figures 20.2.18–20.2.20).[40] A miniscope with a wide field of view, four-way angulation, and an operating channel of 1.7 mm, which can be inserted through a standard duodenoscope will be the future standard for pancreatoscopy.

Conclusion

For centuries the pancreas has been a cryptic organ, difficult to image, and to understand. The absence of a specific therapy that can change the course of acute pancreatitis attests to the limitations of our science. Looking through the endoscope has helped us to better describe the manifestations of exocrine disease and to delay or reverse the pathologic process by simple but effective treatments.

FIGURE 20.2.18. Typical hereditary pancreatic stone with radiolucent center obstructing the dorsal duct in pancreas divisum.

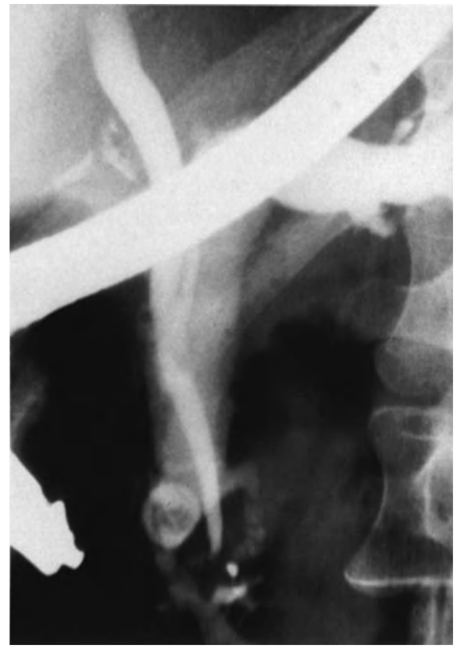

FIGURE 20.2.19. Failed stone removal due to impaction.

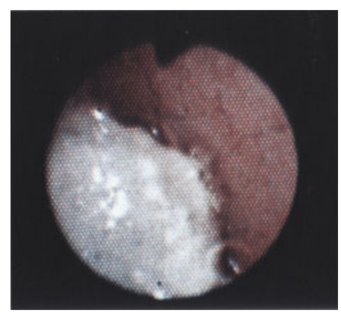

FIGURE 20.2.20. Direct visualization of a pancreatic stone as seen at pancreatoscopy with a "mother-daughter" scope system.

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21
Laparoscopic Surgery of the Liver

Namir Katkhouda and Jean Mouiel

Because of its multiple metabolic, detoxifying, and filtering functions, the liver plays a key role in the field of oncology. Whether it concerns primary cancer or metastases, the liver is often the seat of different tumors. Most of the intra-abdominal organs have portal venous drainage toward the liver, just as other organs closer to the liver also have lymphatic drainage in the direction of this organ. The structure of the liver, with its different lobules, constitutes an obligatory barrier to cancer cells. Depending on number, environment, and susceptibility, as well as other contributing factors, these cells will blossom to produce hepatic metastases, either synchronous or metachronous. The size of the metastases varies greatly and obeys the laws of exponential tumor growth, which means that some of them cannot be detected by conventional viewing methods because of their small dimensions.[1]

Hepatic oncological surgery is very advanced and the technology has been thoroughly tested.[2–4] It is, nevertheless, important to emphasize the specialized nature of this type of surgery. It cannot be properly done if the surgical department has not had a long involvement with the various techniques involved in hepatobiliary surgery. Laparoscopic surgery, which is now out of its infancy, has seen its applications used with most intra-abdominal organs.[5–8] The liver remains the last point of resistance, due to its size, its highly vascular nature, and a certain mystery that surrounds liver surgery. In oncology, laparoscopic surgery of the liver will have to be performed with caution, and only by experienced hepatobiliary surgeons.[6,9,10]

Prerequisites to Laparoscopic Surgery of the Liver

It is essential not only to be proficient in open hepatobiliary surgery, but also to have an experimental laboratory in order to gain experience in laparoscopic surgery. It is imperative that the surgeon get used to handling laparoscopic instruments for use in the liver, and to completely master the techniques of hemostasis and biliostasis. This can only be achieved by carrying out experimental surgery on animals. It is also necessary to have a certain amount of specialized equipment. These requirements are more important for surgery of the liver than for surgery of other intra-abdominal organs. Unfortunately, specialized equipment, for example, the YAG laser, can be very expensive. To alleviate this problem, it is essential that the various disciplines share equipment.[2,3,11] It is important to provide reasonable indications and to follow these indications carefully. Problems can crop up at any time during hepatic surgery and one must be able to convert to open immediately, for the patient's safety.

Reasonable Indications

In the field of oncology, diagnostic laparoscopy can be very useful in searching out small tumors of the liver that are not detectable by conventional imaging techniques (CT scan, MRI, scintigraphy, and hepatic angiography). Cancer of the pancreas, for example, is commonly accompanied by multiple hepatic metastases[18] that are small in size and dispersed throughout the entire liver. Because of their size, these metastases are sometimes not detected by the usual imaging methods, but can usually be seen with the laparoscope. This makes it possible to change an indication for curative resection into palliative surgery, or avoiding an unnecessary laparotomy in advanced cases. Another example is cancer of the gallbladder in elderly persons: preoperative imaging may indicate a cancer, but ultrasonography will not reveal localized hepatic extension. In this case too, the laparoscope introduced through the umbilicus with a single trocar will allow a clear diagnosis to be made, and allow for biopsy. In the case of localized colorectal cancer (stages A and B), laparoscopic resection should be preceded by a thorough examination of the liver to exclude metastases. This examination can be further supplemented by laparoscopic ultrasonography at the time of the attempted resection. Unfortunately, this step is frequently neglected. It is also important to be able to identify benign tumors of the liver at the time of laparoscopy, as these tumors (adenomas and focal nodular hyperplasia) can sometimes be mistaken for hepatic metastases. After thorough evaluation of the liver by laparoscopy with ultrasound, one can decide between taking biopsies only, laparoscopic resection, or conversion to open surgery. Lymph nodes in the porta hepatis, demonstrated with imaging techniques, are also an indication for diagnostic laparoscopy. In cases of cancer of the stomach, pancreas, or gallbladder, these lymph nodes can be involved. This changes the surgical indication from curative to palliative surgery.[1,12] It is then possible to visualize the porta hepatis and also to perform lymph node biopsies and frozen section studies, which will help in better staging of the disease. A further indication for laparoscopy is the possible laparoscopic resection of tumors confined to the liver (Figure 21.1). Metastasectomy with a 2-cm margin is sufficient. This enucleation can be performed by laparoscopy. A segmentectomy limited to one, or at the most two, segments can also be performed by laparoscopy. Finally, a left lobectomy is also possible, but this calls for considerable experience. These resections mostly concern hepatic metastases, but can also be applied to nonmalignant tumors for which there is a formal indication, such as a hepatocytic adenoma (in women taking oral contraceptives) that has increased in size or been complicated by hemorrhage. Apart from these risks of serious complications, limited resection is recommended with this type of tumor, as the histologic diagnosis is frequently uncertain.[13]

In primary liver cancer, the tumors are very often large at the time of diagnosis, and resection by laparoscopy is not a reasonable procedure. Laparoscopic resection is also not recommended if the liver is cirrhotic, given the risk of hemorrhage that can occur at any time, with possible fatal consequences.

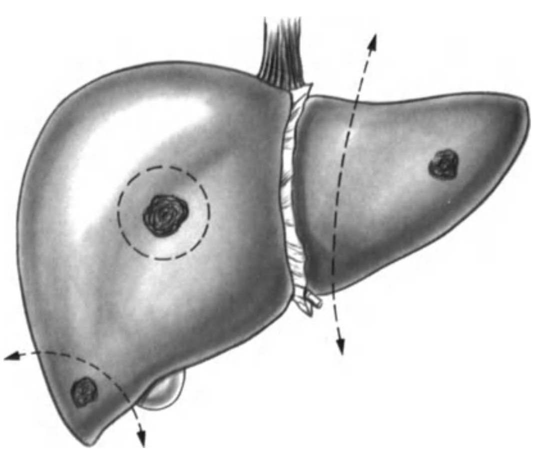


FIGURE 21.1. Reasonable possibilities for resection in laparoscopic liver surgery.

Possible Complications

The major complications of laparoscopic surgery of the liver are the intraoperative risks of hemorrhage and possible gas emboli. These hemorrhagic risks, which at the outset appear to be under control but which suddenly arise during the operation, can take a dramatic turn. It is very important to make a quick decision to convert to open in the event of sudden hemorrhage. As in open surgery, maintaining meticulous control of biliary radicles is also important. This can be achieved with clips or ligatures, as well as intracorporeal sutures. It is essential for every surgeon embarking on this kind of surgery to be able to master the techniques of laparoscopic suturing with both intracorporeal and extracorporeal ligatures. Laparoscopic hepatic surgery is more technically demanding than other types of intracorporeal surgery. It is necessary to become familiar with intraoperative use of the YAG laser,[2] the ultrasonic scalpel,[11] and handling of automatic stapling devices. All of these points will be discussed in more detail in the section on specialized equipment. Finally, one possible problem that must be considered is the extraction of the excised specimen, once the organ has been completely separated from its attachments. There are different ways to do this, but it is necessary to emphasize that the specimen must be placed in an extraction bag in order to avoid intra-abdominal spillage of liver tissue. One must not hesitate to enlarge the umbilical incision or to use other means, such as colpotomy (in female patients). An electric morcellator (Cook Medical), which preserves minimum histological features, is an important aid. This apparatus should be available for standard use soon.

Specialized Equipment

Besides the basic laparoscopic instruments, it is necessary to have unique sets of instruments that are adapted to hepatic surgery. High-quality scopes with a 0°, but also 30° and even 45°, viewing range must be available. The 30° scope is indispensable, since it enables observation of the "blind" areas that cannot be seen by the traditional 0° scopes. The 30° allows visualization of the upper posterior side of the liver and the lateral regions. Moreover, the examination of the blood supply often requires a view of the base of the tumor, which can only be achieved with the 30° scope. Although it is the author's personal opinion that a 30° scope is not indispensable for other intra-abdominal operations carried out laparoscopically, it is an absolute necessity for operations on the liver.[6]

The video camera (Karl Storz) needs to be of high quality and must have the discernment capacity needed to realize complete hemostasis and biliostasis. The light source must be powerful (300 W xenon). Finally, the video monitors must also have the correct dimensions (at least 51 cm) and it is necessary to have two screens so that the surgeon and the assistants have a full comfortable view of the operation. There is nothing specific about the trocars but sufficient trocars (Ethicon Endosurgery, Inc.) should be available, as well as sufficient instrumentation. The forceps used on the liver should be atraumatic, preferably with no teeth. The so-called "crocodile" forceps, or forceps with large teeth, are ineffective and increase the risk of hemorrhage. All of the forceps should be insulated and preferably rotating. The surgeon should have rotating coagulation scissors and an insulated hook. Both should be insulated to the tips. For laparoscopic liver surgery, automatic clip appliers, which allow the clips to be loaded without withdrawing the instruments for reloading, must be available. Finally, stapling devices with vascular clips will be useful for certain vascular pedicles, providing complete safety. Among the more specific instruments, the Nd:YAG laser and the ultrasonic dissector (CUSA-Lap, Valleylab Inc., Boulder, CO) should be mentioned. The Nd:YAG laser is the instrument that is the most adapted to surgery of the liver. Due to its capacity of greater penetration than the CO_2 and argon lasers, it enables a correct cut to be carried out. This was demonstrated experimentally during the excision of hepatic metastases, which compared the YAG laser to conventional electrocautery.[14] At the conclusion of this randomized prospective experimental study, the YAG laser proved to be clearly superior. This instrument is very costly, however, and acquisition is best done on a multidisciplinary basis. The ultrasonic dissector (Tetrad Corp.) is also an extremely valuable instrument. It enables precise dissection of the hepatic parenchyma, exposing the vasculobiliary radicles, thus allowing step-by-step dissection of these structures. The ultrasonic dissector is ideal for the resection of small limited tumors, enabling enucleation with an adequate margin while maintaining control of pedicles. A laparoscopic ultrasound probe (Tetrad Corp.) is a very useful tool especially if coupled with a Doppler.

Another instrument that could be of great help in liver resections is the Harmonic Scissors from Ultracision. The instrument works on high-speed oscillations of the blades that induce cutting and hemostasis without thermal damage. Some experimental work by Swanstrom and his team in Portland, Oregon, has shown an efficient sealing of biliary ducts with this device. Appropriate needle holders are also mandatory; a range of models is available. Pretied catgut endoligatures should be available, and finer sutures should also be available for internal suturing. These should be strong and monofilament, preferably without memory. This kind of monofilament ligature is also useful for extracorporeal tying with the Roeder knot. The specimen bags must be strong and equipped with a closing system. Cook and Advanced Surgical are companies manufacturing appropriate bags.

Tissucol fibrin glue (Immuno, Vienna, Austria) is indispensable for hemostasis after laparoscopic hepatic resection. Its ideal application in this area is on the raw hepatic surfaces. This adhesive fibrin sealant is available in various concentrations and various setting times. It should be applied without pressure to the raw surface of the liver at the end of the resection. Omentum can also be used to advantage in covering the raw surfaces of the liver, at the end of the procedure.

Position of the Patient and the Operating Team

We have opted for the so-called "French" position: the surgeon positions himself between the patient's lower limbs, which are spread and placed in special supports. This position is very comfortable for the surgeon, who does not have to bend unnecessarily, and it provides a symmetrical view "across from" the patient. It also allows free use of the hands, while enabling the foot pedals to be maneuvered. This is also very convenient for the assistants on each side. The two monitors are placed on each side of the anesthesiologist, near the head of the patient, so that the whole arrangement is coherent and ergonomic. The scrub nurse should be to the right of the surgeon, beside the assistant, allowing him or her to pass the instruments to the surgeon's right hand. The position of the patient will be the same as in open surgery, with a wide operating field. All of the traditional basic instruments for open surgery must be on hand in a sterilized area in the operating room, in case the need for conversion arises. The usual rules of anesthesiology for hepatic surgery are followed, but it is necessary to emphasize that the anesthesiologist must be aware of the additional hazards of laparoscopic surgery. Measures must be taken to ensure that there is equipment in the room for rapid transfusion of blood. A sufficient supply of plasma and blood must also be readily available. With proper preparation and equipment, laparoscopic surgery can take place in relative comfort and safety (Figure 21.2).

Approach to the Liver

A minimum of four trocars and cannulae will be introduced if the planned intervention is more than just di-

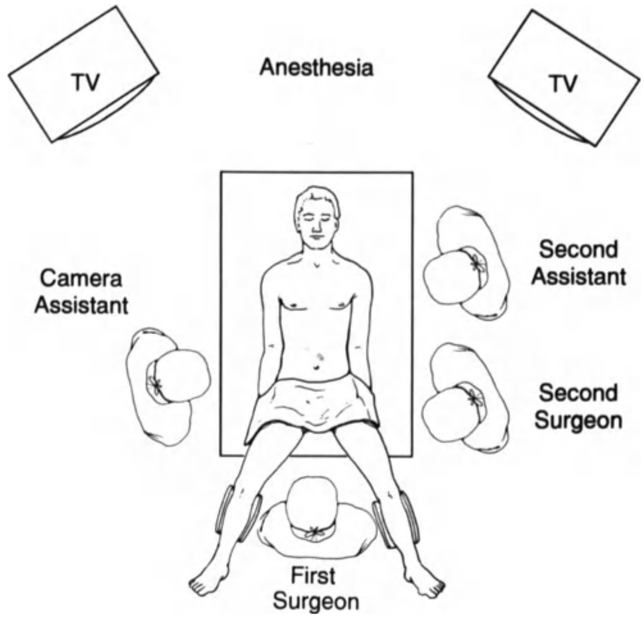


FIGURE 21.2. French position.

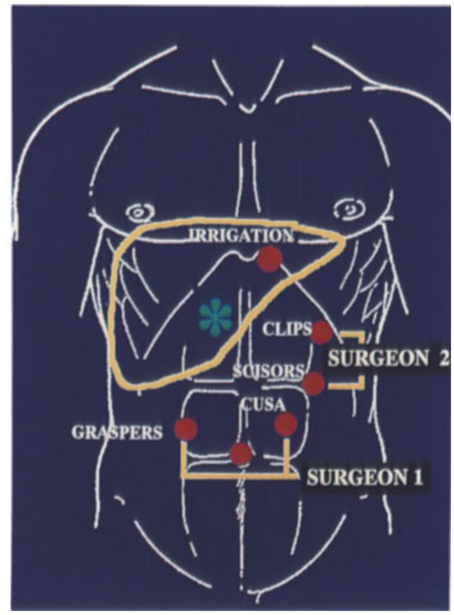


FIGURE 21.3. Four hands technique.

agnostic laparoscopy. The placement of the trocars will allow enough space between them to avoid the "knitting needle" effect of the various instruments. The cannula for the endoscope is usually introduced in the umbilicus, with a cannula for the graspers on the left side and one for the instruments on the right side. This triangle is converted to a rectangle by placing the fourth trocar for the palpator and the irrigation/aspiration probe. This general scheme can be changed according to the location of the lesion and the surgeon's operating style. There is no ideal position for the trocars in this kind of surgery. All trocars must be at least 10 mm in order to allow repositioning of the camera for visualization of the lesion and the parenchyma from different angles. Other trocars—five or six is a maximal number—will be introduced for the use of the YAG laser or the ultrasonic surgical dissector (CUSA). More trocars can affect the operative ergonomy. A new personal concept is the four hands approach, with two surgeons operating simultaneously. One surgeon uses a grasper and the laparoscopic CUSA while the other surgeon manipulates scissors and clip appliers (Figure 21.3).

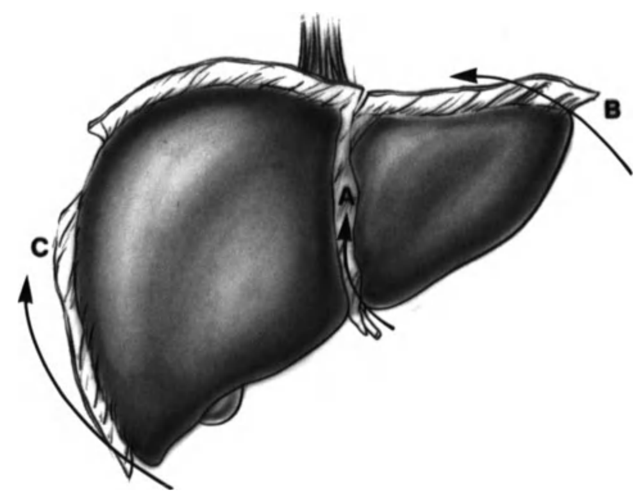


FIGURE 21.4. Laparoscopic mobilization of the liver. A = falciform ligament; B = left triangular ligament; C = right triangular ligament.

Maneuvers Common to All Hepatic Laparoscopic Surgery

As in open surgery, hepatic laparoscopic surgery begins by mobilizing the liver (Figure 21.4). This is key to the success of this type of surgery, as it clears the area surrounding the lesion, so that there is direct and precise access. This procedure, which is familiar to all hepatobiliary surgeons, is as follows: division and ligation of the round ligament between clips; section of the falciform ligament in order that the upper and posterior surface of the liver can be lowered; section of the left triangular ligament, in the event that the lesion is in the left lobe; and partial division of the right triangular ligament, which is more difficult in the case of a right posterior lesion. In the event of a major resection, it is necessary to be able to approach the side of the superior vena cava and the trifurcation of the hepatic veins, in particular the left hepatic vein. A careful dissection and mobilization can be extremely useful, in case a resection of the left lobe becomes necessary. Once the liver is completely mobilized, an ultrasound probe coupled with color Doppler will help define the anatomy and the connection of the lesion to the surrounding vascular structures before an incision is made in Glisson's capsule. This will be done with either a coagulating hook or the YAG laser. Next, long forceps will simulate finger fracture methods. The ultrasonic dissector is convenient at this point, enabling parenchymatous pulverization, while preserving the vasculobiliary elements. All these large-sized vascular and biliary radicles must be clipped and, in the case of major vessels or biliary ducts, surgeons must not hesitate to resort to using extracorporeal ligatures (sliding Roeder knots). Finally, at the end of the operation, the resected specimen must always be contained in a bag that allows extraction without spillage. This extraction is usually done by enlarging the umbilical opening. The specimen can be partially morcellated with Kelly forceps, should an electric morcellator not be available, but it should never be reduced to total pulp, since this would prevent any type of postoperative histological and pathological examination. If the patient is a woman and the specimen is large, it is possible to extract it via a posterior colpotomy, which of course requires appropriate and precise reapproximation. This type of extraction does not entail any delayed complications if the repair is done correctly.

Diagnostic Laparoscopy

As we have already specified in the discussion concerning indications, diagnostic laparoscopy of the liver is extremely important in liver malignancies, as it enables the detection of small tumors as well as metastases. It also provides for directed biopsy to be carried out with ease, due to the magnification provided. It is also possible to examine the lesions macroscopically and to confirm or invalidate the preoperative diagnostic assessment. Laparoscopic ultrasonography is an invaluable technique in the study of the liver. Some users who already have a considerable experience show images that are similar to the images obtained by intraoperative ultrasonography carried out during open surgery. Laparoscopic ultrasonography enables the detection of deeper-lying metastases, as well as allowing the definition of attachment to vital structures, such as the hepatic veins. The hepatic pedicles as well as the hilum can be clearly seen. Biopsies can be carried out without fear of causing major hemorrhage or bile leaks. These ultrasonography probes are always being improved and we can expect very effective instrumentation in the near future, which will increase the precision of laparoscopy, especially when coupled with Doppler probes.

Laparoscopic Treatment of Biliary Cysts

Biliary cysts are intrahepatic lesions that do not communicate usually with the biliary tree. These cysts are lined with a biliary-like epithelium and generally contain a clear serous fluid. They are usually classified as either simple biliary cysts or as components of polycystic liver disease.[15,16] Simple biliary cysts are detected in as many as 2 to 4% of routine hepatic ultrasonographic examinations. Polycystic liver disease is a hereditary disease, transmitted as an autosomal-dominant trait, and is clinically associated with progressive hepatomegaly as well as multiple renal cysts. The vast majority of biliary cysts are asymptomatic even as their size and number increase with time. In 5 to 10% of patients, however, symptoms can occur as these cysts enlarge and compress adjacent structures. Therefore such patients can present with gastric or duodenal obstruction, jaundice, or even portal hypertension.[15,16] Although less common, biliary cysts may become infected, bleed (intracystic hemorrhage), or rupture into the peritoneal cavity. In the past, patients with symptomatic biliary cysts were treated by percutaneous aspiration alone, aspiration followed by alcohol injection, or unroofing of the cyst wall via open laparotomy.[17] Although percutaneous aspiration has been popular in the recent past, its effect is usually transient. Recently it has been shown that both solitary and multiple biliary cysts can be successfully managed laparoscopically.[6,10,18]

Technique

Four laparoscopic cannulae are introduced. Careful evaluation of the preoperative imaging study will help to guide the surgeon to the sites of biliary cyst formation. When viewed laparoscopically, these cysts usually appear as convex distortions along the surface of the liver, and often have a characteristic bluish color to them. The dome of the cyst is identified and opened with an electrocautery hook or curved scissors.

A spurt of serous fluid and collapse of the cyst then usually occur. This fluid is collected with an aspiration probe and sent for bacteriologic studies. The incision over the cyst is enlarged and the remaining fluid is removed. The wall of the cyst is then grasped with a forceps and excised with an electrocautery hook or curved scissors. This dissection is continued until the entire accessible portion of the cyst wall is excised to a point within 2 mm of the cyst-parenchyma junction. A portion of the cyst wall should be sent for histologic examination. Hemostasis is confirmed and attention is then directed to the next cystic lesion. In patients with multiple cysts, one can often unroof a deeper cyst through a previously opened cyst cavity (so-called transcystic fenestration). These maneuvers are repeated until all possible cysts are opened, drained, and excised. In most patients, postoperative drainage catheters are not necessary (Figure 21.5A–D).

Results

From June 1989 to January 1994, we performed laparoscopic biliary transcystic fenestration in a total of 27 patients (14 women, 13 men). The mean age was 51 years. All were found to be symptomatic, experiencing epigastric pain, gastric compression, and painful hepatomegaly. All patients were treated in a manner similar to that outlined above. Follow-up ranges from 2 to 50 months. To date, there have been no operative complications and all patients remain asymptomatic. Although there is no evidence of cyst recurrence at this time, a longer period of observation will be necessary to determine the long-term effectiveness of this operative approach, especially in those patients with polycystic disease.

Laparoscopic Treatment of Hydatid Cysts

It is possible to perform a wide excision of hydatid cysts, a parasitic lesion of the liver resulting from infestation by the parasite *Echinococcus granulosus.* The definitive host of this tapeworm is the dog, with man, sheep, and cattle being intermediate hosts. The dog is infected after ingesting the viscera of sheep that contain the hydatid cysts. Scolices within the cysts attach themselves to the small bowel of the dog and develop into adult worms. Ova are then later shed by the worm into the lumen of the intestine and are carried out with the feces, contaminating grass and crops. Infection in man occurs after the ingestion of contaminated vegetables or even after simple handling of the dog (because the ova also adhere to the animal's hair). The outer envelope of the ova is dissolved by the gastric juices and the liberated ova then penetrate the wall of the intestine. Cysts are then carried by the portal blood flow into the liver, where they develop into adult cysts. Although far less common, ova can also be found in lungs, spleen, brain, and bone.[19,20] Hydatid cysts are more often found in the right lobe of the liver and usually invoke a strong inflammatory reaction within the surrounding parenchyma. At the periphery, fibroblasts are attracted, forming a thick capsule-like layer that often calcifies.

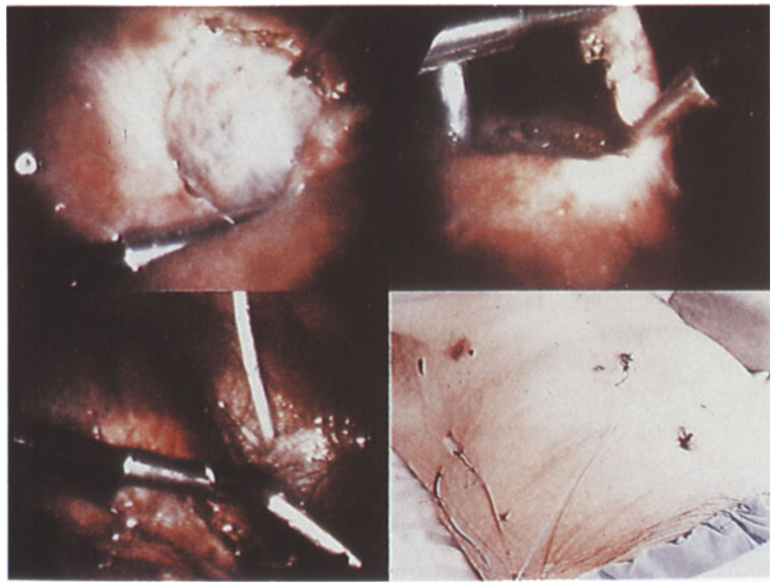
Untreated hydatid cysts will frequently rupture into the peritoneal cavity, resulting in anaphylactic shock, peritonitis, or bowel obstruction. The cyst may also decompress into the bile ducts, leading to cholangitis, and the bile ducts may become secondarily infected with bacteria. Anthelmintic drugs are ineffectual against *Echinococcus,* therefore the only effective method of treatment remains surgical excision.[19,20] At Saint Roch Hospital in Nice, France, 215 patients with 266 hydatid cysts have been operated on since 1970 in open surgery, thus representing one of the largest experiences in the world. In the past year, we have begun offering selected patients a laparoscopic approach to total cyst excision.[9] This is done in the case of favorably located cysts (anterior segments). If the cyst is located posteriorly or near the vena cava, the deroofing technique should be performed.

Technique

The principle of the laparoscopic approach is identical to the conventional procedure. A complete pericystectomy is performed without opening the hydatidoma (Figure 21.6). A plane of dissection is created adjacent to the capsule-like cyst wall but outside of the very friable hepatic parenchyma, which is often found next to the hydatidoma.

The patient is positioned as described earlier, with the surgeon standing between the patient's legs. Pneumoperitoneum is established via either the percutaneous or open technique, and four laparoscopic cannulae are inserted. An abdominal exploration is performed to detect additional lesions that may have been missed on the preoperative imaging studies. In the case of a total pericystectomy, we do not routinely instill alcohol or hypertonic saline solution into the cyst to kill the scolices and daughter cysts as has been reported by other authors.[19] Patients with one or more hydatid cysts often have inflammatory adhesions in and around the liver, and these should be freed using electrocautery scissors. Occasionally it is necessary to divide the triangular ligament to obtain access to lesions within the left lobe of the liver. To facilitate hemostasis, the electrocautery scissors are also used to accomplish this maneuver because there is usually a moderate-sized vein coursing within these tissues.

After the hydatid cyst is exposed, the liver capsule (Glisson's capsule) surrounding the lesion is scored with the contact-tip Nd:YAG laser set at 50 W (continuous mode) (Figure 21.7). If there is persistent bleeding from smaller blood vessels, the sapphire tip can be removed and the defocused beam used for coagulation. This dissection is carried out slowly and methodically around the perimeter of the lesion. The electrocautery spatula has also proved useful for this portion of the procedure. The rounded tip of the instrument is used to bluntly dissect within the hepatic parenchyma. In contrast to other laparoscopic procedures, the electrocautery hook is rarely employed. The magnification of the video laparoscope system is a real advantage during this segment of the operation because it allows the surgeon to identify even the smallest vascular and biliary structures within this tissue plane. Vessels and ducts larger than 1 to 2 mm in diam-



A B C D

FIGURE 21.5. Treatment of biliary cysts. (A) Deroofing of biliary cysts. (B) Specimen removal. (C) Transcystic fenestration. (D) Small suction drains (rarely used).

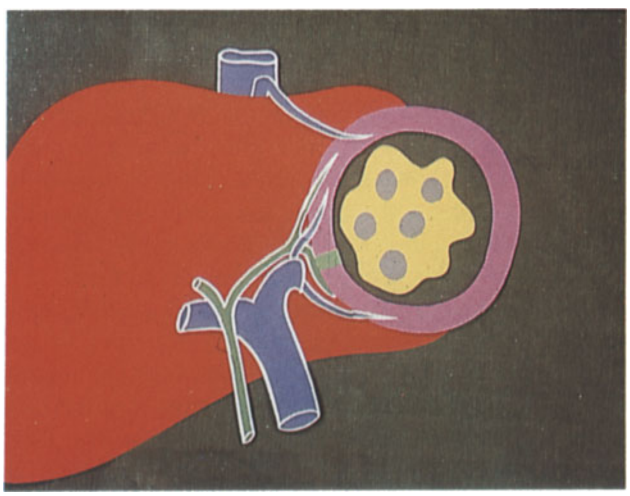


FIGURE 21.6. Total pericystectomy for liver hydatid cyst.

FIGURE 21.7. Resection of hydatid cyst using Nd:YAG laser.

eter are individually ligated with surgical clips and divided with scissors. Another method of providing hemostasis is the application of fibrin glue (Immuno Corp., Vienna, Austria). This material can be applied along the operative plane and has proved very effective in controlling problematic bleeding within the liver tissue. Fibrin glue can also successfully control bile leakage from smaller transected ducts.

The operative dissection is continued until the entire cyst has been freed from the liver. Often smaller probes are used to expose the deeper portions of the tissue plane. If necessary, additional cannulae should be inserted to help to provide the necessary exposure. Blind dissection deep within the cavity space should be avoided because of the risk of cyst perforation. After the hydatid cyst is removed from the liver, it is placed within a sterile bag in preparation for extraction. Use of an impermeable strong bag minimizes the risk of the cyst contents spilling into the peritoneal cavity. The bag and enclosed hydatid cyst are then removed through the umbilical fascial defect. If necessary, this opening can be gradually dilated until it is large enough to accommodate the specimen. Alternatively, a large Kelly clamp can be inserted through the fascial opening and into the bag and used to morcellate the tissues. An automatic or electrically powered morcellating device is also available[6]; however, morcellation with such instruments makes histologic examination of the specimen more difficult.

Following removal of the cyst, the operative site is carefully examined for bleeding or bile leakage. In addition to the electrocautery spatula and Nd:YAG laser, fibrin glue can be used to ensure hemostasis and control bile leaks. After the cyst is completely removed, glue can be injected into the cavity space. Both edges of the cavity are then compressed and held in place with atraumatic forceps until bleeding or bile leakage is controlled. Closed suction drainage catheters are then placed along the liver edge under laparoscopic guidance. Such drains are routinely employed in open hepatic resection surgery so we have decided to continue this practice with the laparoscopic approach. The CO_2 is completely removed from the peritoneal cavity, which in our experience significantly diminishes the amount of postoperative discomfort. If the umbilical fascial opening has been dilated, it is closed in a separate layer. The skin incisions are then closed with sutures or staples.

Special Considerations

In patients with very large hydatid lesions, there may be numerous vascular and ductal attachments. In these cases it is important to have an accurate "road map" of these structures. If such an involvement is suspected preoperatively, selective arteriography and cholangiography should be considered. If a major bile duct leakage is suspected during the operative procedure, the surgeon can perform cholecystectomy and obtain a standard cholangiogram. Alternatively, the surgeon may inject methylene blue through the cholangiogram catheter and look for extravasation within the cyst cavity. On the basis of these studies, the surgeon can decide whether the intrahepatic bile duct can be simply occluded with laparoscopically placed sutures or repaired over a stent (which may require open laparotomy). In the case of a posterior cyst, the deroofing technique should be preferred. In order to kill the parasite, instillation of hypertonic saline should precede the resection of the dome.

Results

At present, we have performed laparoscopic hydatid cyst removal in three patients with one or more lesions. There was no mortality or identified complications. Patients were discharged on the third postoperative day, which is dramatically sooner than when similar patients who have undergone open laparotomy are released from the hospital (mean, seven days). Postoperative imaging studies have been done in all three patients and have confirmed complete resolution of the cysts.

Conclusion

Preliminary experience has shown that laparoscopic surgical techniques may have an important role in the treatment of patients with focal liver abnormalities. For example, patients with solitary liver metastasis from an adenocarcinoma of the colon may be considered candidates for laparoscopic resection, especially since recent data suggest that simple wedge resection is adequate.[14,21]

Confined Resection of Minor Neoplastic Lesions

Metastasectomy best illustrates these techniques (Figure 21.8). A small-sized metastasis in the left lobe is the ideal example of a lesion that can safely be resected using laparoscopy. Four trocars are necessary for access: the umbilical trocar for the video laparoscope, two lateral trocars for grasping forceps and other instruments, and one subxiphoid trocar for the irrigation/aspiration probe. This same cannula can also provide access for Nd:YAG laser fiber and the clip applier. The surgeon begins resection by incising Glisson's capsule 2 cm from the metastatic lesion. Several studies have confirmed that such a margin was adequate. After laser incision there is less smoke than carbonization with conventional electric cautery; this smoke must be intermittently suctioned through the xiphoid irrigation/aspiration cannula. It is then necessary to progressively dissect deeper into the hepatic parenchyma, while separating the edges of the liver with the left-handed forceps. It is sometimes necessary to add a fifth trocar for the insertion of the grasping forceps to be used by the assistant in carefully exposing the tumor. This will create a groove through which a hook or coagulating scissors can pass. Atraumatic forceps will allow the minute structures to be coagulated as they pass through this groove. In the case of larger vessels, clips must be used. It is recommended that a double-clipping technique be used to avoid inadvertent avulsion of a single clip from the vascular pedicle. It is necessary to use the irrigation/aspiration probe in the deep groove of the liver to keep the operating field dry. Maintenance of a bloodless field,

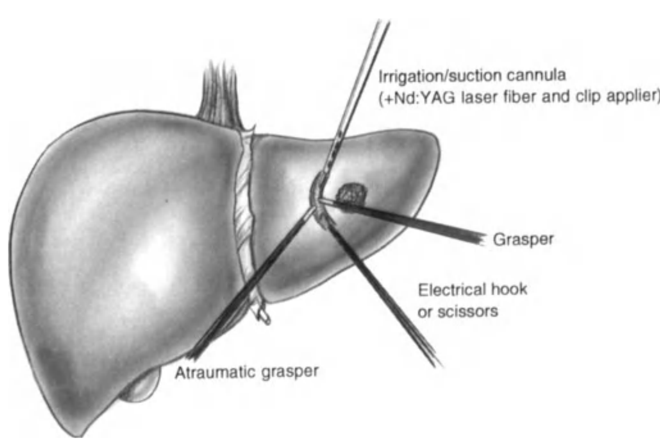


FIGURE 21.8. Laparoscopic metastasectomy.

enabling constant rinsing of the dissection area, is critical. Once dissection is complete, it is necessary to insert a cannula to deliver the fibrin glue (Tissucol, Immuno, Vienna, Austria). This is the last step of the operation.

In cases of small metastasectomy, drainage is not necessary. In cases of larger metastases, we routinely perform cholangiography at the conclusion of the resection, to identify possible biliary leaks. This, of course, cannot be done without a cholecystectomy. Metastases of a maximum of 5 to 8 cm can be extracted without difficulty by enlarging the fascial incision at the umbilicus, so that the extracted specimen is left intact.

Broader Resections, Left Lobectomy (Left Lateral Segmentectomy)

This approach is aimed at larger tumors localized in the left lobe for which enucleation may be incomplete and inadequate treatment. Larger lesions in the left lobe may also be optimally treated by formal lobectomy, as the enucleation procedure may actually be dangerous. A left lobectomy (American left lateral segmentectomy), however, should only be considered by surgeons who have extensive experience in laparoscopy, as these maneuvers are so much easier when performed through open surgery. Laparoscopic left lobectomy nevertheless follows the same rules as open surgery, and must be preceded by a careful hepatic vascular isolation, which can be done with a little patience and by using extracorporeal ligatures. A dissection into the parenchyma will be done after the incision in Glisson's capsule, allowing the deep intraparenchymous dissection and encountering the different elements of segments II and III, which will be clearly visible and recognizable. This will have to be controlled with the aid of clips reinforced with ligatures, thus ensuring complete hemostasis and ligation of the biliary radicles. Finally, the left hepatic vein can be controlled and divided using a vascular stapler. In general, the lobectomy specimen, which must then be placed in an extraction bag, can only be withdrawn if it undergoes some degree of morcellation or, in the case of a female patient, by posterior colpotomy. The raw hepatic surface is inspected and hemostasis completed. A cholangiographic examination for the purpose of detecting possible bile leaks is very useful. The application of fibrin glue is invaluable. The greater omentum can be used to cover the raw surface of the liver at the termination of the procedure. After left lobectomy, we recommend placing two suction drains near the edge of the wound to collect any minor persistent ooze of blood or bile, and to prevent hematomas. Smaller resections, such as limited segmentectomies (wedge) are done in the same way and with the same concern for hemostasis and control of the biliary radicles. One cannot overemphasize the need for precise vascular control to avoid CO_2 gas embolization. In general, the risk in laparoscopic surgery is minimal, as the gynecological series has demonstrated. It is, however, much greater during the surgery of organs that are well vascularized, such as the spleen and the liver, since they are directly linked to the inferior vena cava and to the heart. The risk is significant and should be a constant concern. The patient must be constantly monitored by the anesthesiologist. The emboli are sometimes only detected by the recovery room staff after extubation, and staff must be aware of this possible delayed complication (Figure 21.9).

Treatment and Prevention of Intraoperative Complications

The major intraoperative complication is hemorrhage. Minimal oozing can be controlled with unipolar or bipolar forceps; a coagulating spatula enabling flat application of the coagulating current is also very useful. In the case of more serious arterial bleeding (where there is a clearly visible spurt of blood), it is necessary to grasp the artery with atraumatic forceps and immediately apply a clip or ligature. Management of venous bleeding in hepatic surgery tends to be more complicated since there is often a constant ooze, and hemostasis can be extremely difficult. Placing sutures laparoscopically is not easy, but panic should be avoided; often an appropriate temporary tamponade will stabilize the situation so that the extent of the venous injury can be assessed. It is also possible to control the hemorrhage by a Pringle maneuver using a large atraumatic clamp (Figure 21.9). Bleeding from a small lacerated vein can generally be controlled with coagulation or a clip. If the venous injury is more extensive, such as in a hepatic vein or a branch of the portal vein, one must not hesitate to convert and perform a subcostal incision, which will then allow precise and sufficient access and enable the operation to be concluded safely. It should be stressed that conversion is not an admission of failure, but good surgical judgment. The safety of the patient is always the first priority. Control of biliary leaks is generally easier to accomplish, since the biliary drainage can be seen clearly with the magnification provided by the laparoscope. Another complication that can suddenly appear is that of CO_2 gas embolization. It is necessary to emphasize the importance of careful handling of large vessels inside the parenchyma and the avoidance of injury with scissors. Division of these vessels must only take

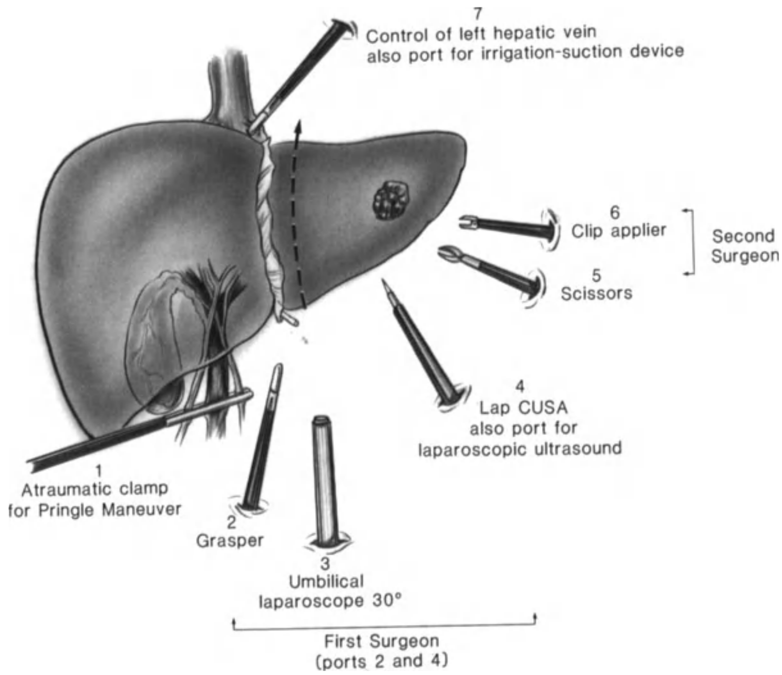


FIGURE 21.9. Laparoscopic left lobectomy (four hands approach).

place after coagulation, or control with clips or ligatures. Finally, there remains the difficulty of extracting the large specimen, which has already been mentioned.

Conclusion

It is important to approach laparoscopic liver resection with the attitude that it is a very complex operation requiring a considerable amount of experience and a high level of competence. This surgery is an attractive alternative to open surgery in the field of diagnostic laparoscopy, and is very useful for resection of confined lesions. It avoids large incisions, which are painful and disabling. Laparoscopy is particularly useful in the evaluation of widespread metastases, obviating the need for laparotomy. The efficacy of this kind of surgery needs to be assessed by evaluation of the results, and therefore multicentric trials are required.

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22
Laparoscopic Splenectomy

Stephen Wise Unger and Gary J. Rosenbaum

Advanced laparoscopic techniques, including intracorporeal and extracorporeal knot tying, and the wide variety of new instrumentation, along with all of the advances in video and laparoscopic imaging, have allowed the skilled laparoscopic surgeon to perform splenectomy with laparoscopic assistance. Several surgeons have presented their initial cases.[1–4] While the operation is technically feasible, the indications and techniques of dissection are still being defined. In Galen's time, the spleen was linked to such emotions as happiness, anger, and even to athletic prowess. As laparoscopic cholecystectomy and laparoscopic herniorrhaphy have forced surgeons to focus their view of the anatomy to a level that was never appreciated previously, similar applications of laparoscopy to treatment of splenic problems has engendered an important understanding of the anatomy and spacial relationships of the spleen, which must be elucidated in order to safely operate on this organ with laparoscopic guidance.

Historical Review

The first reported case of splenectomy for an enlarged spleen was attributed to Leonard Fiorvanti in 1549, while the first elective splenectomy with survival was performed in the late 1860s[5] by Wells in England. In all of these early cases, death after splenectomy was traditionally a result of pancreatic injury, hemorrhage, or infection. Even as late as the early 1900s, splenectomy in the elective situation still carried as high as a 35% mortality. In 1920, Mayo[5] reported a series of 243 splenectomies with a mortality rate of 6.6%, which was extraordinarily low that time. With the improvement in techniques and development of antibiotics, the ensuing 35 years saw a lowering of the mortality rate to present day standards. It was not until 1952, however, that the association between splenectomy and subsequent overwhelming sepsis was detailed by King and Schumacker.[6] In the 1970s, the concept of splenic salvage was the major innovation in splenic surgery and techniques detailing the methods of saving spleens were elucidated.[7–10] In June of 1990, Clayman[11] described his technique for laparoscopic nephrectomy, and that, coupled with the rapid international popularization of laparoscopic cholecystectomy, led to the natural consideration of the spleen as an organ that could be removed laparoscopically. Its hilar dissection encompassed all of the techniques of dissecting in the porta hepatis and its retrieval was a natural extension of the retrieval of the kidney.

Indications for Splenectomy

Indications for splenectomy include hemolytic anemias such as hereditary spherocytosis, elliptocytosis, and enzyme-deficient hemolytic anemias. Thalassemia, sickle cell disease, and idiopathic autoimmune hemolytic anemia may require a splenectomy. In addition, the purpuras, including idiopathic thrombocytopenia purpura and thrombotic thrombocytopenic purpura, are indications for splenectomy. There are multiple causes of secondary hypersplenism, including underlying diseases of cirrhosis, myloproliferative disease, or lymphoproliferative disorders and primary hematologic diseases, including lymphoma, chronic lymphocytic leukemia, and myeloid metaplasia. Splenectomy may be indicated in patients with myloproliferative disorders when the pancytopenia reaches a level that becomes dangerous, either from a hemorrhage or infectious standpoint. Other disorders requiring splenectomy include Felty's syndrome, sarcoidosis, and Gaucher's disease. Unusual conditions requiring splenectomy include infarcts, cystic lesions of the spleen, incidental tumors, abscesses, and occasionally splenic artery aneurysms that require splenectomy for removal. All efforts should be made to salvage the spleen during surgery for trauma. Trauma remains the single largest indication for splenectomy. Clearly, some spleens can become so enlarged that laparoscopic removal may be impossible. On the other hand, there are many instances when the patient's condition would make laparoscopic removal worthwhile because of the potential for faster recovery time. Indications for open versus laparoscopic removal have not been determined. In order to understand the rationale for either open or a laparoscopic approach to the spleen, it is important to clearly understand the anatomy and physiology of the organ.

Anatomy

The weight of the spleen in a normal, healthy adult ranges between 100 and 150 g. The spleen is composed of trabeculae and a pulp enclosed in a 1- to 2-mm capsule. The peritoneum extends from the anterior and posterior aspects of the stomach wall to envelop the hilum of the spleen. This attachment is known as the gastrosplenic ligament and contains the short gastric vessels. This ligament is attached inferiorly to the greater omentum. The posterior aspect of the spleen has peritoneal attachments as well. These attachments extend inferiorly, laterally, and superiorly to form the ligaments known as the spleno- or lienocolic, splenorenal, and splenophrenic ligaments, respectively (Figure 22.1). The location and makeup of these ligaments play a major role in the dissection of the spleen. This is important because applied traction and countertraction are clearly different in open and laparoscopic approaches.

The spleen is usually 12 × 8 × 3 cm. It is located in the left upper quadrant of the abdomen against the diaphragm laterally. Ribs 9 through 11 provide a protective shelter, as well as a potentially damaging cover. In the normal individual, it is unusual to palpate the spleen below the costal margin. The visceral surface of the spleen

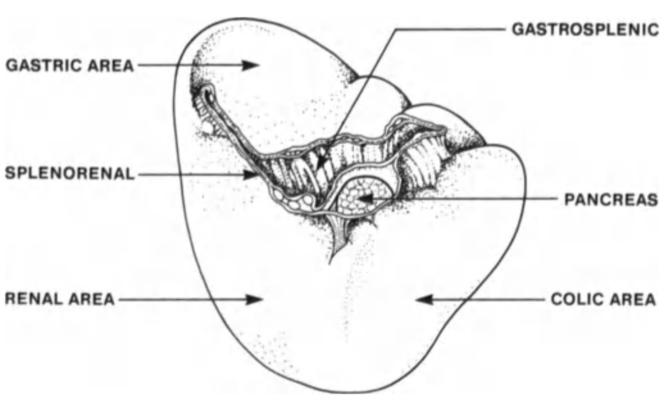

FIGURE 22.1. Surfaces and ligaments of the spleen. Note that the pancreatic surface impinges, in many cases, directly on the splenic surface and that the gastrosplenic ligament contains the major vessels. These relationships change depending on the size of the spleen, stomach, kidney, and colon.

is in contact with the posterior aspect of the stomach, the anterior superior aspect of the left kidney, and the anterior edge of the colon. Depressions are noted in the splenic surface by these organs as they rest in contact with the spleen. These surfaces, and the relationships of the peritoneovascular ligaments that border them, may be affected by chronic distention of either the stomach or colon, or enlargement of the spleen or kidney, and may have an impact on the operative technique used to dissect them (Figure 22.1). The arterial supply of the spleen arises from the celiac trunk. The splenic artery is the largest of the three vessels that arise from the trunk. The splenic artery travels posterior to the omental bursa, anterior to the left kidney, and along the superior aspect of the pancreas. The splenorenal ligament, at its opening at the hilum, contains the artery and the tail of the pancreas. It is estimated that in 15 to 30% of patients, the pancreas is in direct apposition to the medial surface of the spleen. This ligament is essentially avascular, except in the area of the hilum, where the artery passes through it.

As the artery courses medially and laterally, it gives off branches to the pancreas and then divides into the left gastroepiploic artery, the short gastric arteries, and finally branches to the spleen itself. In the majority of patients, the arteries of the spleen separate into segmental branches that supply the superior, middle, and inferior portions of the organ. The short gastrics are branches of the superior hilar artery. The end branches of the splenic artery form terminal arteries that, once inside the spleen, further separate into trabecular branches. Terminal branches are end arteries and do not have anastomoses between them, so obstruction will lead to infarction of the areas supplied. There are two patterns of blood supply of the splenic artery to the hilum of the spleen. The first is the *magistral,* where a long splenic artery divides into short terminal branches near the hilum, entering over one-third to one-fourth of the medial surface of the spleen. The second is the *distributed* type, in which a splenic trunk is short and the vessels actually enter over approximately three-fourths of the surface of the medial vein. These patterns have obvious implications for both laparoscopic and open dissection and are pictured in Figure 22.2.[12]

The splenic vein is formed by a number of tributaries arising in the hilum. In most cases, the splenic artery is anterior and superior to the vein. This is a very important relationship for both the laparoscopic and the open dissection. Attempts to encircle the artery put the inferiorly apposed vein at risk for perforation by blunt dissection, as the vein travels along the posterior aspect of the tail and body of the pancreas. It is joined by the superior mesenteric vein to form the portal vein, along with the left gastroepopolic, pancreatic, and inferior mesenteric veins. The short gastric veins may also drain directly into the spleen rather than into the splenic vein.

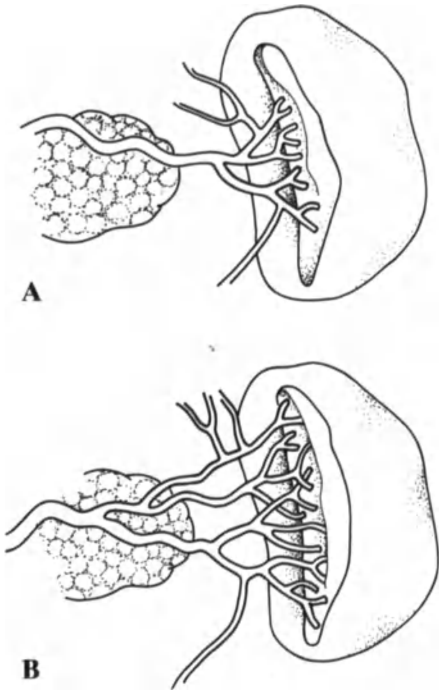

FIGURE 22.2. The magistral (A) and distributed (B) blood supply.

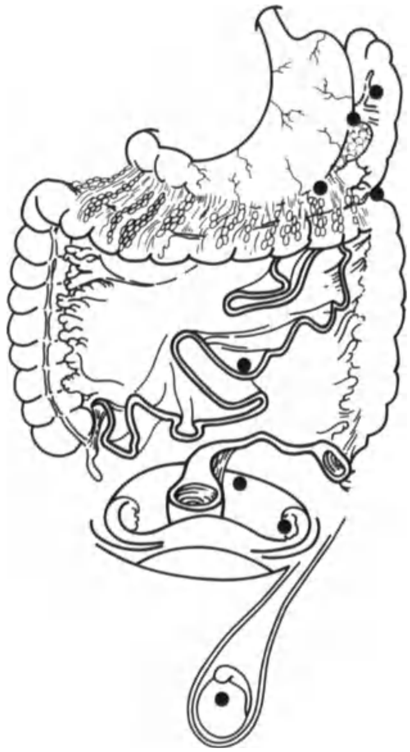

FIGURE 22.3. Possible locations of accessory spleens include the splenic hilum, the tail of the pancreas, the splenocolic ligament, the greater omentum and perirenal fascia, the mesentery of the small bowel, the perirectal area, and the adenexa and the peritesticular areas.

Lymphatic vessels arise from the capsule and trabeculae of the splenic cord. They, along with the splenic vessels, drain into the pancreaticosplenic lymph nodes found on the posterior surface of the pancreas. Nerves to the spleen arise from the celiac plexus and follow the course of the splenic artery, functioning in a vasomotor capacity, which is purely sympathetic.

The embryologic formation of the spleen occurs in the dorsomesogastrium, where there is fusion of mesodermal buds. This fusion occurs as the stomach is undergoing its rotation. The dorsomesogastrium is the future peritoneum. Incomplete fusion of these buds while the peritoneum is evolving, result in the creation of accessory spleens and, hence, their position when they are present (15 to 30% of patients) is most commonly in the hilum of the spleen, followed by each of the ligamentous attachments, the small bowel mesentery, the omentum, and adjacent to structures of the pelvis (Figure 22.3).

Immunologic Effects of Splenectomy

King and Schumacher,[6] in 1952, were the first to note the association between overwhelming sepsis and splenectomy. The spleen plays a critical role in the removal of poorly opsonized antigens. These antigens are usually found on encapsulated bacteria. Overwhelming postsplenectomy infection (OPSI) is characterized by the abrupt onset of weakness that rapidly progresses to bacteremia and sepsis. Coma and death ensue in over 60% of patients. Singer[13] found that infants who underwent splenectomy had an increased incidence of OPSI, which was as high as 200 times the general population. Interestingly, posttraumatic splenectomy patients have a significantly lower incidence of OPSI, compared to those who undergo splenectomy for hematologic disorders. The chance of OPSI developing in a patient with a hematologic disorder is 15 to 20 times greater than in the patient who has had a splenectomy for trauma.[14] It is believed that the patient with hypersplenism from hematologic disorders has additional immune deficiency problems.[14] However, there is usually no impairment of serum opsonization or chemotactic activity following splenectomy for trauma. Splenectomy also results in decreased IgM production and poor antibody response.[14] In addition, these patients have decreased production of properdin, which is an activator of the alternative compliment pathway, which functions in a bactericidal and opsonic fashion. The most effective way to prevent OPSI is to avoid splenectomy, especially in children under the age of two years. Septic mortality in infants ranges from 0.5 to 10%. Pneumococcus species account for the vast majority of cases; however, *Escherichia coli, Hemophilus influenzae,* and *Neisseria meningitidis* are often responsible. Patients who have splenectomy should have pneumococcal vaccine and newer vaccines protect against other etiologic bacteria. Prophylactic penicillin still remains controversial. Most important from a prevention standpoint, is awareness on the part of the patient of his asplenic state, and the suggestion that he undergo early antibiotic intervention for any potential bacterial infection.

Physiology

During the middle and late stages of fetal development, the spleen is significantly involved in the production of red and white blood cells. This does not continue into adult life. The primary function of the spleen in the adult is related to the reticuloendothelial and immunologic functions. Most of the hematologic indications for splenectomy, however, arise from the hyperfunction or dysfunction of this reticuloendothelial system.

Splenic pulp is divided into a red, white, and marginal zone. The white pulp consists of lymphatic tissue made up of lymphocytes, plasma cells, and macrophages. The red pulp contains sinusoids, plasma cells, and macrophages. Blood travels through the splenic artery, to terminal branches that enter the spleen from trabecular arteries. These arteries enter the white pulp as the central arteries. Other branches will traverse the white pulp and terminate in the marginal zone or red pulp. Those in the red pulp deposit the blood into the splenic sinuses, which are essentially the first venous structures of the spleen. They, in turn, drain into the trabecular veins, which drain into terminal veins and finally into the splenic vein.

The tissue between the sinuses is a meshwork of reticuloendothelial fibers and cells that function to remove cellular debris from blood. This meshwork is referred to as the splenic cords. As red cells traverse these cords and sinuses, deformed cells are identified and retrieved from the meshwork (as Howell-Jolley and Heinz bodies) and removed from circulation. During the course of the day, the spleen removes about 20 mL of blood. The constant, unobstructed flow of blood prevents the removal of additional red cells.

Hypersplenism refers to any situation in which the spleen removes excessive amounts of red cells, white cells, or platelets. Hemodynamic abnormalities effecting splenic blood flow make cells vulnerable to extraction by the splenic macrophages. Congestion of the spleen produces a sludging of the blood in the sinuses and red pulp. This results in hypoxia to the cells and renders them more susceptible to extraction. The production of antibodies to red cells, white cells, or platelets makes those cells vulnerable to extraction and is another cause of hypersplenism. Criteria used in the diagnosis of hypersplenism include splenomegaly; splenic destruction of the cell line; normal or hyperplastic cellularity of marrow, with normal representation of the cell line deficient in the circulation; and increased cell turnover in the cell lines affected. Increased numbers of banded neutrophils, immature platelet formation, and nucleated red blood cells can cause increased cell turnover. The hallmark of red cell turnover is reticulocytosis in the absence of blood loss. Neutrophils are removed by the spleen following a half-life of about six hours. The spleen's role in the production of neutropenia may actually be due to sequestration of neutrophils by the enlarged spleen. Platelets survive about 10 days. The action of the spleen in removing platelets has not been adequately demonstrated; however, of note is that 33% of the body platelet pool is located in the spleen and in cases of splenomegaly, this percentage may increase to 90% and result in circulating thrombocytopenia. Removal of the spleen in these patients results in a transient thrombocytosis that may exceed one million.

Principle Behind the Open Technique

Open splenectomy is performed through a generous left subcostal midline or left paramedian incision, depending on the indications (elective, trauma, or staging) or on the surgeon's preference. The ligamentous attachments are mobilized first. Once the splenophrenic, splenorenal, splenocolic, and retroperitoneal reflections are mobilized, the spleen can be lifted anteromedially so the splenic hilum is in full view, and blood vessels can be easily identified. Short gastric vessels in the gastrosplenic ligament are dissected, with progression from superior towards the hilum. This prevents excess tension and tears of the short gastrics if the hilum is dissected first and the spleen is pulled against the remaining short gastric attachments. Attention is paid to identification of the tail of the pancreas, as the organ is pulled ventrally and medially. Short gastrics are ligated away from the stomach and hilar vessels are ligated away from the pancreatic tail, to prevent gastric wall necrosis and pancreatic trauma. Hilar vessels are clamped and ligated, and most authors suggest suture ligature of these vessels to prevent dislodgment of the ligature with gastric distention. However, care must be taken not to injure the gastric surface because of the risk of gastric necrosis from the crush effect. Finally, the hilar vessels are clamped, individually ligated, and the spleen is removed. It is best to ligate the arterial supply first to avoid excessive sequestration of blood in the spleen. It is recommended that the splenic vessels not be ligated en masse because of the risk of arteriovenous fistula formation. At the completion of the dissection, the bed is inspected. Care should be taken to look at the gastric surface, residual of the splenocolic ligament, the diaphragmatic surface, and the retroperitoneum for points of bleeding, which may become problematic. In addition, assessment of the tail of the pancreas for potential injury must be performed, and in cases where there is a possibility of injury to the tail of the pancreas, a closed suction drainage device should be placed.

Rationale or Justification of the Laparoscopic Approach

With newer cameras, roticulating and articulating instruments, and better grasping instruments, as well as stapling devices, it is now possible to retract and carefully dissect anatomic structures with limited risk of injuring adjoining structures and vessels. Laparoscopic splenectomy can be successfully performed in selected patients where length of surgery is not critical, and where the patient can tolerate the pneumoperitoneum and steep changes in table position during the procedure. Also, the surgeon must understand that the minimally invasive approach can be converted to an open procedure. The laparoscopic procedure is justified if these criteria are met, as the patient may recuperate with a shorter hospital stay, less pain, and a rapid return to normal activities. In these circumstances, postoperative morbidity, and even mortality, may be reduced.

Laparoscopic Technique

Most patients undergoing elective splenectomy will have nontraumatic indications for surgery. Preoperative preparation should include routine laboratory tests and chest x-rays. For older patients, an electrocardiogram may be indicated as well. If at all possible, the patient should donate autologous blood, and in those patients with hematologic disorders, counts just prior to surgery may help in determining whether platelets or other blood products are indicated at the time of surgery. Our technique for laparoscopic splenectomy will be described in the following section and alternate techniques will then be compared.

Patient Position

The patient is placed in the supine position. The abdomen is entered at the umbilicus with a 10- or 11-mm cannula. Once the abdomen is explored, the patient is usually rotated into a right-side down, steep reverse Trendelenburg position in order to throw the intestinal contents away from the left upper quadrant. A roll is placed longitudinally in the left lower back between the posterior iliac crest and the inferior margin of the rib cage. This rotates the patient slightly to the right side. In addition, the operating room table is flexed slightly at the level of the patient's kidney. Together with the roll and the table position, the spleen is elevated up out of the depths of the left upper quadrant.

Cannula Placement

A five-puncture technique is employed, as illustrated in Figure 22.4. In addition to the umbilical cannula, 12-mm cannulae are placed in the left lower quadrant, lateral rectus position, adjacent to the mirror image of McBurney's point and inferior to the anterior axillary line. Smaller cannulae may be placed in the epigastrium, one in the subxyphoid position, and the other just to the right of the falciform ligament. It is important to place the inferior left lower quadrant cannula far enough away from the anterior superior iliac spine, so that the surgeon does not have to torque against the iliac crest in order to gain mobility. The other advantage of placing the two left lower quadrant incisions close to one another is that if the incision needs to be enlarged to remove the spleen, these two incisions may be joined in the "bathing suit line" leaving a cosmetically acceptable scar and minimizing the total number of incisions on the abdomen.

Procedure

In addition to reverse Trendelenburg and table tilt to the right, it is ideal if the arms are tucked at the sides. An atraumatic grasper is placed through the subxyphoid port and, either the stomach wall or the stomach wall including the nasogastric tube, is grasped high on the greater curvature of the stomach and retracted to the right. This splays out the gastrosplenic ligament and the short gastric vessels. Gentle countertraction on the spleen is naturally

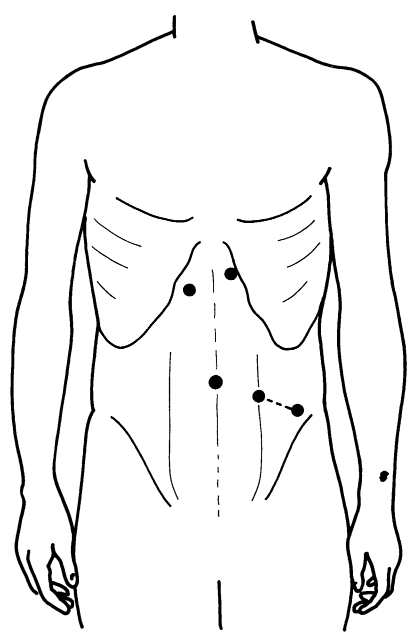

FIGURE 22.4. Cannula placement for laparoscopic splenectomy. The two left lower quadrant sites can be connected to provide an excellent site for specimen removal.

provided by the ligamentous attachments or with an additional instrument or fan retractor (Figure 22.5). The omentum is swept away from the spleen via the right subcostal port, using a dissector. Once cleared, the hilum and splenic vessels are exposed. Occasionally, the colon will still bulge up in the way of the dissection, and a retracting fan may replace the dissector in the right subcostal port and push the colon inferiorly. This exposes the splenocolic ligament on the inferior aspect of the spleen. Using the left McBurney's port as access, the ligament is excised using electrocautery scissors. Except in the cases of portal hypertension, or malignant adhesions, these attachments are avascular. In general, the only ligamentous attachments that have a vascular supply are the short gastrics in the gastrosplenic ligament. Electrocautery can be used for these attachments.

Once the splenocolic ligament is incised, it is possible to lift the spleen from the infraposterior medial aspect, using a second fan retractor through the left lateral port. Lifting the spleen will further distance it from the colon, as well as produce an excellent exposure of the segmental arteries and veins as they perforate the splenic capsule. Dissection is continued through the left McBurney's port access. Vessels are doubly clipped close to the spleen, starting inferiorly and working superiorly. Each vessel is individually dissected. It is preferable to use a roticulating dissector, taking care not to puncture the veins that often lie posterior and inferior to the arteries. Surgeons should always be aware that ports of dissection can be changed and the laparoscope can be shifted to give a different perspective of these vessels, as the dissection proceeds. The splenic artery and veins should be isolated separately and individually clipped, transected with the linear stapler-cutter device, or ligated with extracorporeal suturing techniques. The laparoscope provides a magnified, detailed, close-up view of the dissection and should prevent pancreatic injury. As the vessels are detached from the spleen, the fan retractor continues to lift the spleen from the undersurface. It is important to leave the splenophrenic and splenorenal attachments intact as this dissection proceeds. If they are taken down ahead of time, the final attachment to the spleen will be the short gastrics and the risk of the spleen "cartwheeling" and tearing or avulsing these highly vascular attachments is increased.

While the short gastrics are still in place, but before removing the spleen, it is wise to scan the splenic hilum, peripancreatic area, lesser sac, and omentum for accessory spleens. During the general exploration of the abdomen, the pelvis should have been inspected for accessory spleens. If there is a high index of suspicion, or a hematologic reason for ensuring that all splenic tissues have been removed, it may be wise to explore the omentum and examine the small bowel from ligament of Treitz to ileocecal valve, looking at its mesentery. Each of the short gastrics should be ligated separately and then transected. Using the fan retractor, the spleen is moved medially and inferiorly to the remaining attachments, until the diaphragm, left kidney, and retroperitoneum are taken down.

FIGURE 22.5. Photograph shows the fan retractors pulling the colon down and the spleen laterally, allowing an atraumatic clamp on the stomach to move the stomach medially and splay out the splenogastric ligament. Dissection proceeds through the mid lower port.

The spleen is then placed in a pouch which is brought out through the left McBurney's port. The spleen can then be morselated using a suction catheter, finger dissection, or morselation device. Prior to performing this step, it is important to discuss the appearance of the tissue with the pathologist. There is a risk of spillage and subsequent splenosis. Care should be taken to avoid damage to the bag and contamination of the abdomen. In cases where morselation should not or cannot be done, a muscle splitting incision, which is a mirror image of an appendectomy incision, could be made adjoining the two left lower quadrant cannula sites. At completion of the procedure, the exit wound is sutured, the abdomen is reinflated, irrigated, a final check for hemostasis is performed, and the incisions are closed. Infiltration with 0.5% bipuvacaine will decrease the amount of postoperative pain.

Alternate Techniques

Most authors who have presented case reports in the literature use techniques that are similar to the previously described method. Carroll's group[1] uses a five-puncture technique, placing one in the subxyphoid position, one in the umbilicus, and then uses a left subcostal, right subcostal, and left paraumbilical cannula. Additionally, they recommend ligation of the main splenic artery at the superior border of the pancreas, as well as individual knot tying, and extracorporeal ligation of each of the splenic vessels.

Thibault and coworkers[4] use a variation of the French method, with the surgeon standing between the patient's legs. There is a 10-mm umbilical trocar, two 5-mm trocars just subcostal in either epigastrium, and two 12-mm trocars in the supraumbilical position, lateral to the rectus on either side. They also perform their dissection very close to the spleen, but recommend taking down the short gastric vessels with a linear stapler-cutter. They recommend the use of a "zip-lock bag" with subsequent finger fracture of the specimen. Dalaitre and Maigniem[2] also emphasize the French position with two additional assistants, the first standing on the left side of the table and the second on the right. They use a large right upper quadrant cannula, which is large enough to place a Babcock clamp, fan retractor, or stapler. A 5-mm left paramedian site is used as a suction irrigator. They use a left subcostal port for scissors and forceps dissection, and place a 12-mm port in the left upper quadrant for placement of the stapler-cutter, if needed. They use bipolar cautery for all of the ligamentous transections. Clips are used to transect the inferior splenic polar artery and then they go across the pedicle with a single fire of a linear stapler-cutter. Clips are used for the short gastric vessels. Then the spleen is placed in a bag. In order to fracture the spleen prior to extracting the specimen, a Mayo scissors is inserted through the left lower quadrant incision and through the neck of the bag.

Gazayerli[15] places 10-mm ports in the umbilicus, epigastrium, and left lateral rectus margin below the umbilicus; a 12-mm port in the left anterior axillary line inferiorly; and a 5-mm port in the epigastrium. He emphasizes the use of a 45° scope. Then he retracts the spleen laterally, divides the short gastric vessels, and then places a linear stapler-cutter across the pedicle. Gazayerli has emphasized preoperative embolization of the splenic vein. He is a proponent of extracorporeal ties with individual ligations of vessels.

Equipment Requirements

Several special instruments can be used to facilitate laparoscopic removal of the spleen. We use a 0° scope for most of our procedures, but the addition of a 30° and a 45° scope may make exposure of difficult to see posterior structures or the splenic hilum easier. Newer fan retractors are relatively atraumatic. They assist the retraction so much that they can be considered essential to the operative procedure. All of the currently available disposable and nondisposable retractors function because they are tubular structures on entering the abdomen, and then they expose the retractor surface by some kind of mechanism. When disengaging the mechanism, omentum, small vessels, or pieces of the organs being retracted must not be caught within the retractor mechanism. There is a risk of avulsion or bleeding. It is also important for the full range of ligating instrumentation to be available. This includes intracorporeal and extracorporeal knot tying devices, a full range of clip sizes, and the vascular cartridges for linear stapling devices. Ultrasonic dissection, the argon-beam coagulator, and various laser devices may be favored by certain workers, but we do not feel they are necessary for this operation.

Clinical Results

Laparoscopic splenectomy was performed on five young patients, ranging in age from 7 to 27 with indications including hereditary spherocytosis,[2] splenomegaly,[1] lymphoma,[1] and sickle cell disease.[1] Concomitant procedures included a cholecystectomy and appendectomy in the patient with sickle cell disease. The longest time of surgery was just over three hours. With experience, the length of time decreases rapidly. The length of stay in the hospital averaged two days, with the longest being three days, and one patient being discharged within 23 hours. Estimated blood loss was an average of < 160 cc. There was no significant morbidity and one conversion was necessary because of massive splenomegaly. These results are similar to those presented in Table 22.1, which reflect the findings of several other authors (personal communication). Of most importance in these series is the potential for large amounts of blood loss, as noted by several of the authors, and the small likelihood of conversion once the technique was mastered. Unlike the open approach to splenectomy, postoperative complications, such as atelectasis, ileus, pancreatitis, and wound infection are rare. Oral feeding is usually tolerated within 24 hours and no late sequelae are noted at a minimum of six months.

Comparison to the Open Technique

For the majority of general surgeons, the open technique is so familiar and technically easier that surgery time will be much shorter for open splenectomy. The major difference in the dissection is that of retraction. In the open procedure, the spleen is retracted medially and superiorly to take down all of its attachments before working with the vascular structures. In the laparoscopic dissection, the hilum is dissected first, and once all vascular structures are ligated and transected, the nonvascular attachments are taken down, freeing up the spleen. Extraction of the specimen itself is probably the easiest part of the open splenectomy, whereas it may be the limiting factor in laparoscopic splenectomy, as both bags and morcellating de-

TABLE 22.1. Author's survey of other surgeons' results with laparoscopic splenectomy.

Author	No. of patients in series	Age (yr)	Indication	Associated procedures	Length of surgery (hr)	Estimated blood loss (cc)	Length of stay (days)	Morbidity	Conversion to open
Rosenbaum & Drucker	5	7	Sickle cell disease	Cholecystectomy appendectomy	2.5	100	2	—	—
		11	Hereditary spherocytosis	Accessory spleen removal	3.0	50	2	—	—
		12	Hereditary spherocytosis	—	3.0	200	1	—	—
		15	Splenomegaly	—	1.5	100	3	—	Massive SP
		27	Lymphoma	—	3.5	350	3	—	—
Arregui	5	63	Splenic infarct	—	—	—	Prolonged	—	—
		85	Idiopathic thrombocytopenic purpura (ITP)	—	—	—	2	—	—
		28	HIV, ITP	—	—	—	2	—	—
		23	Hodgkin's staging	Liver biopsy Multiple node biopsies	—	—	4	Seroma of extraction wound	—
		67	Spontaneous rupture ?, trauma	—	Spleen left in	—	4	—	—
Gazayerli	1		Hereditary spherocytosis	—	—	—	—	—	—
	7		ITP						
Petelin	1		Hairy cell leukemia	—	—	—	—	—	—
Hashizume	2	55	ITP	—	6.0	—	—	—	—
		26	ITP	—	8.0	—	—	—	—
Carroll, Phillips	3	27	Hodgkin's staging	Liver biopsy Multiple node biopsies	3.0	100	4	—	—
		16	Hodgkin's staging	Liver biopsy Multiple node biopsies	3.0	800	5	—	Bleeding
		16	ITP	—	2.5	200	2	—	—
Thibault	2	61	Hemolytic anemia	—	—	1,000	> 7	POD #7 bleeding	—
		17	ITP	—	4.0	1,000	2	—	—
Dalaitre, Maignien	1	—	ITP	—	—	—	—	—	—

vices which will facilitate that portion of the operation are still in the design stage.

Advantages and Limitations

The advantages of laparoscopic splenectomy are similar to laparoscopic cholecystectomy. It allows select patients to undergo the procedure with a minimal amount of discomfort, rapid discharge from the hospital, and an extraordinarily short return to normal activities. In addition, with careful technique, the incidence of postsplenectomy pancreatitis, wound infection, atelectasis, and ileus should be lower. Similar to the morbidity associated with the learning curve of laparoscopic cholecystectomy,[16] there will probably be a similar morbidity associated with early laparoscopic splenectomy. Limitations of this procedure may include spleens that are so large that visualization and manipulation are simply impossible; spleens in which contamination of infected material may adversely affect the operation, and it may be better performed by open technique; and spleens in which the extraction requires such a large incision that taking the time to dissect the specimen out laparoscopically does not make sense, since the extraction incision has to be as large as if the operation were being performed via the open technique. In addition, the presence of occult, ectopic spleens may not be as easily identified using the laparoscopic approach. This is certainly true of spleens buried in the mesentery. However, it can be argued that visualization of the pelvis, a frequent site of ectopic splenic tissue, is better from a laparoscopic standpoint.

Laparoscopic treatment for trauma is one of the newer applications. In the course of an exploration for trauma, a ruptured or injured spleen may be identified. There are no reported cases of splenic salvage via the laparoscopic approach, although Arregui's case[17] (see Table 22.1) is an example of a controlled hemorrhage from a spleen, which was not removed, based on the laparoscopic findings. It would seem that stable tears of the spleen could be managed laparoscopically, either with suture ligature of the injuries, or application of hemostatic agents. Almost all of the techniques (application of microfibrillar collagen, application of fibrin glue, and encapsulating the spleen with mesh) can be performed via the laparoscopic approach, although this has not yet been reported.

Discussion

There is little question that it is technically possible to safely remove the spleen laparoscopically. This must be done in centers where the equipment is available for advanced laparoscopic procedures and the technical expertise of the surgeon, as well as the surgeon's judgment, allow a safe approach to splenectomy. Ideal candidates include patients with hematologic disorders, reasonably small-sized spleens, who are in adequate hemodynamic condition to undergo a potentially lengthy procedure with a pneumoperitoneum and changes in table position. As in our series, the ease of this operation in the pediatric age group makes them a particularly attractive group in which to apply the technology. The current instrumentation and technology is adequate to perform laparoscopic splenectomy. There are several steps in the dissection where advances might make the procedure easier. These include better retracting instruments; better and less traumatic grasping instruments; newer and easier ligating devices that are applicable to all of the general surgical population, making individual ligation of vessels a less formidable task for the "nonadvanced" laparoscopist; and finally, the development of extraction systems that will allow removal of a large organ through a small port without making extracted tissue useless as a specimen. These new systems will also help avoid spillage into the abdominal cavity. Rather than being considered a technical *tour de force,* laparoscopic splenectomy is a logical extension of advanced laparoscopic techniques and laparoscopic organ retrieval. The end result will be a safer, more easily tolerated operation, allowing the patient early recovery and more rapid return to normal activities.

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23 Laparoscopic Adrenalectomy

L. Michael Brunt and Nathaniel J. Soper

Adrenalectomy is a relatively recent addition to the growing list of surgical procedures that have been successfully performed using laparoscopic or minimally invasive surgical techniques. The adrenal glands are in many respects ideally suited to a laparoscopic approach, since most adrenal tumors are small in size and pathologically benign. However, the cephalad location of the adrenals in the retroperitoneum, superior to the kidneys and deep to other intra-abdominal organs, has limited their accessibility to most laparoscopic surgeons. Recently, several techniques have been reported for performing adrenalectomy using minimally invasive methods. The indications for adrenalectomy, technical aspects of laparoscopic adrenalectomy, and benefits and risks of the laparoscopic approach compared to open adrenalectomy are reviewed in this chapter.

Background

The adrenal glands are retroperitoneal organs located along the superior-medial aspect of each kidney. The adrenals are composed of a cortex and medulla, each of which has distinct endocrine functions. The adrenal cortex is the site of production of the steroid hormones—cortisol, aldosterone, and adrenal androgens. The adrenal medulla is the principal site for synthesis and secretion of the catecholamines—norepinephrine and epinephrine. Most tumors of the adrenal gland come to medical attention because of hypertension or other symptoms and signs associated with excess hormone production. Surgeons who attempt laparoscopic adrenalectomy should be well versed in the surgical anatomy of the adrenals and adhere to established principles of open adrenal surgery. Proper selection and preparation of patients for operation are also essential for a successful outcome. In this section, an overview of adrenal anatomy, the types of adrenal tumors and clinical hormone syndromes, and the operative approaches to open adrenalectomy are presented.

Adrenal Anatomy

Each adrenal gland weighs 4 to 6 g and measures approximately 4 to 5 cm × 2 to 3 cm × 0.5 to 1 cm in size. The right adrenal gland is somewhat pyramidal in shape, whereas the left gland assumes more of a flattened or crescent shape as it is applied to the kidney. The adrenal glands have a fibrous capsule and can be distinguished from the perirenal and retroperitoneal fat in which they are embedded by their golden orange color and the finely granular texture of the cortical surface. The gland itself has a friable consistency and, with surgical manipulation, is easily subject to capsular disruption, fragmentation, and bleeding.

The anatomy of the adrenal glands and their relationship to surrounding structures is important to understand in carrying out successful adrenalectomy, especially when considering a laparoscopic approach (Figures 23.1 and 23.2).[1] Posteriorly, both adrenals rest on the diaphragm. On the right side, the bare area of the liver and the hepatorenal ligament overlie the anterior surface of the adrenal. A portion of the anterior-medial border of the gland often lies beneath the inferior vena cava. The left adrenal gland is related anteriorly to the posterior omental bursa, which is bordered superiorly by the stomach and superior pole of the spleen, and inferiorly by the pancreas and splenic vein.

The adrenal gland has a rich blood supply derived from the inferior phrenic artery, branches of the aorta, and renal arteries (Figure 23.1). Numerous small arterial branches from these vessels enter along the medial aspect of the gland. The most important aspect of the surgical anatomy of the adrenal, however, relates to the adrenal vein. Each adrenal gland contains a single central vein,

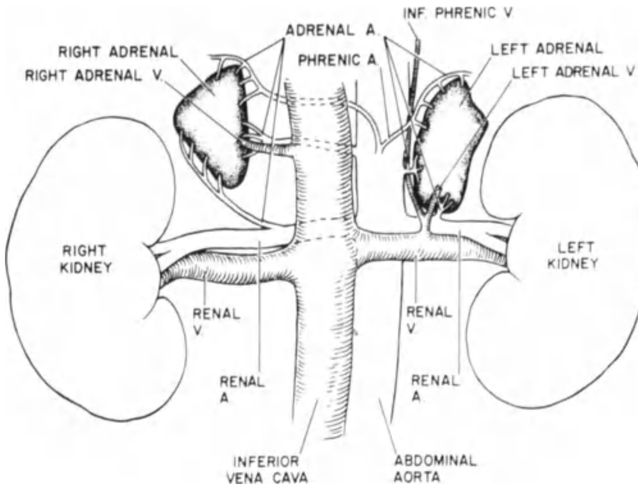

FIGURE 23.1. Anatomy of the adrenal glands. (By permission of Baxter JD, Tyrrell JB. The adrenal cortex. In: Felig P et al (eds). *Endocrinology and Metabolism.* 2nd ed. McGraw-Hill, 1987, p. 513.)

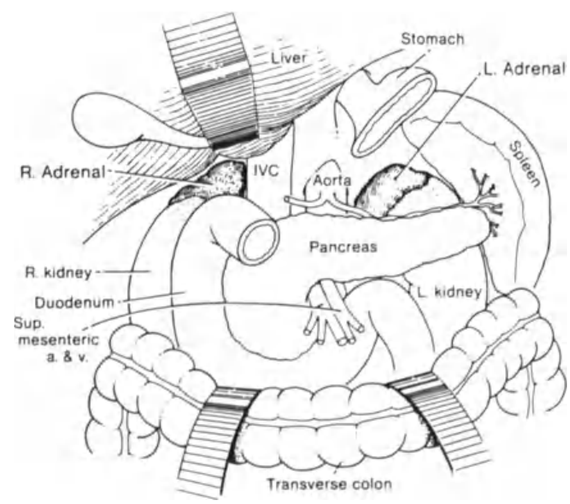

FIGURE 23.2. Anatomic relationships of the adrenal glands and surrounding structures as viewed from the anterior approach. (By permission of Scaljon WJ. Adrenal glands. In: Skandalakis JE, Gray SW, Rowe JS (eds). *Anatomical Complications in General Surgery.* McGraw-Hill, 1983, p. 189.)

which on the right side is short (0.5 to 1 cm in length) and wide and exits the gland medially to enter the posterior-medial aspect of the inferior vena cava. Occasionally, a second adrenal vein is seen on the right, separately entering the inferior vena cava or right hepatic vein. The left adrenal vein is several centimeters in length and, after exiting the gland anteriorly, courses obliquely to empty into the left renal vein. The inferior phrenic vein usually joins the left adrenal vein within 1.5 cm of its entry into the renal vein. Surgical control of the adrenal vein is potentially hazardous, particularly on the right side where laceration or avulsion of the vein can lead to tearing of the inferior vena cava and potentially catastrophic hemorrhage.

Indications for Adrenalectomy

Adrenal Cortical Tumors

Cushing's Syndrome

Excess production of glucocorticoids by the adrenal cortex results in the well-recognized pattern of physical signs and symptoms known as Cushing's syndrome. The most common cause of Cushing's syndrome, which accounts for 60 to 70% of cases, is pituitary hypersecretion of adrenocorticotropic hormone (ACTH) from a pituitary adenoma.[2] Primary adrenal tumors (adenomas and carcinoma) comprise 15 to 20% of cases and the remaining 15% are due to ectopic ACTH-secreting tumors. Biochemical screening for Cushing's syndrome begins with measurement of urinary cortisol excretion rates and plasma cortisol levels. Further biochemical evaluation with the dexamethasone suppression test may be useful in delineating pituitary from nonpituitary etiologies. Patients with elevated cortisol levels and low plasma ACTH levels should be suspected of having a primary adrenal lesion and undergo imaging of the adrenal glands with either a computerized tomographic (CT) scan or magnetic resonance imaging (MRI). Unilateral adrenalectomy is the procedure of choice for patients with Cushing's syndrome due to an adrenal cortical adenoma. Bilateral adrenalectomy is indicated in patients with bilateral adrenal hyperplasia secondary to pituitary Cushing's who have failed treatment of the primary pituitary lesion.

Aldosteronoma

Increased adrenal production of aldosterone by cells of the adrenal glomerulosa results in the syndrome of primary aldosteronism or Conn's syndrome. The hallmark features of hyperaldosteronism are hypertension associated with spontaneous hypokalemia. The principal causes of primary hyperaldosteronism are aldosterone-producing adenomas (65% of cases) and bilateral adrenal hyperplasia or idiopathic aldosteronism (35% of cases).[3] Primary aldosteronism is characterized by elevated plasma and urinary aldosterone levels associated with hypokalemia and suppressed plasma renin activity. Once the diagnosis of primary aldosteronism has been made, further distinction between an aldosterone-producing adenoma and idiopathic hyperaldosteronism is essential, since the latter does not respond well to surgical treatment and is more appropriately managed medically. The most useful studies for distinguishing these two forms of primary aldosteronism are adrenal imaging with a CT or MRI scan and adrenal venous sampling for aldosterone levels. Aldosterone-producing adenomas are typically small, benign tumors (1 to 3 cm) which makes them ideally suited to laparoscopic excision. Aldosterone-secreting adrenal carcinomas are extremely rare, and, when present, usually secrete other steroid hormones as well.

Adrenal Cortical Carcinoma

Adrenal cortical carcinomas are rare tumors that occur at a rate of approximately 1 case per 2,000,000 population per year.[4] Most patients present with large lesions > 6 cm in size and often have a palpable abdominal mass. These tumors are usually biochemically active and frequently produce cortisol, adrenal androgens, and other steroid hormone metabolites. Patients may have Cushing's syndrome or evidence of virilization due to these tumors. The diagnosis of adrenal cortical carcinoma can be difficult by histologic examination alone and is usually made on the basis of tumor size and weight (> 100 g), the presence of vascular or capsular invasion, local extension, and the presence of distant metastases to lung, liver, or bone.

Adrenal Medullary Tumors

Pheochromocytoma

Pheochromocytomas are catecholamine-secreting tumors that arise within the chromaffin tissue of the sympathetic nervous system. Pheochromocytomas are uncommon, and account for only 0.1% of patients with diastolic hypertension.[5] The vast majority of pheochromocytomas occur within the adrenal medulla, but 10 to 15% of these tumors occur in extra-adrenal sites. Pheochromocytomas are bilateral in 10% of cases and about 10% are malignant. The classic presentation of a patient with pheochromocytoma is recurrent paroxysmal spells of hypertension, headaches, palpitations, anxiety, and sweating. The diagnosis is established by demonstrating increased urinary levels of catecholamines and catecholamine metabolites (vanillylmandelic acid and metanephrines). Measurement of plasma catecholamines may occasionally be needed to make the diagnosis in patients with episodic catecholamine secretion. Since most pheochromocytomas are found within the adrenal gland, they can be readily localized with either a CT or MRI scan. The advantage of the MRI scan is that pheochromocytomas have a bright signal intensity on T2 weighted images, whereas adrenal cortical lesions have a lower T2 signal intensity.[6] Radionuclide scanning with ^{131}I-metaiodylbenzylguanidine (MIBG), which is taken-up by pheochromocytomas but not by normal adrenal medullary tissue, is useful in localizing pheochromocytomas in patients with suspected extra-adrenal tumors or malignant lesions.[7] Preoperative α adrenergic receptor blockade and expansion of intravascular fluid volume are critical for avoiding a hypertensive crisis during surgical manipulation and removal of the tumor. β adrenergic blockade is reserved for patients with cardiac arrhythmias and tumors secreting predominantly epinephrine.

Other Adrenal Tumors

The widespread use of CT scanning in the evaluation of abdominal disorders has led to an increased identification of asymptomatic adrenal masses. Most of these lesions are benign, nonfunctioning cortical adenomas. The initial step in evaluating an incidentally discovered adrenal mass is to perform biochemical screening studies, particularly to rule out excess cortisol production or to exclude a pheochromocytoma. If these studies are negative and the lesion is small (< 3 cm), the adrenal mass can be followed with serial CT examinations. Large lesions (> 6 cm) should be removed, regardless of functional status, because of the risk of adrenal cortical carcinoma. The management of patients with intermediate size lesions (3 to 6 cm) is controversial.[2] Most authors recommend the removal of these lesions even though the risk of carcinoma is low. If the tumor appears to be nonfunctioning by biochemical screening studies, then serial follow-up with CT scanning is an alternative approach. Laparoscopic adrenalectomy may prove to be the preferred method of management for patients with intermediate size lesions.

The adrenal gland is a common site for metastases from other malignant neoplasms. The most frequent sources of adrenal metastases are carcinomas of the lung, breast, stomach, and melanomas.[8] The diagnosis can usually be confirmed by fine-needle aspiration or biopsy. Open biopsy or adrenalectomy is reserved for cases in which a needle biopsy is nondiagnostic or rare cases in which excision of a metastasis is indicated for therapeutic reasons.

Myelolipomas are benign, nonfunctioning adrenal tumors that consist of a mixture of mature adipose tissue and hematopoietic elements. Most myelolipomas are asymptomatic and require removal only if they produce symptoms or become quite large. True cysts of the adrenal gland are rarely seen. Most adrenal cysts are pseudocysts due to cystic degeneration of an adrenal neoplasm. They rarely cause symptoms but have on occasion been associated with massive retroperitoneal hemorrhage.

Open Operative Approaches to Adrenalectomy

A variety of open operative approaches are available for performing adrenalectomy. The four principal approaches utilized are the anterior transabdominal approach, the lateral flank approach, the posterior retroperitoneal approach, and the thoracoabdominal approach. The size of the adrenal lesion and nature of the pathology are the primary factors that influence the choice of operative approach. Anterior transabdominal adrenalectomy is carried out via a bilateral subcostal incision. The advantage of this operation is that it provides superior access and exposure for larger tumors and allows for simultaneous manual exploration of the contralateral adrenal. In addition to the excision of large adrenal masses, this operation has been used historically for performing bilateral adrenalectomy for Cushing's disease and for removal of pheochromocytomas. The disadvantage of the transabdominal approach is that it entails making a large, painful incision and is associated with postoperative gastrointestinal and respiratory complications and a slow return to full physical activity. As methods for preoperative localization of adrenal masses have become more precise in recent years, the need for transabdominal exploration has become less compelling in many cases, and most patients can now be managed with posterior unilateral or bilateral adrenalectomy.

Posterior retroperitoneal adrenalectomy is carried out with the patient in the prone jackknife position. A hockey stick type incision is then made from the 10th rib inferior and laterally to the iliac crest. The latissimus dorsi muscle and lumbodorsal fascia are divided and the 12th rib is resected subperiosteally, reflecting the adjacent pleura superiorly. Gerotta's fascia is opened, exposing the kidney and adrenal gland. Of all the open operative approaches, the posterior incision provides the most direct access to the adrenal glands. Furthermore, it avoids the need to mobilize and retract overlying intra-abdominal organs and is carried out entirely within the retroperitoneum. Consequently, this approach has been associated with fewer complications, a shortened hospital stay, and a more rapid convalescence than transabdominal adrenalectomy.[9] Posterior adrenalectomy is ideally suited for the excision of small, unilateral adrenal neoplasms or for bilateral adrenalectomy in patients with pituitary Cushing's syndrome.

The lateral (flank) approach is performed with the patient in the standard nephrectomy position with a 45° tilt. Its current application as an open procedure is primarily for patients with large tumors or for reoperations on the adrenal. The flank approach has also been used to remove pheochromocytomas when preoperative localization studies have clearly localized the lesion to the adrenal and demonstrated a normal contralateral gland.[10] The thoracoabdominal incision is generally restricted to patients with very large adrenocortical carcinomas (> 10 to 15 cm) that cannot be removed with a conventional transabdominal approach.

Technique of Laparoscopic Adrenalectomy

Laparoscopic adrenalectomy is a new procedure in which a variety of different approaches have been utilized, and the preferred method for performing the procedure has not yet been firmly established. To date, reports of successful laparoscopic adrenalectomy in humans have been limited to anecdotal reports of small numbers of cases, with the exception of the relatively large series recently reported by Gagner and colleagues in Montreal.[11] Developmental studies of laparoscopic adrenalectomy in experimental animal models have also been limited.[12] The basic goal of the laparoscopic approaches used thus far has been to duplicate the most commonly used open surgical approaches to adrenalectomy—anterior transabdominal approach, lateral flank approach through the abdomen, and posterior retroperitoneal approach. Regardless of the method of laparoscopic adrenalectomy, two basic principles for removal of the adrenal glands should apply: (1) extracapsular dissection of the gland to avoid tearing and fragmentation, as this may result in implantation of adrenal tumor in the retroperitoneum; and (2) a meticulous dissection technique and hemostasis with particular attention to safe and secure ligation of the adrenal vein.

The basic operating room (OR) set-up for performing laparoscopic adrenalectomy is shown in Figure 23.3. In addition to the standard video system, camera, and insufflator, the laparoscopic equipment available for performing adrenalectomy includes an angled videotelescope (30°, 45°, or flexible), a basic instrumentation set,

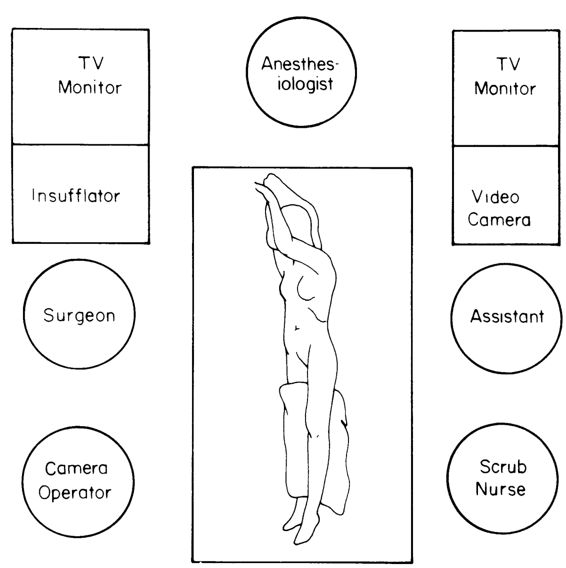

FIGURE 23.3. Operating room set-up for laparoscopic left adrenalectomy. The surgeon is positioned on the opposite side of the table for right adrenalectomy.

cautery scissors, atraumatic grasping forceps, an endoscopic clip applier (9 or 11 mm), and an impermeable entrapment sac for removing the gland. A fan type retractor may also be useful, particularly for retracting the liver during right adrenalectomy. All ports and trocars should be 10 to 11 mm in diameter to allow complete flexibility in positioning the videotelescope, dissecting scissors, and grasping and retracting instruments. Most adrenal lesions are small enough to be removed via the entrapment sac, with only minimal enlargement of the incision. Morcellation of the tissue to allow removal of large specimens through the 10- to 11-mm port incision site, as has been done with laparoscopic nephrectomy,[13] should be used judiciously, if at all, because of the importance of pathologic examination of the excised adrenal.

Laparoscopic Transabdominal Adrenalectomy with a Lateral Flank Approach

The greatest success with laparoscopic adrenalectomy to date has been with the transabdominal lateral flank approach as developed by Gagner and colleagues in Montreal.[11] First reported in September 1992,[14] Gagner and colleagues have since performed 21 laparoscopic adrenalectomies in 18 patients using this method, with only one patient requiring conversion to an open adrenalectomy.

The method for laparoscopic transabdominal adrenalectomy using the lateral flank approach as originally described by Gagner and associates[11] is as follows. The patient is placed in a lateral decubitus position with the left side up for left adrenalectomy (Figure 23.4) and right side up for right adrenalectomy. The OR table may also be flexed to allow greater access to the flank area where the laparoscopic ports are to be placed. The patient should be secured to the OR table with tape and safety straps to prevent patient movement and to allow tilting the table into the reverse Trendelenburg position. A bean bag placed under the patient will provide further security and limit movement of the patient due to positional changes during the operation. Care must be taken to pad pressure points such as the axilla and hip to avoid complications of nerve compression.

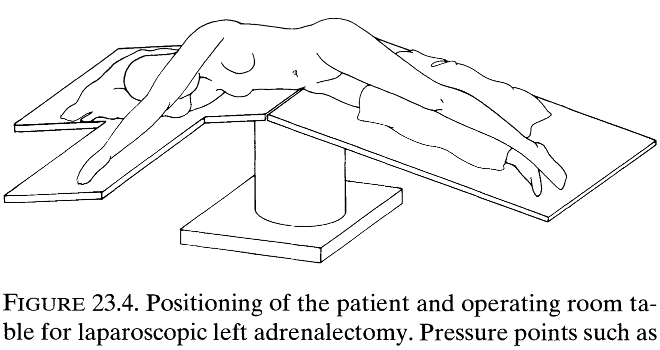

FIGURE 23.4. Positioning of the patient and operating room table for laparoscopic left adrenalectomy. Pressure points such as the axilla and hips should be well padded to prevent nerve compression injuries.

The operation begins with insertion of the Veress needle into the abdominal cavity in the subcostal region between the midclavicular and anterior axillary lines. Position is confirmed with aspiration and the saline drop test, and the abdomen is insufflated with CO_2 to 15 mm Hg pressure. The volume of CO_2 required to achieve 15 mm Hg may be less than expected because of the lateral position of the patient. A 10- to 11-mm trocar is placed into the abdominal cavity at the site of Veress needle insufflation and a 30° videotelescope is inserted. Two additional 10- to 11-mm ports are then inserted under direct vision in the flank below the 12th rib and above the iliac crest as shown in Figure 23.5. Placement of these ports may be facilitated by flexing the OR table to open up the flank region. Before the more dorsal fourth port can be placed at the level of the posterior axillary line, mobilization of the splenic flexure of the colon on the left and right triangular ligament of the liver and hepatic flexure of the colon on the right with entry into the retroperitoneal space is usually necessary.

For left laparoscopic adrenalectomy, the splenic flexure of the colon is mobilized by incising its lateral peritoneal attachments and freeing it from the inferior pole of the spleen, using cautery scissors. The retroperitoneal

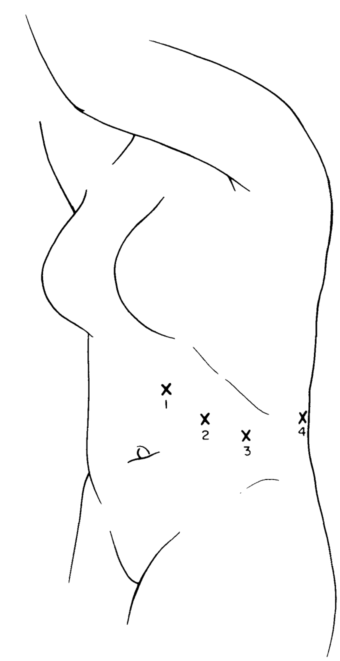

FIGURE 23.5. Sites of port placement for laparoscopic left adrenalectomy. Port 1 is placed subcostally at the mid-clavicular level. Port 2 is placed in the anterior axillary line, port 3 is midway between the anterior and posterior axillary lines, and port 4 is at the posterior axillary line. The ports are placed in a mirror image position for right adrenalectomy.

space between the spleen and kidney is then opened by dividing the splenorenal ligament. This ligament can be used for gently retracting the spleen medially. Placing the patient in the reverse Trendelenburg position at this point may facilitate the exposure by allowing inferior displacement of the intestines and any fluid that accumulates during the dissection. The dissection then proceeds superiorly between the spleen and kidney toward the diaphragm at which point the adrenal gland should come into view (Figure 23.6).

The adrenal gland itself is distinguishable from surrounding retroperitoneal fat by its golden orange color and the granular texture of the cortical surface. The superior pole of the adrenal gland is mobilized first, followed by the medial aspect of the gland, where most of the arterial blood supply enters. Mobilization of the adrenal and control of its blood supply are accomplished using cautery scissors with liberal application of endoscopically placed clips for discreet arterial branches. A second atraumatic grasper should be used to retract the adrenal gently and provide traction, either by depressing the kidney or gently retracting the adrenal itself, taking care not to disrupt the capsule of the gland. The video camera, dissecting instruments, and grasper should be moved freely between the different port sites to maximize visualization and provide the proper angles for efficient dissection and retraction. As the dissection progresses inferiorly, the central adrenal vein comes into view. This vessel is doubly ligated with endoscopic clips and divided. The lateral aspect of the adrenal is relatively avascular and may be mobilized before or after the adrenal vein has been ligated. After the gland has been completely freed from surrounding tissues, it is placed in an impermeable entrapment sac. The retroperitoneal dissection site is then irrigated with saline solution and inspected for bleeding sites with special attention to the adrenal vein. The entrapment sac containing the adrenal gland is then removed from the most anterior port site. A small drain may be placed into the retroperitoneum to evacuate any fluid or blood that accumulates over the first 24 hours postoperatively. The peritoneal cavity is evacuated of CO_2 and all ports are removed. The incisions are then closed using absorbable 0 suture for the fascial layer and absorbable 4–0 suture for the skin.

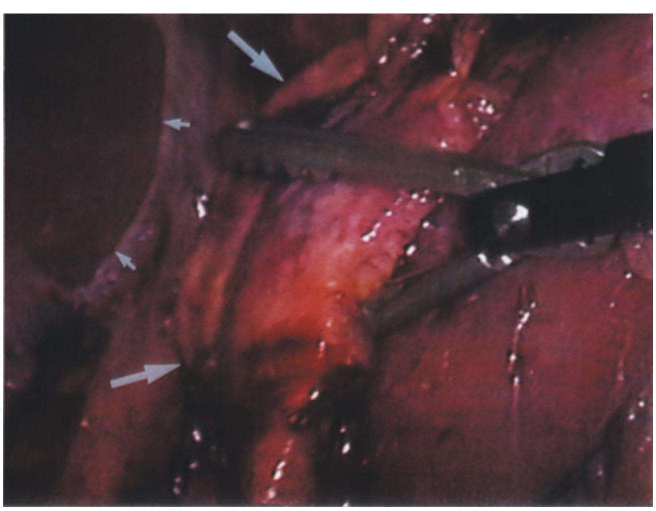

FIGURE 23.6. Laparoscopic view of the left adrenal gland as seen from the transabdominal flank (lateral) approach. The adrenal gland (large arrows) has been partially mobilized and is grasped with an atraumatic instrument. The spleen (small arrows) is seen medial to the adrenal and the kidney is lateral to it.

The technique for right laparoscopic adrenalectomy is similar to that for left adrenalectomy, except for modifications required by differences in anatomy. However, the operation is more difficult because of the more cephalad position of the right adrenal behind the liver as well as the relationship of the gland to the inferior vena cava and the anatomy of the adrenal vein. Insufflation with the Veress needle and laparoscopic port placement are carried out in a mirror image position to the left side. Some mobilization of the hepatic flexure of the colon and right triangular ligament of the liver is necessary to allow dorsal placement of the fourth trocar. The right triangular ligament must be incised sufficiently to allow retraction of the right lobe of the liver and visualization of the inferior vena cava and adrenal gland. The superior pole and lateral border of the adrenal are mobilized first. As the dissection proceeds medially along the lateral edge of the inferior vena cava, the right adrenal vein is encountered as it enters the posterior-medial aspect of the vena cava. Extreme caution must be exercised during this portion of the dissection to avoid tearing the adrenal vein as it enters the vena cava. A large (11 mm) endoclip may be necessary to ligate the right adrenal vein which may measure up to 1 cm in width. Once the adrenal vein has been divided, the adrenal is freed of its remaining attachments and the operation is completed as described for left adrenalectomy.

Anterior Transabdominal Approach

The first successful laparoscopic adrenalectomy was performed in early 1992 by Petelin using an anterior transabdominal approach.[15] Several investigators have since used this approach for performing laparoscopic right or left adrenalectomy. The advantages of this approach are that it provides the laparoscopic surgeon with a large working space and uses the traditional view with which the surgeon is most familiar. The disadvantage of this approach is that in order for there to be adequate exposure, additional effort is required for retracting intra-abdominal organs that overlie the adrenal gland. Anterior laparoscopic adrenalectomy is carried out with the patient in a supine or hemilateral position. Four or five 10-mm trocars are used. The initial trocar is placed at the umbilicus for either right or left adrenalectomy and is used as the site for placement of the telescope. Additional ports may be placed lateral to the midline, on the side of the adrenalectomy at a level just below the xiphoid, midway between the xiphoid and the umbilical port, subcostally at the anterior axillary line, and lateral to the rectus, just above the level of the umbilicus.[16] The use of steel skewers to lift the abdominal wall and reduce CO_2 insufflation pressure to 8 mm Hg has also been reported with this approach.[17]

For left adrenalectomy, the adrenal gland may be approached medially by entering the lesser sac between the stomach and colon, or through the transverse mesocolon and mobilizing the tail of the pancreas. Alternatively, a lateral approach may be utilized. It entails reflecting the splenic flexure of the colon medially and dissecting along the anterior surface of the kidney. With either method, the inferior portion of the adrenal gland is dissected out first with early ligation of the adrenal vein. Laparoscopic right adrenalectomy is more difficult to perform using this approach. Mobilization and retraction of the right lobe of the liver, hepatic flexure of the colon, and second portion of the duodenum may all be necessary, and control of the adrenal vein is more treacherous because of the greater difficulty in providing adequate exposure.

Posterior Retroperitoneal Approach

The most direct open surgical approach to the adrenal gland is via a posterior incision using an entirely retroperitoneal dissection. Two different endoscopic methods have been used to try and duplicate the advantages of the posterior retroperitoneal approach using minimally invasive techniques. Okada and colleagues[18] have performed posterior retroperitoneal endoscopic adrenalectomy, using a wide endoscope that was originally developed as a wide lumen resectoscope for transanal endoscopic surgery.[19] The endoscopic unit is 40 mm in diameter and 120 mm in length. It contains a wide channel for the telescope, along with four working channels for endoscopic instruments. Access to the retroperitoneum is gained using a 5-cm incision along the 12th rib. The retroperitoneal space is opened under direct vision and the endoscope is inserted. The adrenal gland is mobilized using the endoscopically inserted instruments and the adrenal vein is ligated with sutures or clips. The adrenal lesion is then removed through the main endoscopic channel or after removing the endoscope.

Recently, a technique for expanding the retroperitoneal space by CO_2 insufflation, so the surgeon can perform percutaneous retroperitoneal insertion of the laparoscope and direct retroperitoneoscopy, has been described experimentally and clinically.[20–23] This approach not only provides access to the kidney, but may also allow surgical access to other retroperitoneal structures, such as the adrenal gland. An experimental protocol to develop the technique for performing retroperitoneal endoscopic adrenalectomy using CO_2 retropneumoperitoneum was developed in our laboratory in a domestic swine model.[12] The procedure entails a two-step process: (1) insufflation of the retroperitoneal space with CO_2 and endoscopic entry into the retroperitoneum; and (2) endoscopic excision and removal of the adrenal gland.

Retroperitoneal CO_2 insufflation is carried out under fluoroscopic guidance. A ureteral catheter is first passed retrograde into the ureter on the side of the planned adrenalectomy. The patient is placed in a prone position with the ipsilateral flank raised slightly. The ureteral catheter is injected retrograde with contrast material, allowing fluoroscopic visualization of the kidney and ureter. The sequential steps in performing CO_2 insufflation of the retroperitoneum and accessing the expanded retroperitoneal space with laparoscopic ports are shown radiographically in Figure 23.7. The Veress needle is inserted into the retroperitoneal space just caudad to the inferior pole of the kidney and position is confirmed fluoroscopically in both the anterior-posterior and lateral planes (Figure 23.7 B). The Veress needle is aspirated and a saline drop test performed. The retroperitoneal space is then insufflated with 1.5 to 2.0 L of CO_2 to a maximum pressure of 15 to 20 mm Hg. As the retroperitoneal space is filled with CO_2 gas, the kidney is displaced anteriorly and laterally (Figure 23.7B). The retroperitoneal space is entered with a 10- to 11-mm trocar placed inferior to the midportion of the lower pole of the kidney and just above the iliac crest. A videotelescope (0 or 30°) is then inserted through this port into the retroperitoneum and is used to bluntly dissect the retroperitoneal fat and connective tissue away from the kidney.

Three additional 10- to 11-mm ports are then placed under direct endoscopic visualization as shown in Figures 23.7 and 23.8. The location of the second port is at the lowermost rib (14th rib in the pig, 12th rib in humans). More cephalad placement of this port increases the risk of traversing the diaphragm and pleura with subsequent pneumothorax. The third port is placed at the midportion of the kidney just lateral to the sacrospinalis muscle. The fourth port is inserted approximately 2 cm lateral to the lateral border of the kidney. In the animal model, the adrenal gland is easily identifiable along the superior-medial aspect of the kidney. In humans, further dissection of retroperitoneal fat and connective tissue is necessary to locate the adrenal gland. Dissection and removal of the adrenal gland with ligation and control of the adrenal vein is then performed using the techniques previously described.

After developing the technique for performing retroperitoneal endoscopic adrenalectomy in three animals, a

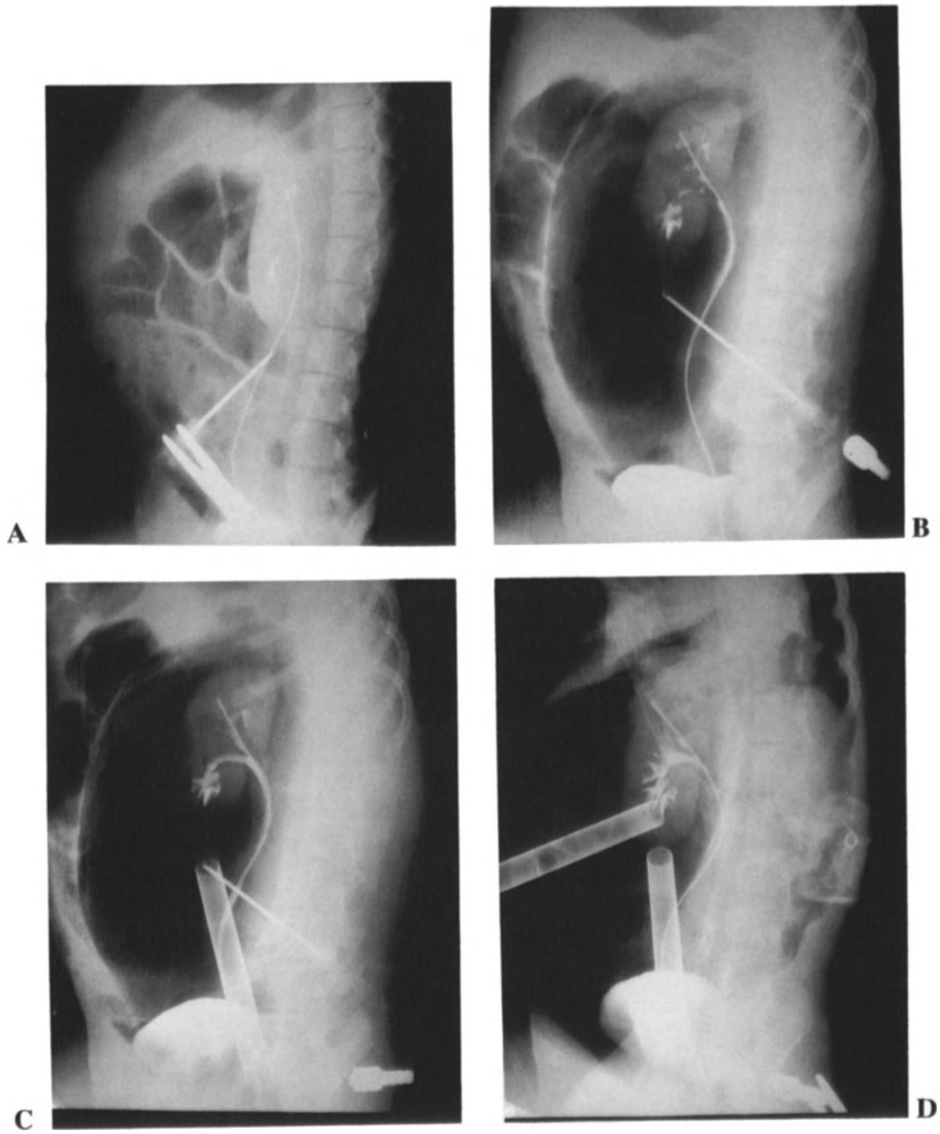

FIGURE 23.7. Radiographic view of the sequential steps in retroperitoneal endoscopic adrenalectomy in an experimental swine model. (A) Insertion of the Veress needle just below the inferior pole of the kidney. (B) Expansion of the retroperitoneal space with CO_2 gas. The kidney has been displaced laterally. (C) An 11-mm trocar has been inserted into the retroperitoneum with the Veress needle still in place. (D) View of the expanded retroperitoneum with four laparoscopic ports in place. (From Brunt et al.,[12] by permission of *Surg Laparosc Endosc.*)

chronic survival study was undertaken in eight pigs.[12] There were two deaths that occurred under anesthesia after retroperitoneal insufflation with CO_2 and insertion of the retroperitoneal endoscopic ports, but prior to dissection of the adrenal gland. In one case, autopsy showed penetration of the diaphragm by the most superior trocar and a right sided pneumothorax, which may have been a factor in the animal's death. No explanation for the death in the second animal was found at autopsy.

In the remaining six animals, unilateral right ($n = 3$) or left ($n = 3$) adrenalectomy was performed. Insufflation of the retroperitoneal space and insertion of the first retroperitoneal trocar was accomplished in a mean ± SEM time of 14.5 ± 7.5 min (range 7 to 30 minutes). The mean time for performing adrenalectomy was 100 ± 20.6 min (range 65 to 120 minutes). In each case, the peritoneal cavity was entered because of fusion of the adrenal capsule with the peritoneum anteriorly. In spite of this, however, retroperitoneal CO_2 insufflation was maintained and no adverse consequences were noted.

There were no postoperative complications in these six animals that survived. All animals resumed a regular diet the day following surgery and gained weight during the observation period. Autopsies performed 37 to 51 days after the procedure showed minimal scarring of the adrenalectomy bed and secure placement of the clips on the adrenal veins. No evidence of vascular compromise of the lumen or patency of either the left renal vein or inferior vena cava was encountered.

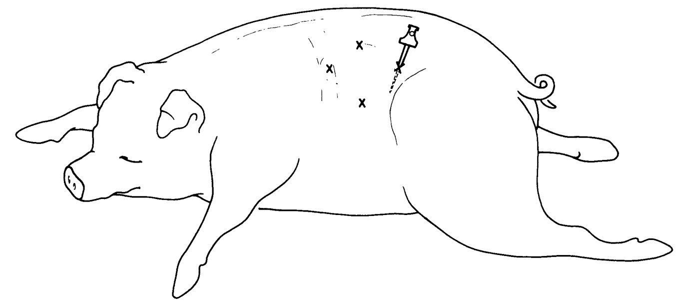

FIGURE 23.8. Diagram of laparoscopic port placement sites in experimental retroperitoneal endoscopic adrenalectomy in a swine model. The Veress needle is shown at its insertion site caudad to the inferior pole of the kidney.

Clinical Results

An analysis of the results of laparoscopic adrenalectomy is complicated by the variety of surgical approaches that have been used, differences in the patient populations, and in the types of adrenal neoplasms selected for operation. Furthermore, most of the few reports on the technique have been published in abstract form only. A preliminary analysis of the results of successful operation according to operative approach is thus presented as shown in Table 23.1.

Transabdominal Flank Approach

Gagner and associates[11] have the most experience worldwide with laparoscopic adrenalectomy. Their group has attempted 21 laparoscopic adrenalectomies in 18 patients using the transabdominal lateral flank approach. Laparoscopic right adrenalectomy was successful in 9 of 10 cases and left adrenalectomy was performed in all 11 attempted cases. One patient required conversion to an open operation because of a 15-cm angiomyolipoma in which the dissection of the posterior aspect of the mass was too difficult. The most common conditions for which patients underwent laparoscopic adrenalectomy were: nonfunctioning cortical adenoma (five patients); bilateral adrenal hyperplasia from pituitary Cushing's disease (two patients); pheochromocytoma (three patients); Cushing's adenoma (three patients); and aldosteronoma (two patients). Three patients underwent bilateral adrenalectomy: two of these patients had pituitary Cushing's disease with a previous failed transsphenoidal hypophysectomy and one patient had bilateral malignant pheochromocytomas associated with the multiple endocrine neoplasia (MEN) type 2B syndrome. The patient with the pheochromocytoma also had laparoscopic removal of a periaortic lymph node that contained metastatic pheochromocytoma. The average operative time per adrenal gland removed was 2.3 hours. The time required for performing left laparoscopic adrenalectomy (1.8 hours) was less than for right laparoscopic adrenalectomy (2.7 hours). The average operating time for bilateral adrenalectomy, including the time necessary for repositioning the patient, was 5.3 hours.

Several patients underwent concomitant laparoscopic procedures at the time of adrenalectomy including cholecystectomy (three patients), common bile duct exploration (one patient), distal pancreatectomy for pancreatic cystadenocarcinoma (one patient), and laparoscopic colostomy closure (one patient). Patients were discharged from the hospital an average of 4 days (range 2 to 19 days) postoperatively. Two patients developed anemia postoperatively, requiring transfusion of two units of blood. Other complications included colonic pseudo-obstruction in the patient with MEN 2B, urinary tract infection (one patient), and a trocar site hematoma (one patient). Of the three patients with pheochromocytomas, two patients developed intraoperative hypertension during manipulation of the adrenal gland, whereas the blood pressure was stable throughout the procedure in the remaining patient.

Prinz and Albala also have experience with laparoscopic adrenalectomy using this approach. Their group has successfully performed laparoscopic adrenalectomy in six of seven attempted cases, with one patient requiring conversion to open operation (R. Prinz, personal communication). Four patients underwent right adrenalectomy and three patients had a left adrenalectomy.

Our group has recently performed laparoscopic adrenalectomy in 12 patients using Gagner's method. One patient had a benign 3.5-cm nonfunctioning cortical adenoma with central necrosis of the lesion seen on MRI scan (Figure 23.9). Indications for adrenalectomy in the remaining 11 patients included aldosteronoma (4 patients), pheochromocytoma (6 patients), and bilateral adrenal hyperplasia for Cushing's disease (1 patient). Average operating time for adrenalectomy in these 12 patients was 2 hours 48 minutes. Average blood loss was approximately 100 mL and no transfusions were required. All patients were started on an oral diet on the first postoperative day. The patients were discharged on average on the third postoperative day, tolerating a regular diet, and with stable blood pressure and hemoglobin levels.

Anterior Transabdominal Approach

Anterior transabdominal laparoscopic adrenalectomy was successfully performed by Sardi and McKinnon[16] in

TABLE 23.1. Results of successful laparoscopic adrenalectomy.

Technique	Author (ref.)	No. of patients Total	Right	Left	Operating time (hr)	Mean discharge day (range)	Conversion to open adrenalectomy
Transabdominal flank	Gagner et al[11]	18[a]	10	11	2.3	4 (2–19)	1
	Brunt & Soper[d]	12	4	9	2.8	3	0
	Prinz & Albala[c]	7	4	3	2.45	2.5 (2–5)	1
Anterior transabdominal	Sardi & McKinnon[16]	2	0	2	3.25	2	0
	Higashihara et al[17]	3	0	3	7.0	12.3	0
	Suzuki et al[27]	5[b]	—	—	4.25	—	0
	Go et al[28]	6[b]	—	—	5.33	—	0

[a]21 laparoscopic adrenalectomies were performed in 18 patients. Three patients underwent bilateral laparoscopic adrenalectomy.
[b]From abstract reports that do not include all the variables listed in the table.
[c]Unpublished.
[d]One patient underwent bilateral adrenalectomy.

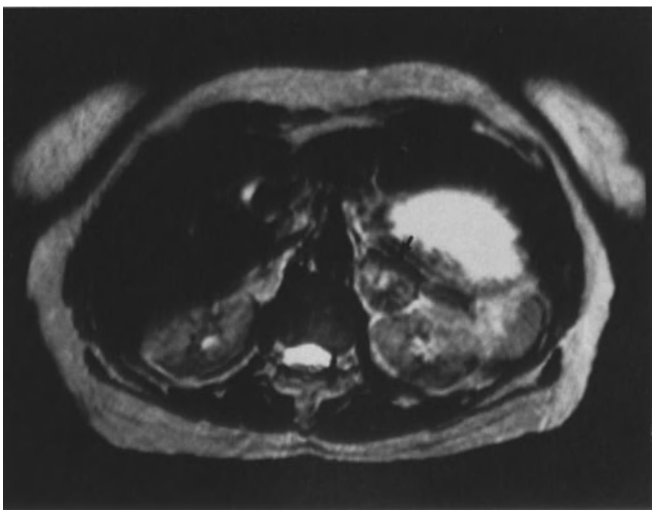

FIGURE 23.9. MRI of the abdomen showing a 3.5-cm mass in the left adrenal (arrow). The patient underwent successful laparoscopic left adrenalectomy using the transabdominal flank approach.

two patients with aldosteronomas. Operating time ranged from 2 to 4.5 hours and both patients were discharged on the second postoperative day. Isolated cases of successful transabdominal laparoscopic adrenalectomy have since been reported by other surgeons.[24–26] A series of laparoscopic adrenalectomies (Table 23.1) have also been reported by several groups using an anterior transabdominal approach and positioning of the patient in a semilateral or hemilateral position.[17,27,28] Higashihara[17] retrospectively compared the results in three patients undergoing laparoscopic adrenalectomy to five patients who had undergone adrenalectomy using an open posterior approach. Laparoscopic adrenalectomy was performed with the patient in a semilateral position and using steel skewers to assist in lifting the abdominal wall. Patients undergoing the laparoscopic procedure had significantly longer operating times (418 versus 192 minutes) and a reduction in the length of postoperative hospitalization (12.3 versus 23.2 days) compared to patients who underwent the open posterior approach. No significant differences between the groups were noted, however, in terms of operative blood loss, use of analgesics, and days of restricted physical activity.

Posterior Retroperitoneal Approach

Okada and colleagues[18] attempted posterior adrenalectomy using the wide lumen resectoscope in six patients with adrenal masses. They successfully completed the procedure in four patients and in two cases, enlargement of the skin incision and completion of the adrenalectomy by manual exploration was required.

Our group initiated a clinical trial of retroperitoneal endoscopic adrenalectomy using retroperitoneal CO_2 insufflation and retroperitoneoscopy after completion of the previously described experimental study in animals. Endoscopic adrenalectomy was attempted in two patients, both of whom were converted to open adrenalectomy. One patient had a 6-cm pheochromocytoma of the right adrenal gland (Figure 23.10). Most of the blood supply to the adrenal mass, including the adrenal vein, was successfully ligated endoscopically, but the large size of the tumor and small confines of the retroperitoneal space precluded endoscopic separation of the lesion from the kidney. The second patient had bilateral adrenal hyperplasia from persistent Cushing's syndrome in spite of transsphenoidal hypophysectomy. Due to the large amount of retroperitoneal fat in this Cushingoid patient, attempted laparoscopic left adrenalectomy was unsuccessful and a bilateral open posterior adrenalectomy was performed. Subsequently, the retroperitoneal endoscopic approach has been used successfully by Clayman (RV Clayman, personal communication) to perform endoscopic nephrectomy, and in several cases adrenalectomy has been performed in conjunction with removal of the kidney.

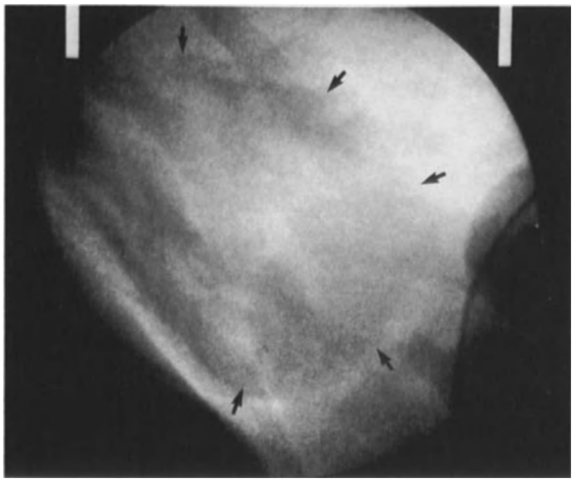

FIGURE 23.10. Retropneumoperitoneum in a patient with a 6-cm pheochromocytoma undergoing attempted right retroperitoneal endoscopic adrenalectomy. The pheochromocytoma (arrows) is outlined by the CO_2 in the retroperitoneal space.

Comparison of Techniques

The results reported by Gagner,[11] as well as our own experience comparing the posterior versus the lateral flank approaches, suggest that the transabdominal flank approach is currently the preferred method for performing laparoscopic adrenalectomy. The advantages of this approach are several: (1) the lateral position of the patient allows gravity retraction of adjacent organs, thus facilitating exposure of the adrenal; (2) placement of the trocars from the midsubcostal region to the posterior axillary line provides both cephalad and posterior access within the abdominal cavity and retroperitoneum; and (3) the transabdominal access allows for a large working space and examination of the rest of the abdominal cavity, as well as simultaneous performance of other laparoscopic procedures. The principal disadvantage of this approach is that control of the adrenal vein on the right as it enters the inferior vena cava may be difficult, especially in cases where the tumor is large. The time required for carrying out this operation should be comparable to that for open adrenalectomy except in cases of bilateral adrenalectomy. Due to the need to access each flank separately, and thus require that the patient be repositioned and reprepped between sides, bilateral adrenalectomy will be a longer procedure. The laparoscopic view, with the patient in the lateral decubitus position, may also be temporarily disorienting to the laparoscopist accustomed to the traditional anterior approach.

The advantage of the anterior transabdominal approach is that the operative viewpoint is the same as for other laparoscopic operative procedures. However, exposure of the adrenal glands is more difficult and the reported operating times have been considerably longer than for the lateral flank approach. The need for mobilization and retraction of colon, liver, and spleen may also increase the risk of injury to these organs.

Posterior retroperitoneal endoscopic adrenalectomy remains an intriguing possibility because it is the most direct route of access to the adrenals and avoids the need for retraction of overlying viscera. However, as clinical trials have been initiated, several disadvantages of this technique have become apparent. The space within the retroperitoneum is small and limits the dissection angles and working distances, and the posterior view of the anatomy can be disorienting. The proximity of the pleura to the 12th rib may also increase the risk of pneumothorax. Indeed, pneumothorax was a complication of the first patient to undergo retroperitoneal endoscopic nephrectomy using this technique.[20] The difficulty of the dissection may also be increased by perirenal fat present within the retroperitoneum, especially in patients with Cushing's syndrome. Finally, the procedure requires an additional procedure, with cystoscopy and placement of a ureteral catheter, to allow fluoroscopic access to the retroperitoneum. The use of alternative methods for accessing and expanding the retroperitoneal space as reported by Gaur[29,30] who used balloon dilatation may eliminate this obstacle to this approach. Further studies will be necessary to determine whether posterior retroperitoneal endoscopic adrenalectomy will be indicated in carefully selected patients with small adrenal neoplasms who do not have excessive retroperitoneal fat.

Extra-Adrenal Paragangliomas

Extra-adrenal chromaffin tumors (paraganglionic tumors) may occur anywhere in the sympathetic chain, but are most commonly found in the organ of Zuckerkandl and para-aortic and paravertebral regions in the abdomen. These tumors may be nonfunctional or may secrete catecholamines (extra-adrenal pheochromocytomas). Paragangliomas have a higher incidence of malignancy than adrenal pheochromocytomas[31] and may not be suitable for a laparoscopic approach, if preoperative imaging studies suggest an invasive tumor. Biochemical screening studies for catecholamines and metabolites are essential preoperatively to identify functioning extra-adrenal pheochromocytomas that must be prepared pharmacologically for surgery.

Navarette and Arregui[32] recently reported the first successful laparoscopic resection of a paraganglioma in a 68-year-old woman. The tumor measured 4 cm in size and was located in the paravertebral region between the caudate lobe of the liver and inferior vena cava, cephalad to the pancreas and medial to the portal vein. Preoperative biochemical studies revealed that the tumor was nonfunctional. The laparoscopic procedure was completed without difficulty and the patient did well postoperatively; she was discharged from the hospital on the first postoperative day.

Postoperative Management

Patients are allowed to ambulate and to resume a diet on the evening of surgery or the next morning. Until additional experience is gained with the procedure, most patients should be observed in the hospital setting at least one to two days postoperatively. Patients with functional adrenal tumors should be discharged when their hypertension has been adequately controlled and electrolyte abnormalities have been corrected. As with other laparoscopic surgical procedures, it should be possible to discharge patients from the hospital without restrictions in their physical activity except as required by their medical condition.

Discussion

The role of laparoscopic adrenalectomy in the management of patients with an adrenal mass is still under evaluation. If the results of the transabdominal flank approach as reported by Gagner can be duplicated in other centers, however, more widespread implementation of the technique would appear warranted. Certainly, the procedure requires advanced laparoscopic surgical skills and a thorough understanding of adrenal anatomy and the pathophysiology of adrenal disorders. Questions regarding laparoscopic adrenalectomy that remain to be answered include the proper selection of individuals for the procedure, the size and type of adrenal lesions suitable for this approach, and outcomes when compared to open adrenalectomy techniques.

Our group currently favors the laparoscopic approach for patients with small (< 5 to 6 cm), benign adrenal masses (Table 23.2). Patients with pheochromocytomas may be considered candidates for the laparoscopic approach, provided the adrenal lesion has been well localized, the patient is medically stable, and has been pharmacologically prepared for surgery with α receptor blockade. Large adrenal lesions > 6 cm in size should be approached cautiously for two reasons: (1) the difficulty of the dissection is increased in large masses and control of the blood supply may be more difficult, particularly for right-sided lesions in which control of the adrenal vein may become treacherous; and (2) the risk of adrenal cortical carcinoma increases as lesions increase in size beyond 6 cm in diameter. Suspicion of an adrenal cortical malignancy should, at this time, be considered a contraindication to the laparoscopic approach because of the potential for capsular disruption and implantation of adrenal tumor. Patients with adrenal involvement by metastases, however, may be candidates for laparoscopic adrenalectomy in selected cases, especially if the resection is being done for diagnostic rather than therapeutic indications.

TABLE 23.2. Indications/contraindications to laparoscopic adrenalectomy.

Indications	Contraindications
Cushing's syndrome	Adrenal cortical carcinoma
Adrenal cortical adenoma	
Bilateral adrenal hyperplasia after failed treatment of pituitary Cushing's	Malignant pheochromocytoma
Aldosterone-producing adenoma	Inability to tolerate general anesthesia
Pheochromocytoma	Uncorrectable coagulopathy
Nonfunctioning cortical adenoma (> 3 cm)	
Angiomyolipoma	
Adrenal metastases	

Whether the traditional benefits of laparoscopic surgery—reduction in postoperative pain, shortened hospitalization, an earlier return to full physical activity, and reduced hospital costs—will be realized for laparoscopic adrenalectomy compared to conventional open adrenalectomy is unknown. Besides these advantages, however, the laparoscopic procedure may have other benefits. The characteristic problems with wound healing seen in patients with Cushing's syndrome may be reduced by the minimally invasive approach. With the availability of the laparoscopic technique, patients with bilateral adrenal hyperplasia from Cushing's disease who have failed treatment of the pituitary lesion may also be referred earlier for definitive surgical treatment. In patients with pheochromocytomas, wide fluctuations in intraoperative blood pressure may be diminished if there is less manipulation of the tumor using the laparoscopic approach. Finally, laparoscopic adrenalectomy may lead to a more expeditious and definitive approach to the treatment of patients with intermediate size adrenal lesions (3 to 6 cm) discovered as incidental findings on CT scan. Controlled multi-institutional clinical trials will be necessary to answer some of these questions. Finally, it should be remembered that open adrenalectomy is a safe, effective, and proven technique. The morbidity associated with the open posterior approach is minimal and patients should not be subjected to the laparoscopic approach unless the well-established principles of open adrenalectomy can be followed.

Summary

In summary, laparoscopic adrenalectomy is a relatively new technique that has only recently been added to the armamentarium of the surgical laparoscopist. Our experience with open adrenal surgery and analysis of the early results of laparoscopic adrenalectomy suggest the following: (1) laparoscopic adrenalectomy is a safe and efficacious operation when performed by an experienced laparoscopist and can be carried out in a time frame comparable to that of open surgical techniques; (2) the preferred technique currently is the transabdominal flank (lateral) approach that offers good exposure of the adrenal, controlled access to the adrenal blood supply, and access to other structures within the abdominal cavity; (3) adherence to the principles of open adrenalectomy with extracapsular dissection of the adrenal gland is critical to successful operation; and (4) open adrenalectomy should be the preferred approach for patients with suspected adrenal cortical malignancies. Laparoscopic adrenalectomy is a challenging surgical procedure that requires advanced laparoscopic surgical skills, an understanding of adrenal anatomy, proper patient selection, and adherence to the principles of open adrenal surgery for proper and safe completion of the operation.

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24
The Use of Laparoscopy in Trauma

Chris Salvino, Greg Pulawski, and Peter Geis

History and Review of Literature

Laparoscopy offers a novel avenue for the diagnosis and treatment of traumatic abdominal injuries. The technique of laparoscopy was first described by Kelling in 1902. Since that time, laparoscopy has been used widely for gynecological disorders and increasingly for elective surgical conditions. The recent surge of interest in laparoscopy by general surgeons has stimulated serious reinvestigation of its role in trauma care,[1–6] which until now has been sporadic.[1,7–9]

Laparoscopy was first used in the trauma setting in 1956 by Lamy who observed two cases of splenic injury.[10] Heselson reported the use of laparoscopy in 68 patients with blunt or penetrating trauma.[11] His criteria for laparotomy was laparoscopic identification of intra-abdominal blood or peritoneal penetration that resulted in one false positive and no false negatives. Gazzaniga reported on 23 patients with penetrating or blunt trauma who underwent laparoscopy followed by laparotomy. He found that injuries identified during laparotomy correlated with laparoscopy.[3] Carnevale performed laparoscopy on 20 patients with clinical indications for exploratory laparotomy.[2] Laparotomy was avoided in 12 patients based on laparoscopic findings. There was one nontherapeutic laparotomy in the remaining eight patients. Cortesi evaluated 106 blunt trauma victims with laparoscopy.[12] Laparotomy was performed for findings of intra-abdominal blood or injury. Forty patients were successfully observed. There were two false negatives and two false positives. Berci reduced the number of nontherapeutic celiotomies performed for hemoperitoneum by 25% through the use of laparoscopy in 150 blunt trauma patients.[13] Berci's study and most of the others described so far have based the need for operation primarily on the presence and perceived amount of intra-abdominal hemorrhage. Noting the persistence of active bleeding or performing systematic abdominal exploration with description of injuries were not major factors in the diagnostic technique. The potential for missing significant injuries to hollow viscera or the diaphragm make it desirable to carry this technique further. Livingston performed laparoscopy on 39 trauma victims prior to planned celiotomy.[6] In 31 of 32 patients, laparoscopy correctly identified injuries noted at celiotomy. In seven patients, no intraperitoneal injuries were identified. These patients did not undergo celiotomy, and were observed without morbidity.

Two groups have reported specifically on the use of laparoscopy in penetrating trauma.[5,14] Sosa found laparoscopy to be 100% accurate in identifying peritoneal penetration in eight patients who sustained tangential gunshot wound to the abdomen.[14] Ivatury identified peritoneal penetration in 20 of 40 patients with 34 stab wounds and 6 gunshot injuries.[5] Those without penetration were watched without sequelae. Those with penetration usually underwent both laparoscopy and laparotomy, with laparoscopy failing to identity two hollow viscus injuries in this group. Neither author *ran* the intestine. The results of these studies show that laparoscopy can correctly identify peritoneal penetration and potentially reduce the nontherapeutic laparotomy rate. However, unless the intestine is completely inspected laparoscopically, hollow viscus injuries will be missed.

Two studies to date have compared diagnostic laparoscopy to diagnostic peritoneal lavage (DPL) in blunt trauma patients.[1,15] Cuschieri reported nontherapeutic celiotomy ratios of 3/12 for DPL and 1/13 for laparoscopy.[15] We studied 75 patients (59 blunt traumas and 16 stab wounds) who required abdominal evaluation by performing diagnostic laparoscopy followed by DPL, with the laparoscopist being blinded as to the DPL results.[1] Ninety-three percent were performed in the emergency department and 59% under local anesthesia. Indications for laparotomy were a positive DPL or a grossly abnormal laparoscopy with negative DPL. Criteria for a positive DPL in blunt trauma were based on those proposed by the American College of Surgeons Advanced Trauma

Life Support course.[16] Criteria for stab wounds were ≥ 10,000 RBC/mm³ or > 500 WBC/mm³. Overall, management based on laparoscopy rather than DPL would have improved care in 10% of cases. By mechanism, reliance on laparoscopy over DPL would have improved care in 25% of stab wounds (4/16 with diaphragmatic lacerations and negative DPL counts) and 5% of blunt traumatic injuries.

Experience with laparoscopic treatment of traumatic injuries is limited. Spinelli successfully repaired an iatrogenic full-thickness stomach injury in one patient.[17] Ishitani effectively applied fibrin glue under laparoscopic direction into the base of liver injuries in an animal model.[18] Survival rate was 83% (five of six) for animals with treatment of all injuries. We found a reduction in mortality from 63 to 0% in an animal model, with severe standardized liver and splenic injuries in the control versus treatment group, respectively.[19] The treatment group had their injuries controlled laparoscopically with fibrin glue injection 30 minutes after damage to the liver and spleen. The control group had no intervention performed on their injuries. No clinical complications were noted in the surviving animals.

Initial Management and Diagnosis

Initial trauma management is the art of discerning and immediately treating critical areas of injury in the correct sequence, while preventing more minor injuries from being overlooked. In order to supervise relatively inexperienced personnel in this endeavor, it helps to have a framework for the activities that need to be performed for the diagnosis and treatment of the trauma patient. In most university settings, this is done by having various protocols and policies in place. In the private practice setting, the experienced practitioner will have developed logical and sequential plans for dealing with the various situations. In the patient with major injuries, this necessitates interspersing treatment with diagnostic maneuvers. Laparoscopy has the potential of providing improved care by being incorporated as a diagnostic or therapeutic method in some trauma management scenarios.

Typically a trauma patient arriving at a hospital undergoes a rapid primary evaluation. During this time, immediate problems such as airway compromise are dealt with, a brief history and physical, with an estimation of blood loss and cardiac status are performed, and initial therapy is instituted. Therapy may include vascular access and tube thoracostomies. Patients with obvious intra-abdominal catastrophes are transported to the operating room with minimal delay. Diagnostic studies are limited to one or more of the following as needed: chest, pelvis, and lateral neck radiographs, and computed tomography (CT) of the head. These severely injured patients comprise 5% of total trauma seen at most locations. The remaining patients remain stable enough for secondary assessment. Diagnostic maneuvers during this period vary, depending on whether the mechanism of injury is blunt or penetrating.

Blunt Trauma

In patients with blunt trauma who have no alteration of sensorium, physical examination can be misleading. Approximately 40 to 50% of patients with a significant hemoperitoneum may have no peritoneal signs.[20] The two most popular methods of screening for intra-abdominal injury are peritoneal lavage and CT scan. The indications for DPL or CT include abdominal pain, unexplained hypotension, altered mental status, paraplegia, pelvic fracture, need to perform emergent extraperitoneal surgery, or probable mechanism for injury such as rib fractures in zone II (nipples to umbilicus). There are advantages and disadvantages to the two methods.

Peritoneal lavage for blunt trauma is considered positive if the RBC count is > 100,000/cc, WBC count > 500/cc, or the smear shows bacteria or enteric content. Ten milliliters of gross blood or amylase content of more than 200 U/dL may also be considered a positive lavage.[16] Advantages of DPL are: results can be obtained rapidly, it can be performed in the emergency room or the operating room without transporting the patient, and it is quite sensitive. Its disadvantages are: inaccuracy in evaluating retroperitoneal or diaphragmatic injuries, does not indicate what organ is injured, requires skill, and may be contraindicated in the patient with previous surgery or one who is pregnant. In addition, its main advantage may be its disadvantage. DPL is so sensitive that there is a definite incidence of either negative or nontherapeutic laparotomies. Nontherapeutic laparotomies typically demonstrate injuries to the spleen or liver that have ceased to bleed. The results one can expect with diagnostic peritoneal lavage in blunt trauma are outlined in Table 24.1. In Henneman's series, analysis of DPL accuracy in predicting *necessary* laparotomy for blunt trauma resulted in

TABLE 24.1. Diagnostic peritoneal lavage in blunt trauma.

Author	No. of patients	% False negative	% Nontherapeutic laparotomy
Diamond[21]	259	5%	27%
Danne[22]	384	0.3%	19%
Sorkey[23]	365	7%	14%
Henneman[24]	944	3%	15%
Meredith[25]	116	1.7%	15.5%

a sensitivity of 87%, specificity of 97%, PPV (positive predictive value) of 85%, and NPV 97%.[24] Nontherapeutic laparotomies are associated with a significant and real morbidity and mortality rate. Lowe found a 2.4% mortality rate among 245 patients with nontherapeutic laparotomies.[26] The overall complication rate was 19%, which compares favorably with others.[27–29]

With the present trend toward observing certain types of splenic and liver trauma, CT scan examination of the abdomen has found increased usage. CT technique involves the use of double or triple contrast administration (oral, intravenous, and enema). The advantages of CT scanning are that it shows specific injuries that may permit selective management, requires no surgical skills to perform, and can evaluate the retroperitoneum including the genitourinary tract. The disadvantages of CT scan are that it is not as sensitive as peritoneal lavage, generally takes more time to perform, may require the patient to be transported, is more expensive, and the patient must be stable for an extended period of time. In 1985, Max compared CT to DPL in 19 patients. CT missed three significant splenic injuries, one hepatic laceration, and two hemoperitoneums; all these patients had a positive DPL. The average time required for DPL was 26 minutes compared to 47.4 minutes to obtain a CT.[30] Other series have had various results (Table 24.2).

In summary, for a stable, blunt abdominal trauma patient it would be ideal to have a diagnostic method that would, on one hand, be sensitive enough to prevent missed injuries, and on the other, be specific enough to prevent nontherapeutic laparotomy. It would also be ideal if this method were cost-effective and relatively rapid to perform. Laparoscopy has this potential in selected cases of blunt trauma. Unlike CT or DPL, it can differentiate between active and inactive intraperitoneal bleeding. It also has potential as a therapeutic modality. For instance, converting a bleeding hepatic or splenic laceration into a nonbleeding one suitable for observation is certainly possible through laparoscopic means.

Penetrating Trauma

The management of patients with penetrating trauma continues to evolve. World War II saw mandatory exploration of all penetrating trauma. This milestone changed the nonoperative mortality of 67 to 81%, reported in 1891 by Coley, to the operative mortality of 6% reported by Wilson in 1960. Since that time, attempts have been made to decrease the number of nontherapeutic laparotomies through selective exploration utilizing various diagnostic methods. Approximately 30% of stab wounds and 80% of gunshot wounds involve serious intraperitoneal injury.[33] Selective management of stab wound injuries is widely accepted. Selective management of civilian missile injuries is more controversial.

TABLE 24.2. Computed tomography in blunt trauma.

Author	No. of patients	% False negative
Marx[31]	5	60%
Meyer[32]	301	15.7%
Meredith[25]	116	6.9%

After excluding patients with peritonitis; visceral evisceration; or blood in the stomach, rectum, or bladder, it is acceptable to perform further studies to determine the need for laparotomy. Options generally available for selective management are: serial examinations, local wound exploration for peritoneal penetration, CT scan, and peritoneal lavage. Local wound exploration is primarily of use in anterior abdominal stab injuries. It is not recommended for gunshot wounds. The purpose of this maneuver is to determine whether peritoneal penetration has occurred. Exploration after demonstrated peritoneal penetration yields a 25% negative laparotomy rate. This is the same negative exploration rate documented for omental herniation through a stab injury.[34] Triple contrast CT scan is especially useful for back and flank injuries since it can assess the retroperitoneum, liver, and spleen. It can provide much of the information that previously required IVP and arteriography. Its weakness lies in evaluation of the hollow viscera and the diaphragm.

Peritoneal lavage has been tried in penetrating trauma with varying criteria for a positive result. One common set of criteria for positivity calls for any of the following to be true: 1 cc gross blood, RBC $> 10{,}000/mm^3$, WBC $> 500/mm^3$, or presence of bacteria.[29] Another common setting is RBC $> 5{,}000/mm^3$. In one series this gives a sensitivity of 97%, specificity of 89%, accuracy of 89%, PPV 75%, and NPV 95%.[24] In this series, 125 patients underwent laparotomy, 26% of which were not necessary. Peritoneal lavage can even miss diaphragmatic injury in anterior abdominal stab injuries with RBC counts below $1{,}000/mm^3$.[1]

Use of laparoscopy from a diagnostic standpoint in anterior abdominal stab injuries is superior to peritoneal lavage or CT scanning because evaluation for diaphragmatic injury and peritoneal penetration is extremely reliable. With low velocity, tangential missile injuries, laparoscopy for peritoneal penetration is an attractive option. Use of minilaparoscopy for this purpose can be accomplished in the emergency department under local anesthesia. Should peritoneal penetration be found, exploratory laparoscopy under sedation or general anesthesia is a potential alternative. The potential for therapy also exists, since it is easy to close small, hollow viscus defects through the scope and apply certain hemostatic maneuvers.

Initial Indications for Laparoscopy in Trauma Management

Guidelines for diagnostic and therapeutic laparoscopy in the trauma setting are in flux and in the process of being formulated. As surgeons gain experience, techniques become refined, equipment is developed, and more studies are completed, the indications for laparoscopy in trauma will become better defined. At this time, several problems in the stable patient seem tailored to the use of the laparoscope in trauma: stab wounds, tangential gunshots, shotgun blasts from a distance, and elevated DPL counts. In the stable patient with an anterior or flank abdominal stab wound, laparoscopy can determine peritoneal penetration and the abdominal contents can be evaluated (Figure 24.1). Evaluation for peritoneal penetration may be performed under local anesthesia in the emergency department or under general anesthesia in the operating room. Use of the optical Veress, needle facilitates this technique in the emergency department under local anesthesia, with potential cost benefits. If peritoneal penetration is not seen, then the patient is allowed to recover and is discharged. If peritoneal penetration is noted, then formal diagnostic laparoscopy (FDL) is undertaken under general anesthesia in the operating room using additional operating ports. If FDL does not reveal an injury that requires intervention, then the patient is recovered. If FDL reveals injury that requires intervention, then a decision is made to proceed with therapeutic laparoscopy versus laparotomy. This decision is based on the severity of the injury, stability of the patient, and skill of the surgeon. If therapeutic laparoscopy is unsuccessful, conversion to laparotomy is necessary.

Because of the severity of intra-abdominal injuries with gunshot wounds, we do not recommend laparoscopy at this time in those with obvious abdominal cavity penetration. However, a subset of patients with tangential gunshot injuries or shotgun blasts from a long distance frequently do not have peritoneal penetration. Diagnostic laparoscopy can play a role in this setting by evaluating for peritoneal penetration. Because of the potential for life-threatening injuries, we recommend that laparoscopy be performed in the operating suite under general anesthesia in these situations. A single trocar and laparoscope are used in the evaluation. If no penetration is seen, the patient is observed. If penetration is seen, then laparotomy is recommended.

A third group of patients who should benefit from laparoscopy are stable, blunt trauma victims with elevated or positive DPL counts. We presently perform laparoscopy in patients with DPL counts > 50,000 RBC/mm³. Use of this criteria enhances the diagnosis of intra-abdominal injury, while laparoscopy maintains specificity by determining the injury's location and severity. Ideally, laparoscopy should reduce the significant nontherapeutic

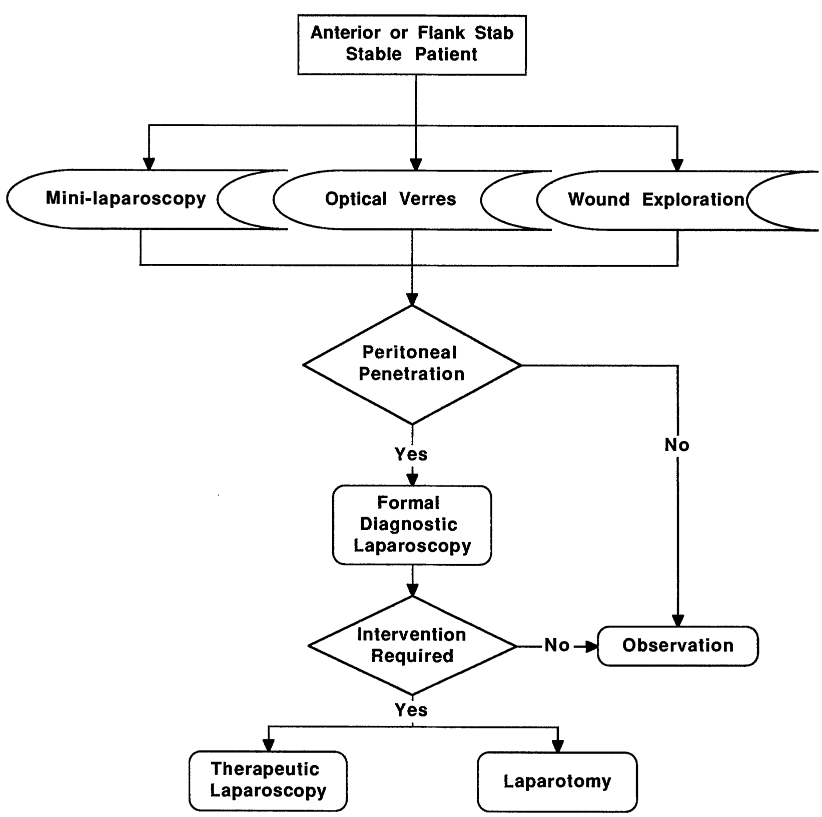

FIGURE 24.1. Laparoscopic algorithm for stable patients with anterior or flank abdominal stab wounds.

laparotomy rate associated with DPL. Because of the excellent negative predictive value of DPL in this population, the cost of laparoscopy is not justified for blunt trauma patients with a negative DPL.[1] Therefore, diagnostic laparoscopy is used as a secondary tool in blunt trauma.

Laparoscopy for blunt trauma with an elevated DPL count is performed in the operating suite under general anesthesia (Figure 24.2). Because the procedure is being performed in the presence of intraperitoneal hemorrhage (abnormal DPL), a complete exam with FDL is warranted. If the exam reveals injuries that require no further intervention, the patient is observed. If injuries are noted, a decision to perform therapeutic laparoscopy versus laparotomy is made. Again, this decision is tempered by the stability of the patient, skill of the surgeon, and severity of injury. If therapeutic laparoscopy is undertaken and is unsuccessful, conversion to laparotomy is required.

Further experience with diagnostic and therapeutic laparoscopy may allow the inclusion of other subsets of patients such as all stable gunshot injuries and those with specific injuries noted on CT scan. In addition, as clinical data are collected, the indications of laparoscopy in blunt trauma and optimal threshold for its use based on DPL should become more solidified.

Technique

Monitoring

Frequent monitoring of hemodynamic and respiratory parameters is necessary. Need for invasive monitoring should be dictated by the clinical situation. We find no

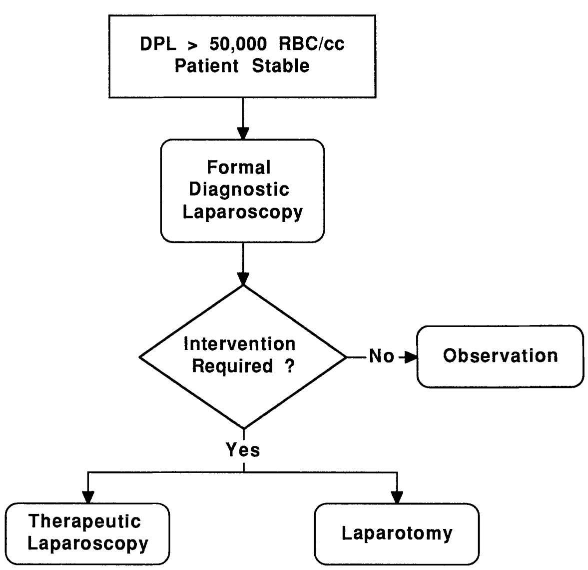

FIGURE 24.2. Laparoscopic algorithm for stable blunt trauma victims with DPL counts > 50,000 RBC/mm^3.

reports of deleterious cardiovascular events associated specifically with laparoscopy in the trauma environment. While the mortality rate associated with laparoscopy is extremely low in the general laparoscopy literature,[35] isolated cardiovascular events such as hypotension, shock, and cardiac arrest have been reported.[36–39] Motew found mild circulatory stimulation manifested by elevated arterial and central venous blood pressures and tachycardia, with intraperitoneal CO_2 pressures up to 20 mm Hg.[40] Insufflation above 20 mm Hg resulted in an inverse effect: cardiac output, central venous, and arterial blood pressures were depressed. Presumably this was secondary to impeded venous return to the heart as a direct effect of abdominal pressure.[41] We have had no cardiovascular events in our patients in which intra-abdominal pressures are maintained at < 15 mm Hg.[1] It should be kept in mind that a few seemingly stable trauma patients may become unstable with apparent innocuous changes such as addition of pneumoperitoneum.

The hypercarbia associated with CO_2 insufflation[40] could become an issue in trauma patients with head injuries. Alexander and others have shown that the increase in CO_2 tension is primarily due to the diffusion of CO_2 from the peritoneal cavity.[37–39] With ventilation kept constant throughout each procedure, Motew noted an increase in average $PaCO_2$ from 28.8 to 38.2 mm Hg in women undergoing tubal sterilization with average intraabdominal pressures of 20 mm Hg.[40] Further increases in $PaCO_2$ were seen with greater than average intraperitoneal pressures. With close monitoring of CO_2 tension and directed ventilatory adjustments, we have not had a problem with uncontrollable hypercarbia.

Anesthesia

Laparoscopy for trauma performed under general anesthesia in the operating room affords the best climate for complete evaluation of the abdominal cavity and potential for therapeutic interventions. A limited minilaparoscopy can be performed under local anesthesia. Because of the discomfort associated with this technique, potential for evaluation and therapeutic intervention is limited. Patients who may benefit from minilaparoscopy under local anesthesia are those suffering anterior or flank abdominal stab wounds in which peritoneal penetration needs to be evaluated.

Positioning

Best visualization is obtained with the patient secured to an operating table that rotates easily on two axes allowing gravity to aid in retraction. The upper abdominal cavity is best evaluated in reverse Trendelenburg, while the pelvis is best visualized in Trendelenburg position. Side-to-side rotation of the table enhances evaluation of the lateral gutters. If a single monitor is used, we have found placement at the foot or head of the table to be equivalent in diagnostic work. When two monitors are available, one at the head and the second at the foot works well.

Trocar Placement

The abdominal cavity is prepped and draped widely. The location for the initial port is usually the periumbilical area, if there is no pelvic fracture or scar from previous surgery. Either the open or closed method of entering the abdomen may be used. Using the closed method, the anterior abdominal wall is retracted upwards, and a Veress needle guided into the abdominal cavity. In the open method, the area where the umbilicus penetrates the fascia is spread with a Metzenbaum scissors and a 5-mm port, with the sharp trocar removed, is placed directly into the abdominal cavity for insufflation. This may be changed to a 10-mm port placed under direct internal visualization later, if needed. If the periumbilical area is not chosen for the first trocar site, either a purse string suture tensioned with a Rummel tourniquet, or a Hassan trocar will be needed to prevent gas leakage after the port is placed under direct visualization. If the closed method is chosen, a Foley catheter and nasogastric tube are both mandatory prior to the procedure. With the open method, these decompressive tubes are optional but preferred. Unless the optical Veress needle is used, the closed method of entering the abdomen has the disadvantage of requiring the abdomen to be fully insufflated prior to port and telescope placement. This could lead to problems in patients with unrecognized diaphragmatic injuries.

In most cases, two additional trocars are required for complete abdominal evaluation and intervention. These are placed just lateral to the rectus complex, at the level of the umbilicus. In select circumstances, these additional ports can be placed more cephalad or caudad as the situation warrants. Both trocars are placed percutaneously under direct internal visualization. Rarely, a fourth or fifth trocar may be necessary for complex intestinal repairs.

Formal Diagnostic Laparoscopy

After the first port is placed, minimal insufflation is instilled (< 5 to 8 mm Hg) with the telescope in place and the patient in reverse Trendelenburg position. Evaluation of the diaphragm is performed before insufflating further since full insufflation with diaphragmatic injury can result in a tension pneumothorax. Additionally, abdominal wall lifting retractors may be used to allow adequate visualization of the diaphragm without the need for pneumoperitoneum (Figure 24.3). If a tear is noted in the diaphragm, then the pneumoperitoneum is released and a chest tube is inserted. At this point, a decision must be made to either repair the tear through the laparoscope or to proceed to laparotomy. If the repair is to be attempted by laparoscopy, it must be performed prior to further evaluation of the abdominal cavity because gas will leak through the chest tube until the tear is closed, precluding adequate evaluation of the rest of the abdomen. Once diaphragmatic integrity is ensured, pneumoperitoneum is allowed to build up to 15 mm Hg and two additional trocars (10 mm) are inserted as previously described. Evaluation of the upper abdominal cavity can then be completed with evaluation of the lower hemidiaphragms, liver, spleen, anterior stomach, and esophagus. We have found broad, fan-type retractors to be very useful in manipulating solid organs such as the liver and spleen and use them extensively (Figure 24.4).

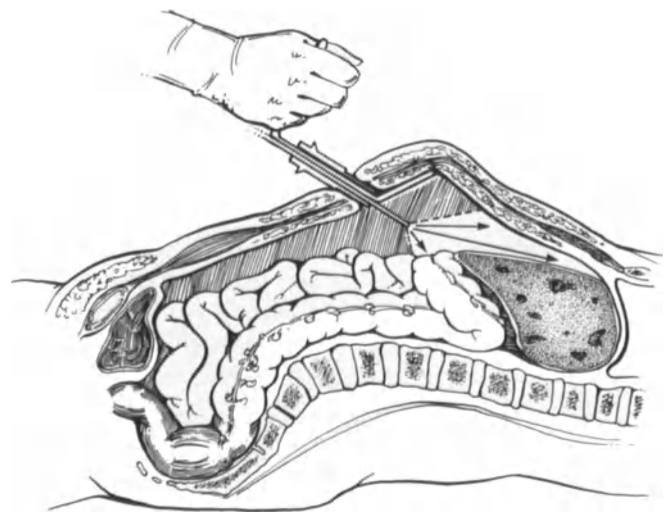

FIGURE 24.3. Gasless evaluation of the diaphragms and upper abdomen with an abdominal wall lifting device.

The table is rotated into the Trendelenburg position and the pelvis is evaluated. We usually switch to using Babcock instruments in the lateral ports for retracting bowel. When evaluation of the pelvic contents, including the sigmoid colon and rectum is complete, the table is rotated left side down, elevating the patient's right lower quadrant. Using the Babcock retractors, the ascending colon is viewed to the level of the hepatic flexure. The distal small bowel is examined starting at the ileocecal valve and working proximally. The use of two Babcocks allows for complete visualization of both sides of the mesentery as the clamps walk up the bowel. As the midjejunum is reached, the table is rotated flat. Further advancement towards the proximal jejunum is facilitated by rotating the table into reverse Trendelenburg with the left side up. This position helps complete evaluation of the ligament of Treitz, transverse, and descending colon.

At this point, the intraperitoneal contents have been viewed, with the exception of the lesser sac. Evaluation

FIGURE 24.4. Fan retractors facilitate the manipulation of solid organs such as the liver and spleen.

of this area and the retroperitoneal duodenum and pancreas requires additional maneuvers, if indicated. Viewing the lesser sac can be accomplished by placing the patient in reverse Trendelenburg, placing a fourth port in the left lateral abdominal wall between the level of the umbilicus and the costal margin, and opening the gastrocolic omentum between clips. Viewing the pancreas can be facilitated either by changing to an angled-view scope or by moving the telescope to a left lateral port while elevating the greater curve of the stomach. Completely viewing the second portion of the duodenum is the most difficult maneuver, requiring careful retraction of the liver and hepatic flexure with fan-type retractors, and use of an angled scope or optimal placement of the telescopic trocar. Decisions to explore hematomas or to reflect the right or left colon depend on location, mechanism, and technical skill. The laparoscopist should be aware of the limitations of his technique when considering the alternative of diagnostic laparoscopy (missing a duodenal injury would be a sobering event).

If the diagnostic evaluation reveals that further intervention is required, then laparotomy is performed or therapeutic laparoscopy is attempted. This decision is dependent on the skill of the laparoscopist, severity of injury, and stability of the patient. Issues involved in therapeutic laparoscopy are discussed in a later section.

Minilaparoscopy

The use of laparoscopy under local anesthesia in the emergency department as a primary diagnostic test has been advocated by some authors.[42,43] Our experience and that of others suggests that this is difficult, except for the simplest diagnostic needs. Minilaparoscopy can be performed in the emergency department or the operating room, often under local anesthesia. The main indication for this technique is assessment for peritoneal penetration after stab wounds or tangential gunshots (Figure 24.1). Peritoneal penetration requires further evaluation for possible intra-abdominal injury by FDL, laparotomy, or perhaps peritoneal lavage. Minilaparoscopy with a single 5-mm telescope through an umbilical port works well. Alternatively, a smaller incision and puncture can be performed with an Optical Veress Needle (OVN) using an insertion technique identical to that of the standard Veress needle. This tool is a combination of a Veress needle and a fiberoptic telescope. The field of view is more limited than a 5-mm operating telescope, but is adequate to evaluate for peritoneal penetration. As the optical quality is improved, the OVN may play an increasing role in abdominal evaluation.

When performing minilaparoscopy under local anesthesia, monitoring should include frequent blood-pressure checks and continuous pulse oximetry, with oxygen administration by face mask. The patient's respirations are monitored for frequency and depth with intra-abdominal pressures kept below 15 mm Hg. We have had two instances of shortness of breath with insufflation above 15 mm Hg. These symptoms resolved when pressure was reduced below 15 mm Hg.[1] We use intravenous sedation with a reversible drug such as morphine or midazolam. In addition, we and others have found nitrous oxide to be less of a peritoneal irritant than CO_2 for pneumoperitoneum induced under local anesthesia. Using electrocautery with nitrous oxide insufflation is not advised because nitrous oxide can be explosive when mixed with other gases. It is, however, an ideal gas to use for diagnostic purposes in the emergency department.

Fibrin Glue

Fibrin glue is a natural adhesive that duplicates in an enhanced manner the final stages of normal coagulation.[44] In the presence of calcium chloride, a fibrin monomer is formed when fibrinogen is mixed with thrombin. This monomer is then transformed into a strong fibrin polymer in the presence of factor XIII. Most of the strength of fibrin glue is gained in less than 5 minutes.[45] Recently, fibrin glue has been used to successfully arrest hemorrhage from hepatic and splenic injuries.[18,45–50] Topical application of fibrin glue has been successful in treating superficial injuries and capsular avulsions. Injection of fibrin glue into the base and surrounding tissue has proved effective in controlling hemorrhage from deep parenchymal lesions.[18,47,51] Fibrin glue may be used successfully in the presence of severe coagulopathy because it is not dependent on host intrinsic clotting factors. The laparoscope offers a new method for the delivery and application of fibrin glue in the treatment of traumatic injuries. This approach has been reported experimentally by us and others.[18,19] and was discussed in the previous section. Complications ascribed to fibrin glue injection have raised particular concern for its use in the trauma victim. Sudden hemodynamic collapse has been associated with the intraparenchymal injection of fibrin glue.[52,53] Fibrin glue pulmonary emboli or anaphylaxis may be an etiology. Theoretically, the potential for abscess, inflammation, or infarction exists with injection of this compound intraparenchymally. We did not see this at necropsy in an experimental setting with chronically recovered animals.[19]

Controversies in Therapy

The addition of laparoscopy to the field of trauma complicates several aspects of trauma management that are already controversial. These areas are primarily management of injuries to the spleen, liver, colon, and diaphragm. Each of these will be reviewed in detail with suggestions as to where laparoscopic management may be appropriate.

Spleen

The spleen is the organ most frequently injured in blunt trauma. Concerns to be addressed when determining optimal treatment in splenic trauma include: age of the patient; associated injuries; blood loss and risk of transfusion; risk of postsplenectomy sepsis; stability of the patient; complications of repair; and complicating medical conditions (such as hemophilia or portal hypertension). In adults with blunt traumatic injury to the spleen, 20% have associated visceral injuries that need repair. Children are much more likely to have isolated splenic injury. The risk of viral transmission and immunologic consequences is significant with transfusion. Blood transfusion may be more hazardous than splenic loss. Currently the options for management of splenic injury are: observation; angiographic hemostasis; splenorrhaphy; splenectomy; and splenectomy with autotransplantation.

Nonoperative Management

Generally, nonoperative management of splenic injury may be attempted in stable, conscious patients with blunt trauma in whom splenic injury has been confirmed by imaging methods, as long as these patients have no other suspected intra-abdominal injury and do not have a coagulopathy. This method of therapy was initially used with children because of concerns for overwhelming postsplenectomy sepsis (OPSS) in the pediatric population. Initial protocols included certain transfusion tolerances prior to converting to laparotomy (often more than 50% of blood volume).[54] Successful avoidance of many splenectomies led to extension of this method to the adult population with less favorable results (Table 24.3).

There has been concern regarding the risks and benefits of nonoperative therapy. Luna and colleagues, using individual series and combined reports from the literature through 1987, compiled statistics on: risk of OPSS; risk of OPSS versus transfusion; and impact of observation on operative splenic salvage.[57]

> The authors concluded that the generally quoted incidence of OPSS incidence has been overestimated 10 to 20 fold. OPSS risk is 0.026% adults and 0.052% children. 35–40% of successfully observed patients required transfusion averaging 40–50% of blood volume. Those unsuccessfully observed required 2 to 3 times more blood. 20% of children and adults undergoing immediate surgery receive an average of 2 units of blood. The hepatitis risk identified by the Transfusion Transmitted Virus Study at the time was 6.9% for 1 unit, 10.3% for 2–3 units, and 12% for 6–15 units. Factoring in the long term 5%–10% mortality for chronic active hepatitis, one finds that post-transfusion hepatitis mortality is 0.14% per unit. Up to 10% of observed children undergo a laparotomy with 75% chance of splenectomy. 40% of observed adults undergo laparotomy with a 93% chance of splenectomy.

Using these numbers, the probability of death in a child with nonoperative treatment was 0.17% compared to 0.06% for initial operative treatment. The adult patient would have 0.26% nonoperative versus 0.06% operative management mortality. Because of these and other analyses, attempts have been made to try to eliminate the transfusion of homologous blood while still trying to preserve the spleen. This has lowered the threshold for laparotomy, decreased the concern over OPSS, and made angiography a part of splenic nonoperative management.

Angiography

Angiography has been advocated by some[58] as a way of stopping splenic arterial bleeding and the demonstrating feasibility of observation without transfusion. Some have also advocated therapeutic angiography to achieve this end. If a CT shows a splenic injury in a stable patient and if associated injury to the bowel and pancreas can reasonably be excluded, the extent of splenic injury can be assessed by diagnostic arteriography of the celiac axis. If

TABLE 24.3. Nonoperative splenic trauma management.

Series		Patients observed	
Splenic injuries		Success	Failure
Lally[54]	children	44 (14 transfused)	5 (5 transfused)
Malangoni[55]	adults	3	7
Cogbill[56]	both	99	1 child (2%), 12 adults (17%)

arterial extravasation is identified, transcatheter arterial embolization of the splenic artery just distal to the dorsal pancreatic branch can be performed to diminish primary splenic inflow and promote hemostasis. Splenic perfusion is maintained by collaterals from the left gastric, gastroepiploic, and dorsal pancreatic arteries.

Surgical Management

Current surgical management of splenic injury can be divided into two categories: splenic removal and splenic preservation. Splenectomy is the most rapid means of hemostasis for the unstable patient with a coagulopathy or multiple visceral injuries. In discussing splenic repairs it is customary to classify splenic injuries into grade I to IV.

Grade I: incomplete parenchymal tear
Grade II: parenchymal tear or deep fracture extending to but not through the hilus
Grade III: severe fracture or through and through injury that may divide the spleen into two pieces but leaves the blood supply intact
Grade IV: splenic fragmentation or a stellate fracture with a hilar injury

Success with splenorrhaphy depends upon the grade of injury, technique used, and time that can be devoted to this maneuver. Feliciano, in 1985, reported on 326 operative cases in which splenorrhaphy or splenectomy was performed. He reports successful splenorrhaphy in 88.5% grade 1 and 2, 61.5% of grade 3, and only 7.7% of grade 4 patients with a complication rate of 11.8% for splenorrhaphy and 21.1% for splenectomy.[59]

Just as in nonoperative therapy, risk of transfusion has been a significant factor in determining optimal surgical therapy. Beal concluded that if splenorrhaphy requires blood replacement, the mortality of transfusion hepatitis far outweighs the risk of postsplenectomy sepsis.[60] Because of these concerns, one must consider using the cell-saver during attempts at splenic preservation if there is blood loss. In a study by Witte, 20 pediatric and adult patients with splenic trauma were managed nonoperatively. Nine underwent surgery because of continued hemorrhage. Use of the cell-saver allowed an average of 790 cc of intra-abdominal blood to be infused during splenorrhaphy. Only three of those patients required homologous blood and all survived.[61]

Methods of surgical repair include: use of hemostatic agents such as electrocautery; argon-beam coagulator; collagen powders and fabrics; gelatin foam sheets; laser; simple suture repair with or without debridement, perhaps using bolsters of Teflon pledgets or omental fat; and omentoplasty. The blood supply to the spleen is segmental, which allows partial resection. If individual hilar vessels are clamped, this may stop bleeding and produce demarcation of the area to be resected. Interlocking sutures or a carefully and slowly applied linear stapler can obtain hemostasis at the resection margin. An absorbable mesh bag or envelope can be used to tamponade the bleeding from a severely fractured spleen[62,63] but care must be taken to prevent ischemia.[61] Finally, ligating the splenic artery, or temporarily occluding it, in conjunction with any of the other methods may prove helpful.

Another method that is considered experimental is autotransplantation of a portion of the spleen. This method consists of placing approximately 50 g of thin slices of splenic tissue between the leaves of the omentum. Several series report postoperative radioisotope spleen scans showing functioning splenic tissue with peripheral blood smears showing absence of Howell-Jolly bodies.[64,65] There is, however, a report of one late death in an adult from overwhelming sepsis five months after surgery using this procedure.[63] There is also concern regarding adhesions forming. Laparoscopy can have both a diagnostic and a therapeutic role in splenic trauma.

When evaluating a splenic injury, it would be ideal to be able to pick out patients who have isolated, nonhilar splenic injury and cessation of active hemorrhage. This would permit a higher level of confidence that such a patient would not need transfusion or delayed laparotomy for a missed visceral injury. Diagnostic laparoscopy can provide such information. In addition, laparoscopy has potential as a therapeutic tool. Hemostatic modalities that are available through the laparoscope include electrocautery, laser, and argon-beam coagulation. It is also possible to apply collagen powders and fabrics, and gelatin sheets. With some skill, sutures may be placed. One of the most effective, newer methods has been the use of the fibrin glue described earlier. Presently, the role of therapeutic laparoscopy in splenic trauma should be limited to low-grade (grade I to III) injuries, pending further experience and clinical trials.

The future of laparoscopy in splenic trauma has various possibilities. Laparoscopic splenectomy for hematologic disease has been performed. It is certainly possible to ligate the splenic artery. It is possible to place a mesh bag into the abdomen and to place the spleen into it. Development of the mesh bag technique might permit the performance of laparoscopic splenorrhaphies in severe splenic trauma. The future of splenic trauma will be affected by the increased detection of hepatitis C virus-infected blood donors. This has had a revolutionary impact on the risk of transfusion and the risk of using cryoprecipitate in the preparation of fibrin glue. In May 1990 all blood collection agencies in the United States began screening for HCV using EIA-1 testing. Using this test, risk of HCV was 0.57% per patient and 0.03% per unit in one study.[66] Recently developed, second-generation anti-HCV EIAs are even more sensitive. One such assay, termed EIA-2, resulted in a risk of 0.017%, or 1 in 6,000 units transfused, which would make the risks of postsplenectomy sepsis and transfusion roughly comparable.[67]

Diaphragm

With the current trend toward observation of stable trauma patients, diagnosis of diaphragmatic injury from blunt or penetrating trauma is problematic. Many diaphragmatic injuries are asymptomatic and may not be apparent on imaging studies or DPL. Diaphragmatic injuries cannot be expected to heal spontaneously even if they are small; consequently, any injury to the diaphragm is an indication for operative management. Ideally, injuries to the diaphragm should be repaired in the acute setting because, unrecognized, they may remain latent for years before presenting as an obstructive event.

Since acute diaphragmatic injuries can be missed, the true incidence is impossible to determine. In blunt trauma, reports of left-sided injuries predominate.[68,69,71,72] Perhaps this is because the liver offers protection to the right hemidiaphragm. Therefore, the herniation of abdominal contents on the right side may be blocked by the liver, or major liver injuries associated with right diaphragmatic injuries may take the lives of most patients. Diagnosis of diaphragmatic injuries based on a chest x-ray is missed about 50% of the time. The chest x-ray may appear completely normal.[70,71] Doctors using peritoneal lavage have missed these injuries with some frequency.[73] CT is poor at delineating diaphragmatic defects unless there is herniation. A method that improves the likelihood of making the correct diagnosis involves inducing a pneumoperitoneum, followed by an upright chest X-ray. In some cases the diagnosis has been made by seeing peritoneal lavage fluid draining from a chest tube.[72]

Operative treatment depends to some extent on the size of the disruption and on whether the problem is acute or chronic. Most defects in an acute setting may be repaired through an abdominal approach even with right-sided injury.[72] Chronic defects with herniation are often best approached through the chest since it is easier to divide adhesions and re-expand any chronically compressed lung.[70] Blunt injury usually results in large radial tears, whereas penetrating injuries result in small defects. Repair usually can be effected using one layer of interrupted, nonabsorbable suture. Rarely, prosthetic material may be used to patch a defect.

Laparoscopy can contribute much to managing traumatic diaphragmatic injury even when used in a minimal fashion. Visualization of the diaphragm is possible with minimal insufflation. This can be accomplished through patient positioning, laparoscopic retraction of intra-abdominal organs, and abdominal wall lift maneuvers that alleviate concerns regarding iatrogenic tension pneumothorax.

In penetrating trauma, many surgeons routinely explore missile injuries and selectively manage stab injuries. Utilizing minilaparoscopy, we have demonstrated that diagnostic peritoneal lavage misses a significant number of diaphragmatic injuries in patients with stab wounds. The application of formal exploratory laparoscopy may eliminate the need for exploration of some penetrating injuries. Formal exploratory laparoscopy usually requires full insufflation and thus is unavailable or not advised in cases of an injured diaphragm, unless the diaphragm can be repaired in an airtight fashion. We have demonstrated that airtight diaphragm repair is possible in an acute setting through a laparoscope using currently available equipment. There are no long-term results of such repairs available. There is one anecdotal report of a delayed pericardial tamponade from a laparoscopic diaphragmatic repair.

Liver

The liver is the second most commonly injured organ following blunt abdominal trauma and is the most commonly injured organ in patients with penetrating trauma of the abdomen. Although use of segmental anatomy for operative classification of liver injuries has been proposed,[75] most use the classification described by Moore.[76]

Grade I: capsular avulsion or parenchymal fracture < 1 cm deep
Grade II: parenchymal fracture 1 to 3 cm deep, subcapsular hematoma < 10 cm in diameter, or a peripheral penetrating wound
Grade III: parenchymal fracture > 3 cm deep, nonexpanding subcapsular hematoma > 10 cm in diameter, or a central penetrating wound
Grade IV: lobar tissue destruction or massive expanding central hematoma
Grade V: extensive disruption of both hepatic lobes, major hepatic vein injury, or retroheptic vena cava injury

CT scanning has been useful in successful nonoperative grading of injury.

Nonoperative Management

Because physical exam cannot accurately determine the presence of significant intra-abdominal injury, since 1965 peritoneal lavage has been widely used to determine the need for exploration based on the presence of intraperitoneal blood. The ensuing nontherapeutic laparotomies led to trials of nonoperative management of splenic and liver injuries, depending on CT to determine the extent of injury. Results of some nonoperative management series are instructive (Table 24.4). In the first series, 70 CT scans and 7 hepatobiliary scans (for bile leak) were performed. Three of the complications were subcapsular bil-

TABLE 24.4. Nonoperative hepatic trauma management.

Series	No. of patients	Grade of injury I & II	Grade of injury III & IV	Failures	Transfused
Bynoe[77]	26	16	10	5	6
Knudson[78]	52	34	18	1	12

omas and two were free bile leaks. In the second series, serial CT scans were used in 21 patients with 5 showing persistent defects months after injury.

Bits of information that can be gleaned from these and other series are: (1) CT scanning can estimate the amount of free blood in the peritoneal cavity, but it cannot tell whether the bleeding is active or has already stopped; (2) a single CT scan is unable to differentiate bleeding from bile leakage; (3) serial CT scans are needed to follow these patients; (4) there is potential for significant transfusion requirements while carrying out this form of management in stable patients; (5) careful patient selection must be used; (6) this kind of management can be performed successfully more often if one can determine the patients who are no longer bleeding and do not have significant bile leaks.

Laparoscopy can be helpful for diagnosis by identifying those patients who have intraperitoneal blood but do not have any ongoing active bleeding or bile leakage. This may obviate the need for repeated CT scanning, laparotomy based on diagnostic peritoneal lavage, laparotomy based on the amount of intraperitoneal blood, or intensive care monitoring. From a therapeutic standpoint, actively bleeding minor (grade I and II) and even some of the major (grade III and IV) injuries only require the application of electrocautery, argon-beam coagulation, or hemostatic agents (with or without drainage) in order to stop the hemorrhage. Observation of such a patient might lead to either a failure due to hemorrhage or the need for transfusion (with its attendant risks) while natural hemostatic processes occur. Application of therapeutic laparoscopy could obviate this in certain cases.

Operative Management

With the evolution of various surgical techniques and ensuing controversies, operative management of liver trauma ranges from the simple to the complex. Grade I and II injuries are usually treated using simple techniques such as electrocautery, argon-beam coagulation, or application of laser or other thermal energy. Temporary packing with pressure, or topical hemostatic agents such as thrombin, gelfoam, or collagen sheets and powders are helpful. More serious injuries often require complex treatment. Often these patients are hypotensive and require maneuvers to initially control hemorrhage and restore normal blood volume. This is usually done by opening the abdomen in the operating room, applying packs, and gentle pressure. Some patients, however, require emergency room thoracotomy as part of their initial management. Once normal blood volume is re-established and associated injuries in the other three quadrants have been assessed or treated, one is ready to evaluate the liver damage. The liver is connected to three vascular systems via the portal vein, the hepatic arteries, and the hepatic venous system. If the Pringle maneuver controls the bleeding, one can assume that the bleeding originates from the hepatic arteries or the portal venous system. No reduction in hemorrhage with the Pringle maneuver suggests that the bleeding is from the hepatic veins or an intrahepatic caval injury, especially if voluminous bleeding occurs with caudad retraction of the liver.

If the Pringle maneuver controls bleeding and there is no coagulopathy, the wound can be explored with finger fracture technique and individual control of bleeding vessels by clip or suture is done. Obvious nonviable tissue is removed and the area may be drained. In addition, selective hepatic artery or portal vein branch ligation may be performed in a few patients. Resectional debridement or segmentectomy can be carried out for more significant injuries in this group. Omentum may be used in a manner similar to a pack for added hemostasis of raw liver surfaces and to obliterate parenchymal dead space. (Successful Pringle maneuver times greater than two hours have been reported in trauma situations with 5-minutes recovery periods every 20 minutes.) When and how to drain these injuries remains controversial.

For a patient with significant bleeding after the Pringle maneuver and no evidence of coagulopathy, injury to the vena cava or hepatic veins must be considered—especially if the bleeding is from: the posterior aspect of the liver; anterior lesser sac; deep in the parenchyma; beneath the porta hepatis; or at the diaphragm anteriorly. In these cases vascular isolation of the liver may be considered using: (1) an atria-caval shunt; (2) placement of a femoral catheter shunt (Moore-Pilcher IVC shunt GA-194, Bard Cardiopulmonary Division, Billerica, MA),[79] (3) femoral to axillary vein pump assisted bypass; and (4) Heaney maneuver (clamping the supra- and infrahepatic cava and applying the Pringle maneuver).

There are several other options that have been described for the treatment of liver injuries. One is temporary packing. This is done for control of massive hemorrhage where, for various reasons, repair or resection must be abandoned, coagulopathy develops, or local bleeding persists despite surgical maneuvers. Occasionally this is done in desperation, but success usually depends on using this technique carefully before transfusion requirements become excessive. It can be successful even in the presence of unrepaired caval or hepatic injury. Packing is done in such a way that the liver is compressed uniformly without occluding the vena cava. Packs are removed at a subsequent operation. Coagulopathy as a function of blood replacement is reported in one series as occurring in only 17% of patients requiring < 15 units of blood, and complicating 55% of cases requiring > 15 units.[80]

Using a method similar to packing and analogous to a maneuver used in splenic preservation, Jacobson describes managing four patients with massive parenchymal liver injuries by wrapping the liver with an absorbable mesh under tension.[81] After a Pringle maneuver, the liver is mobilized by division of the falciform, triangular, and coronary ligaments. Major vessels and large segmental ducts are ligated. Two 7 × 9-cm sheets of absorbable mesh are stapled together and wrapped anteriorly under tension excluding the gallbladder. They are secured with TA-90 staplers. One pseudoaneurysm in the parenchyma was embolized as the only complication. Intraoperative use of fibrin glue has been described by some authors. There are at least nine case studies in the literature of successful management by intraparenchymal fibrin glue injections in spite of grossly abnormal coagulation profiles. This maneuver was tried in these patients after some attempts at conventional treatment, including packing.[47,49]

Laparoscopic treatment of more serious liver injuries requires several capabilities that are not generally readily available. These include rapid evacuation of large amounts of clotted and liquid blood with or without cell-saver hookup and nonprototype fibrin glue injectors. It would also be ideal to have a commercial source of fibrinogen (as in Europe) rather than have to wait for cryoprecipitate from the blood bank. It is, however, feasible to perform a laparoscopic Pringle maneuver rapidly if adequate blood evacuation is possible. It is also possible to isolate the liver from the caval circulation using the femoral catheter previously mentioned. With cautery and argon-beam coagulation being suited only for fairly minor hemorrhage, laparoscopic treatment of more major hepatic injury, at the moment, will depend on development of readily available fibrin glue, hemostasis technology, and methods of easily deploying absorbable mesh "packs" or "bags."

Concerns regarding laparoscopy in hepatic trauma include the possibility that insufflation pressures (when used in place of abdominal wall lift and positioning to view the upper abdomen) may cause temporary tamponade of venous bleeding, and that these same pressures may lead to gas embolus (especially when the hepatic veins may be injured). Risks of intraparenchymal fibrin glue injection have already been outlined.

Colon

Injury to the colon can occur with both penetrating and blunt trauma. Sigmoid perforation is the most common type of colon injury in blunt trauma.[82] This can be missed on CT, especially if triple contrast technique is not used, resulting in significant morbidity and mortality. The current trend in surgical treatment of civilian colon injuries is to perform primary repair whenever feasible, rather than colostomy or exteriorization. When primary repair is not possible, resection and anastomosis is often performed. Favorable conditions for success have been studied and various scoring systems have been used to supplement clinical judgement. Even in the extreme case when primary repair or resection is carried out irrespective of associated injury, degree of fecal contamination, shock, transfusion, injury location, or mechanism, there have been reports of results superior to diversion.[83] Colostomy and presacral drainage remain the basis for successful treatment of extraperitoneal rectal injuries.

Laparoscopic repairs can be carried out using suture or staples. Elective anastomosis and resection have been described in this text. Options for performing this in a trauma setting are: delivery into a minilaparotomy, intraperitoneal stapling, and use of the Valtrac Biofragmentable Anastomosis Ring (VBAR).[84,85] There are no reports of laparoscopic repairs of noniatrogenic colonic injury in the literature.

The Use of Thoracoscopy in Trauma

In the United States, four people per million per day will require hospitalization for thoracic injuries.[86] Thoracic injuries directly account for 25% of traumatic deaths and are associated with another 25%.[87] Early deaths from thoracic trauma are due to disruptions of the heart or great vessels, cardiac tamponade, aspiration, or airway obstruction. Later deaths are due to respiratory complications, missed injuries, and infections.[87] In blunt trauma, up to 33% of those injured will have thoracic pathology[88] and 45 to 50% of unrestrained drivers in motor vehicle accidents suffer chest injury.[89] In penetrating trauma, over 40% of all patients will have thoracic injuries.[88] Penetrating injuries to the thorax occur up to three times more frequently than to the abdomen.[90] Approximately 85% of patients with thoracic injury are managed nonoperatively with tube thoracoscopy, respiratory support, and pain control.[91] The remaining 15% require thoracotomy. The average length of stay for management with observation and tube thoracoscopy is three days compared to 7 to 14 days for thoracotomy.[87]

Pathophysiology

The type of injury that can be expected depends on the causative mechanism and the direction of applied force. Thoracic injuries from blunt trauma are due to deformation from deceleration, compression, or crushing. Low-velocity gunshots and stab wounds cause damage through laceration. High-velocity missiles add the mechanisms of cavitation shock waves, and the production of secondary missiles such as bone fragments, to the type of injuries expected.

Historical Perspective

The first historical record of injury to the chest was cited in the Edwin Smith Surgical Papyrus written about 3000 BC.[92] Gladiators had their wounds treated with open packing. Improvement in respiratory function with thoracic wound closure postinjury was noted in 1767 by Henson. Guidelines for performing a thoracotomy were established during World War II. This partially accounted for the reduction in thoracic trauma mortality from 25% in World War I to 12% in World War II.[87] The physical exam and the chest x-ray are the most frequently used tools in the diagnosis of thoracic trauma.[87,93] Other diagnostic modalities used in selected cases include ultrasound, angiography, and CT scan.

Tube thoracoscopy is an invasive procedure that offers both diagnostic and therapeutic capabilities in thoracic trauma. In a collection of 5,508 trauma patients undergoing tube thoracostomy and observation, 85.4% did not need thoracotomies.[94] Tube thoracoscopy can be fraught with problems. Expectant management with tube thoracoscopy can delay definitive therapy in the few needing operation. Tube thoracoscopy can offer a false sense of security, as manifested by those few patients who suddenly exsanguinate after apparent stabilization of hemorrhage with a chest tube.[95,96] In addition, 2.7% will require delayed thoracotomy for empyema or clotted hemothoraces.[94] Because of the severity of these complications, some have recommended thoracotomy for the majority of those who meet the criteria for tube thoracoscopy, except those with very minor injuries.[95,97] Thoracoscopy addresses the majority of these issues in the stable patient. This modality may offer improvement over current diagnostic tests, especially in the areas of injury to the intercostal vessels and chest wall, lung, diaphragm, and persistent chest tube hemorrhage.[98–102] Bleeding that is persistent or large in amount usually originates from intercostal or internal mammary arteries.[102,103] With present technology, therapeutic intervention is possible for many stable injuries requiring further intervention. It is the hope of these authors that, with time, thoracoscopy will earn a defined role in the management of thoracic trauma, both as a diagnostic and a therapeutic tool.

Trauma Thoracoscopy Literature Review

The clinical use of thoracoscopy was first described more than 80 years ago by Jacobeus.[104] Since then, there has been discussion,[90,98] but few reports, of the use of thoracoscopy in the trauma setting. In 1946, Branco was the first to describe the use of thoracoscopy in penetrating trauma.[99] In five patients, thoracoscopy was helpful in identifying the thoracic injuries and removing clotted blood. Senno observed two additional patients with intrathoracic hemorrhage and successfully performed the first therapeutic intervention by controlling intercostal vessel bleeding.[100,101] The first large series of patients treated with thoracoscopy was described by Jones and colleagues in 1981.[94] They evaluated 36 stable patients suffering penetrating trauma. All patients had hemothoraces of varying degree, initially drained by chest tubes. In 33 patients, the procedure was performed under local anesthesia. Injuries were correctly identified in 35. If the indication for thoracotomy is considered to be persistent hemorrhage of greater than 200 mL per hour for more than two hours via the chest tube, then 11 patients (30.5%) had their management altered. Hemorrhage control was successful with relatively simple maneuvers such as evacuation of intrathoracic clot and electrocautery of intercostal vessels. Thoracoscopy identified diaphragmatic injury in six patients. No complications were noted. Ochsner and colleagues used thoracoscopy to specifically evaluate for diaphragmatic injury in nine patients with penetrating trauma, based on position of the external wound.[102] Laparotomy confirmed thoracoscopy findings in seven patients with diaphragmatic tears and two without. Complications included brief arrhythmias (one patient) and empyema (one patient). Experimentally, we have shown that 2-cm tears to the diaphragm could be successfully repaired in an airtight fashion with a laparoscopic stapling device in less than five minutes, either via a thoracic or abdominal approach in an acute porcine model (unpublished data).

Diagnostic Thoracoscopy

Indications

Guidelines for diagnostic and therapeutic trauma thoracoscopy remain in the early stages of development. As techniques become refined, surgeons gain experience, equipment is developed, and data are collected, the indications for thoracoscopy in the trauma setting will become more solidified. Two situations in the stable patient seem tailored to the use of the thoracoscope. The first is persistent hemorrhage, noted from the chest tube, from blunt or penetrating trauma. The second is penetration in which there is a possible diagnosis of diaphragmatic injury.

In the patient who is stable, has required a chest tube for hemothorax, and has persistent hemorrhage from the chest tube, thoracoscopy is indicated (Figure 24.5). As data are collected, this indication should eventually be refined to more accurately define the parameters used in

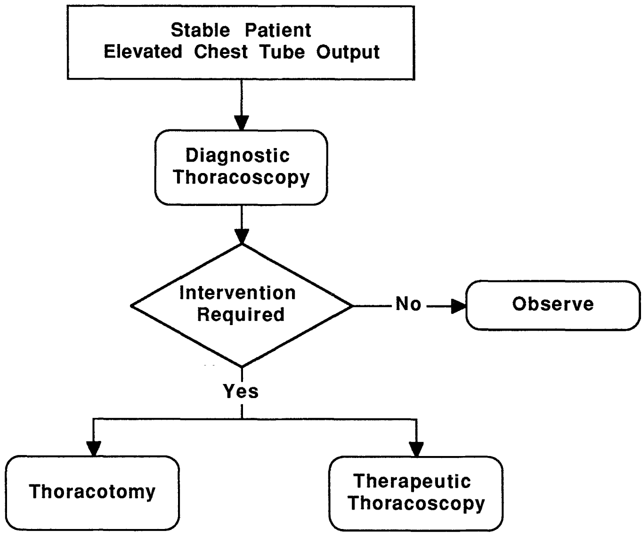

FIGURE 24.5. Thoracoscopic algorithm for stable patients with persistent and elevated hemorrhage from the chest tube.

the decision to perform thoracoscopy. Presently, we use greater than 200 mL of blood per hour for more than two hours. If diagnostic thoracoscopy reveals an injury that does not require intervention, then no further treatment besides observation is required until the chest tube is removed, usually in 24 hours. If the thoracoscopy reveals an injury requiring further intervention, then a decision should be made to proceed with either therapeutic thoracoscopy or thoracotomy, based on the severity of the injury, stability of the patient, and experience of the surgeon. If therapeutic thoracoscopy is unsuccessful, conversion to thoracotomy is required.

Another frequent diagnostic dilemma is the stable patient who has suffered a penetrating injury in whom diaphragmatic injury is a possibility based on external wound position and trajectory. Thoracoscopy offers a realistic alternative to present diagnostic modalities (Figure 24.6). Depending on the clinical situation, either diagnostic laparoscopy or thoracoscopy may be used. If diagnostic thoracoscopy is used and found to be negative for diaphragmatic injury, then the patient is observed. If positive, then a decision to repair the diaphragm through the thoracoscope or by thoracotomy should be made. This decision depends on the stability of the patient, mechanism of injury, experience of the surgeon, and severity (length) of injury. Small tears seen with stab wounds are usually amenable to thoracoscopic repair. If the repair is unsuccessful through the thoracoscope, then open repair is performed. Following thoracoscopic repair from stab wounds, diagnostic laparoscopy or diagnostic peritoneal lavage should be performed because of potential intra-abdominal injury. Gunshots with diaphragmatic penetration usually require formal laparotomy, with diaphragmatic repair undertaken at that time. Transmediastinal penetration found at the time of thoracoscopy should be evaluated using standard methods until further information is collected on the use of thoracoscopy in this setting. Other indications await further experience with thoracoscopy. However, we can envision the use of thoracoscopy expanding rapidly to include the evaluation of the descending thoracic aorta in blunt trauma, diagnosis and treatment of stable pericardial tamponade, and the evacuation of retained clot.

Monitoring

One of the most important components to a successful trauma thoracoscopic procedure is communication between the surgeon and anesthesiologist during the perioperative period. This is especially important in issues of airway control and intraoperative parameter changes. Frequent monitoring of blood pressure, heart rate, cardiac rhythm, PCO_2, and PO_2 is necessary. The need for invasive monitoring should be dictated by the clinical situation and severity of the trauma.

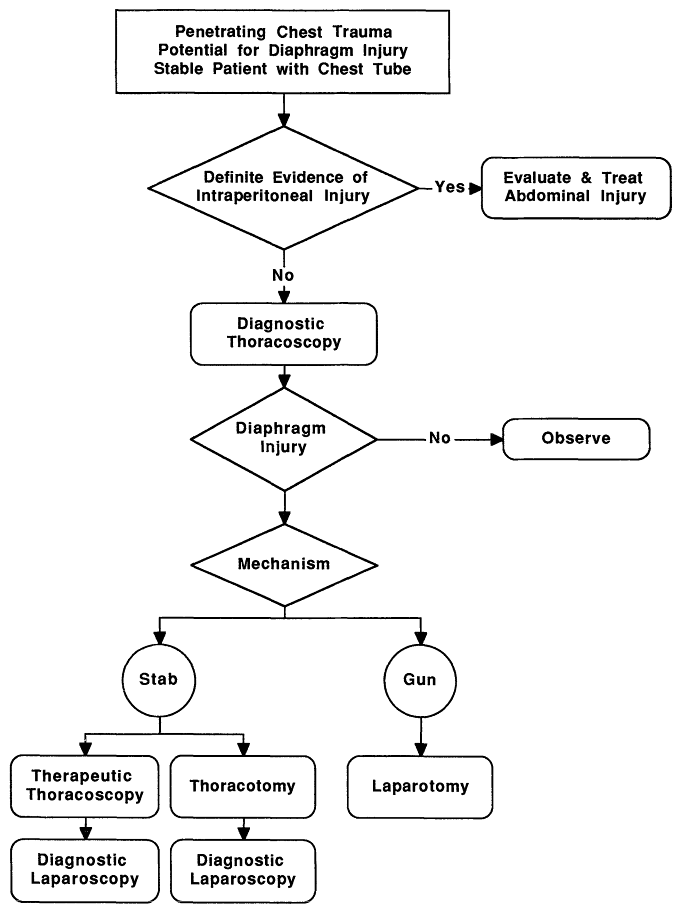

FIGURE 24.6. Thoracoscopic algorithm for stable patients with penetrating chest trauma and potential for diaphragmatic injury.

Anesthesia

The anesthetic choice for trauma thoracoscopy can be tailored to the clinical situation and includes local, regional, and general.[94,105–108] The best visualization is obtained with single lung ventilation with a double lumen endobronchial tube and is the technique of choice when therapeutic thoracoscopy is contemplated. This allows for controlled collapse of the lung on the operative side. With this type of ventilation, frequent monitoring of respiratory parameters is important to prevent hypoxia and hypercarbia. Single lung ventilation may not be possible if the ventilated lung has suffered a severe pulmonary contusion. Dual lung ventilation with a single lumen endobronchial tube may be used, but visualization and thoracic evaluation may be more difficult. In many circumstances, the patient may have been intubated prior to the decision to perform thoracoscopy and it may be too risky to switch over to single lung ventilation if a cervical injury is suspected or if the original intubation was difficult.

Local anesthesia, with or without regional intercostal block, can be used in the cooperative patient not requiring an extensive diagnostic evaluation or therapeutic intervention.[94,105,106] The ideal candidate would be a patient with a stab wound in whom evaluation of an anterior lateral diaphragmatic tear is contemplated. Almost all patients in whom an injury requiring thoracoscopic repair is found should be switched to single lung ventilation under general anesthesia.

Positioning

Overall visualization is best obtained with the patient in the full lateral decubitus position. This allows for a general overview of the thoracic cavity. A semilateral decubitus position (30° to 45° angle) can be useful to more fully visualize the pericardium and the aortopulmonary window. The supine position may be used for further evaluation of the anterior thoracic cavity. Of note, the supine position may be the only choice when injury to the spine has not been ruled out and the patient cannot be turned. All three positions can be used to advantage in certain circumstances to enhance complete visualization of the thoracic cavity. This can be accomplished by completely securing the patient in the semilateral position and pivoting the table in the longitudinal axis to achieve the full range of visualization. If a single video monitor is used, it is generally placed at the head of the bed, with the bed angled to allow the anesthesiologist room to manage the patient. If two monitors are used, their optimal location may vary depending on the situation.

Trocar Placement

If there is a chest tube in place, it is removed and the site used for the initial trocar. If the patient does not have a chest tube, a 2-cm incision is placed in the eighth intercostal space in the midaxillary line (Figure 24.7). Using blunt dissection, the thoracic cavity is entered. Digital inspection is performed to determine the presence of limiting adhesions that, if present, may be a contraindication to proceeding further with thoracoscopy. Barring significant adhesions, a 12-mm thoracic trocar is placed through the incision and the operating telescope is passed.

Under certain circumstances, the single operating telescope may be all that is required to evaluate the injury in question and to make a treatment decision. An example would be a 10th intercostal stab wound in the anterior position where there is a possible diaphragmatic injury. However, for more complete evaluation of the thoracic cavity, two more manipulating ports are placed under direct visualization. One port is placed in the anterior axillary line in the fifth or sixth intercostal space in a similar manner as the initial port. The second is positioned in the posterior axillary line in the fifth or sixth intercostal space again using blunt dissection. All trocars should be 12 mm. Placing the anterior and posterior ports in the same intercostal space will allow for easier transition to formal thoracotomy if the need arises.

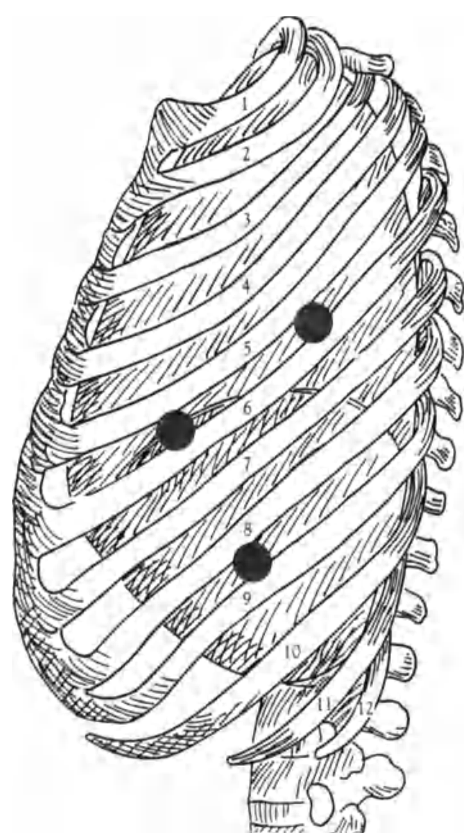

FIGURE 24.7. Sites for placement of thoracic trocars on the lateral chest wall.

Thoracic Evaluation

The thoracic cavity is evaluated in a systematic fashion, working from superior to inferior. Thoracoscopic manipulating instruments such as lung clamps, tissue manipulators, and suction/irrigators can be used through the accessory ports to completely explore the thorax, especially in the areas of the posterior diaphragm, mediastinum, and the parenchymal hilum. Complete visualization of the hemithorax may be improved through several methods. Assuming that the patient is adequately secured to the operating table, longitudinal rotation of the patient can be used to facilitate visualization. The operating telescope and manipulating instruments can be moved from port to port as needed, and in certain circumstances, angled or flexible telescopes may be helpful. Blood clots should be removed as completely as possible, both to help in evaluation, as well as to reduce the incidence of postoperative empyema. If single lung ventilation has been used, the lung should be examined while re-expanded. This may prevent injuries from being missed that may be obscured with a collapsed lung.

At this point, a decision is made as to the next step in management (see Figures 24.5 and 24.6). If no further intervention is required, then the ports are removed and a chest tube placed through the existing incision in the eighth intercostal space. The other two incisions are then closed. If minimal or no intrathoracic pathology is noted, the chest tubes can be removed within 24 hours. Although we have no experience with this, some general thoracic surgeons do not place a chest tube if minimal manipulation is performed.[105,109] If significant injury is noted, especially parenchymal, the chest tube may need to remain in longer and be evaluated for a leak prior to removal. If further intervention is required, based on the diagnostic evaluation, either formal thoracotomy or therapeutic thoracoscopy is required. This decision depends on the skill of the thoracoscopist, severity of the injury, and the stability of the patient. If thoracotomy is indicated, the thoracoscopy equipment is removed and the thoracotomy incision made, ideally incorporating the superior trocar sites. The use of therapeutic thoracoscopy is discussed below.

Therapeutic Thoracoscopy

If diagnostic thoracoscopy reveals a minor to moderate injury requiring intervention, therapeutic thoracoscopy should be considered. This decision will be tempered by the skill of the surgeon as well as the patient's stability. Unstable patients, severe injuries, or an unskilled thoracoscopist are contraindications to performing therapeutic thoracoscopy. This section covers some frequent types of injuries that can realistically be treated with the thoracoscope.

Hemorrhage Control

One of the most common problems following either penetrating or blunt trauma is persistent hemorrhage. A frequent finding with active hemorrhage is a large intrathoracic clot and a minor injury. In many instances, simply evacuating the clot results in cessation of bleeding.[94,99] Explanation for this phenomena is elusive; however, it may be that the clot puts tension on a small, torn vessel keeping it patent, or increased fibrinolytic activity from the clot[110] results in continued hemorrhage. Another frequent source of continued bleeding is injury to an intercostal or mammary artery.[94,103,111–114] Electrocautery, internal clips, or intrathoracic suturing can control these vessels. Another method is to pass a straight needle and suture from outside into the thoracic cavity under thoracoscopic visualization and then guide the needle back out through the chest wall with a needle driver. This is repeated and then tied down to the chest wall resulting in a figure eight tie around the vessel. Minor lacerations to the lung surface with persistent hemorrhage can be controlled, especially when the injury is lateral. Electrocautery, suturing, or topical hemostatic agents may be useful. For lateral injuries, an additional technique is exclusion of the injury by using an endoscopic linear stapler fired twice in a *V* fashion around the laceration.

Diaphragmatic Injury

Large injuries to the diaphragm require a thoracotomy to repair. Smaller injuries such as those seen from stab wounds or low-caliber gunshots may be amenable to thoracoscopic repair. We feel that the safest repair would be with sutures in a fashion similar to open thoracotomy. This can be performed in a running or interrupted fashion with nonabsorbable sutures. Presently, we do not feel that the existing generation of thoracoscopic stapling devices have strong enough staples to hold diaphragmatic tissue together. If it is necessary to perform this repair with staples, then reinforcing the repair with a synthetic patch stapled around the wound may suffice; however, we have no experience with this technique either experimentally or clinically.

Lung Injury

Traumatic injury to lung tissue is common, especially after penetrating trauma. Lateral injuries are easier to repair through the thoracoscope than medial. Dual lumen anesthesia is mandatory for safe repair. Small tears may be sutured. Larger injuries, especially to the lateral surfaces of the lung may be excluded with two applications of a thoracoscopic linear stapler in a *V* fashion. At the completion of the repair, evaluation for an air leak should be performed by expanding the lung and viewing the surface.

TABLE 24.5. Complications of general thoracoscopy.

Complications of general thoracoscopy	
Intraoperative	
Hemorrhage	1.0%
Respiratory insufficiency*	2.0%
Arrythmias*	0.5%
Air embolism	0.2%
Local emphysema	Common
Mediastinal emphysema	Rare
Postoperative	
Bronchopleural fistula	Rare
Persisting pneumothorax	Rare
Empyema	2.0%

*Seen with local anesthesia.
Based on Viskum. Contraindications and complications to thoracoscopy. *Pneumologie* 1989; 43:55–57.

Pericardial Window

Cardiac tamponade can be recognized through the thoracoscope as a fluid bulge and loss of cardiac visualization through the pericardial membrane. Decompression is performed in a similar fashion to the open technique. Using the two manipulating ports, the pericardium is grasped and then cut ventral and parallel to the phrenic nerve. Large blood clots can then be removed with blunt manipulation and suction. If active bleeding is encountered, conversion to thoracotomy is necessary.

Future Procedures

As improvements are made in thoracoscopic equipment, clinical trials are conducted, and skills are improved, the potential scope of therapeutic procedures will widen. Future procedures may treat large diaphragmatic tears, esophageal injuries, complicated lung trauma, flail chest, and other injuries. Theoretically, the only limitations to the use of therapeutic thoracoscopy may be hemodynamic instability and large vessel injury.

Complications

The number of clinical trials performed in trauma thoracoscopy have been limited; consequently, information on complications is sparse. However, both intraoperative and postoperative complications should be infrequent if incidence may be inferred from general thoracoscopy[115] (Table 24.5).

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25
Laparoscopic Hernia

25.1 Laparoscopic Inguinal Herniorrhaphy: Current Techniques

José Camps, Nam Nguyen, Riccardo Annibali, Charles J. Filipi, and Robert J. Fitzgibbons, Jr.

Laparoscopic cholecystectomy has rapidly become the procedure of choice for uncomplicated biliary tract disease, primarily because of decreased postoperative pain and lack of scarring, which is so attractive to the patient. In addition, surgeons have embraced the operation because viewing critical anatomical structures is improved and there is an early return to normal activities and a marked decrease in postoperative morbidity in cases without complications. Not surprisingly, therefore, therapeutic laparoscopy has now extended to other surgical fields. It has established a position in antireflux surgery, colorectal surgery, complicated biliary tract disease such as choledocholithiasis, and is being evaluated in other upper gastrointestinal procedures, along with expansion in its traditional role in gynecological surgery and diagnosis.[1,2] This chapter will detail the latest and perhaps most controversial indication—laparoscopic inguinal herniorrhaphy.[3–8]

The key ingredients that have resulted in the development of laparoscopic inguinal hernia repair (LIHR) have been the acceptance of prosthetic materials to produce a tension-free herniorrhaphy, the apparent efficacy of the preperitoneal approach, and the development and widespread use of therapeutic laparoscopy in general surgery. LIHR has the following potential advantages: (1) less postoperative discomfort/pain; (2) reduced recovery time allowing an earlier return to full activity; (3) easier repair of a recurrent hernia, because the repair is performed in tissue that has not been previously dissected; (4) the ability to treat bilateral hernias; (5) the performance of a simultaneous diagnostic laparoscopy; (6) the highest possible ligation of the hernia sac; and (7) an improved cosmesis.[9–13] The earlier return to full activity is an important socioeconomic factor, because the decrease in time away from work could potentially offset the higher operative costs. Finally, assuming a 10% overall recurrence rate for conventional hernia repair, it is theorized that the rate might be lower for LIHR because of the mechanical advantage gained by placing the prosthesis in the preperitoneal space proximal to the abdominal wall defect.[14–15]

The main arguments against LIHR are that: (1) conventional hernia repair (CHR) is an effective operation already performed as an outpatient procedure with low morbidity and mortality; (2) conventional hernia repair may be performed under local anesthesia whereas LIHR usually requires general anesthesia and (3) LIHR is more expensive.[16,17]

To justify replacing a safe and effective technique like the classical hernia repair with laparoscopic herniorrhaphy, two aims must be met: (1) reduction in postoperative discomfort/pain; and (2) reduction in the rate of recurrence.

In achieving these goals, safety must be of prime importance. There is a small but definite incidence of cardiac dysrhythmia following induction of pneumoperitoneum.[18] This may be minimized by careful technique and by avoiding rapid insufflation and high pressures. These procedures should always be carried out with full facilities for resuscitation. Laparoscopy usually requires general anesthesia with muscle relaxation, and all the risks that entail. Epidural or spinal anesthesia is theoretically possible, but surgeons have little experience with therapeutic laparoscopy under these conditions.[19] Finally, if inguinal herniorrhaphy is to be performed laparoscopically, the patient and surgeon must accept the risks that are inherent with laparoscopy including perforation of the bowel and major vascular injury. In addition, delayed adhesive small bowel obstruction related to sites where the peritoneum has been breached by instruments or incisions must be considered. Thus, a recommendation for laparoscopic inguinal herniorrhaphy instead of conventional must be made in the light of these possible complications, and a clear understanding that the benefits outweigh the risks for an individual patient.[14]

The work of Stoppa and colleagues implies that there is little risk of infection using prosthetic materials.[20] Monofilament meshes are less likely to allow infection to occur later on. Evidence from the use of prosthetic arthroplasties suggests that the organisms leading to infection are usually implanted at the time of surgery. It would appear logical to adopt a "no touch" technique, and the use of prophylactic perioperative antibiotics should be considered.[21]

Patient Selection for Laparoscopic Herniorrhaphy

All adults who are candidates for general anesthesia can be considered candidates for laparoscopic inguinal herniorrhaphy. Although there may be a role for laparoscopic herniorrhaphy in the pediatric patient, primarily to examine the opposite side for an occult hernia, this is yet to become well accepted.[22] Relative contraindications include uncontrolled coagulopathy, intra-abdominal adhesions from previous abdominal surgery, incarceration, severe obesity, peritonitis, or osteitis. Patients need to be informed of the investigational nature of the procedure. It is not clear at the present time which patients will be better served by laparoscopic herniorrhaphy and which by the conventional procedure. Specific recommendations cannot be made until data from various trials mature.

Operating Room Set-Up

Figure 25.1.1 depicts the operating room set-up most commonly employed for the laparoscopic herniorrhaphy procedure. The surgeon usually stands on the opposite side of the table from the hernia, because the angle for dissection and staple placement is most appropriate. After induction of general anesthesia, a Foley catheter is placed to ensure continuous decompression of the bladder. Although diagnostic laparoscopy is possible under local anaesthesia, the considerable dissection involved in these procedures precludes its use with the possible exception of the intraperitoneal onlay mesh (IPOM) operation, which will be described later.

Cannulae placement is depicted in Figure 25.1.2. The initial cannula is placed in the umbilicus to allow generalized exploration of the abdomen. The patient is then placed in Trendelenburg position to allow the bowel to fall away from the pelvis and to allow good access to the inguinal area. Two additional cannulae are placed lateral to the rectus sheath on either side at the level of the umbilicus. All three are large cannulae (10 to 12 mm), as this will allow free movement of the laparoscope and the stapler to any position, depending upon the patient's anatomy.

The operating room set-up for the totally extraperitoneal (EXTRA) procedure is identical to that of the IPOM or the transabdominal preperitoneal (TAPP) except that the placement of the cannulae varies. Dr. McKernan prefers positioning all three cannulae in the midline: the first at the umbilicus; the second at symphysis pubis; and the third midway between these two.[11] Other surgeons recommend placing two cannulae in the midline and the third lateral to the rectus sheath on the same side as the hernia, at the level of the umbilicus.

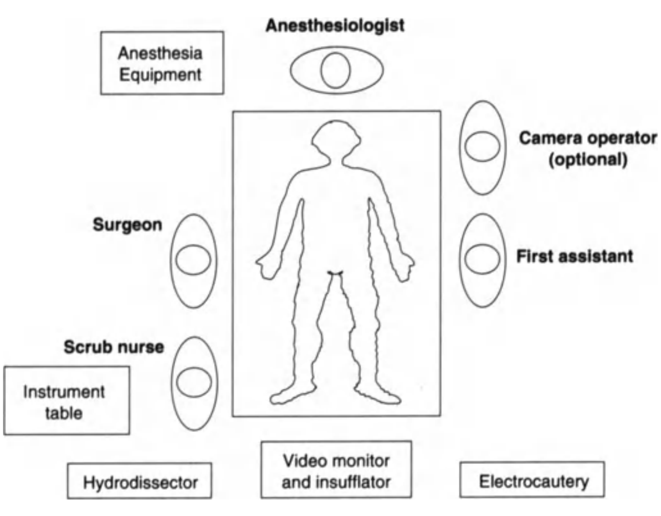

FIGURE 25.1.1. Operating room set-up most commonly employed for the laparoscopic herniorrhaphy.

The Plug and Patch Techniques

The first announcement of a laparoscopic herniorrhaphy at a scientific meeting was in 1989, when Bogojavlensky presented a videotape at the American Association of Gynecological Laparoscopists meeting in Washington, DC. He illustrated the treatment of indirect inguinal and

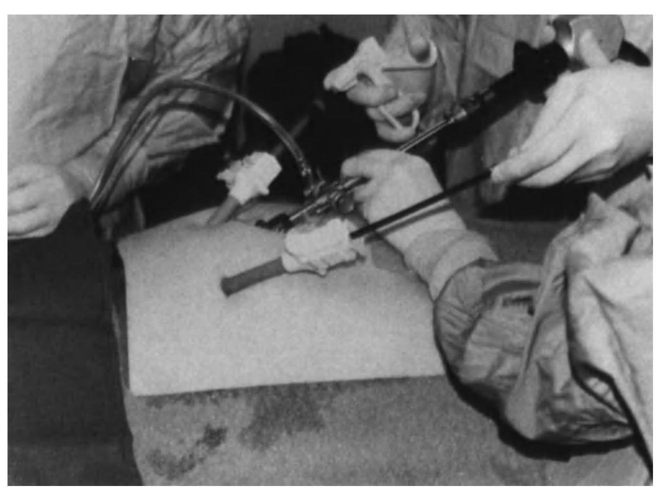

FIGURE 25.1.2. Cannulae placement.

femoral hernias by the laparoscopic introduction of a roll of polypropylene mesh into the sacs. The peritoneum was then closed over the defects using sutures.[23] In 1990 Schultz of Minneapolis, MN, presented preliminary results of a clinical trial involving a series of 20 patients subjected to laparoscopic hernia repair. His method consisted of incising the peritoneum adjacent to the musculofascial opening and filling the hernia defect with sheets of polypropylene mesh rolled into a cylinder resembling a cigarette. Two or three additional 1 × 2-in. pieces of mesh were placed over the defect. After partial decompression of the pneumoperitoneum, the peritoneum was closed. Dr. Schultz recommended the use of an angled (45°) laparoscope.[5] The latter is very important in laparoscopic hernia repair techniques. Corbitt of West Palm Beach, FL, and Seid from Santa Monica, CA, also published short series using modifications of Schultz's technique.[24,25] These procedures, often referred to as the plug and patch techniques, have now been abandoned. Long-term follow-up revealed an unacceptably high recurrence rate, probably related to the fact that the entire inguinal floor was not reconstructed. In addition, migration of mesh plugs has been a particularly distressing problem.[14]

Currently Accepted Laparoscopic Herniorrhaphies

Most laparoscopic inguinal herniorrhaphies can be classified as one of three types. These are: (1) the transabdominal preperitoneal or TAPP; (2) the intraperitoneal onlay mesh or IPOM; and (3) the totally extraperitoneal or EXTRA. Common to all three is the placement of a large prosthesis widely overlapping the hernia defect, reinforcing all potential sites of recurrent groin herniation (direct, indirect, and femoral spaces). Although other laparoscopic inguinal herniorrhaphies such as simple closure of the internal ring for small indirect inguinal hernia and placement of minimally sized prosthesis for small, recurrent direct hernia are occasionally performed, they are uncommon.[26,27] A formal sutured laparoscopic hernia repair has also been described but has not gained great popularity.[28] The TAPP technique is the most commonly used procedure for laparoscopic herniorrhaphy with the IPOM second. However, the EXTRA is rapidly gaining popularity. A detailed description of the three procedures follows.

Initial Entry to the Peritoneal Cavity

Initial access to the peritoneal cavity is an important feature of laparoscopic inguinal herniorrhaphy. Safety is of paramount importance. Complications of laparoscopy such as major vascular injury must be avoided if the procedure is to compete with conventional herniorrhaphy. Contrary to the thinking of many surgeons, the literature does not support the concept that open laparoscopy will prevent injury to solid or hollow organs.[29] However, most authorities agree that open laparoscopy will prevent the potentially life-threatening complication of major vascular injury.[30] Whether an open technique, a Veress needle, or direct trocar insertion is used, it is imperative that the surgeon use extreme caution.

TAPP

This procedure is particularly attractive to the laparoscopic surgeon because it is similar to the conventional preperitoneal hernia repair. The only difference is that the preperitoneal space is entered through an incision in the peritoneum instead of through a conventional skin and abdominal wall incision. The inguinal regions are inspected to confirm the pathology and to check the contralateral side. Two further cannulae are then inserted under direct vision. An 11- or 12-mm operating port is introduced contralaterally, just lateral to the rectus muscle and another 11- or 12-mm cannula is introduced in an equivalent position ipsilaterally (Figure 25.1.2). The median umbilical ligament is identified and divided if it appears to compromise exposure. Bleeding from small vessels is controlled using electrocautery. The peritoneal flap is then created by extending this incision at a distance of 2 cm above the myopectineal defect to the anterior superior iliac spine. The flap is mobilized downwards using sharp and blunt dissection. The inferior epigastric vessels, symphysis pubis, transversalis fascia, and cord structures are exposed. For direct hernias, the sac and preperitoneal fat are reduced from the hernia orifice using gentle traction. The thinned out transversalis fascia (referred to as the "pseudo-sac") lining the defect is left behind, if necessary separating it by sharp dissection (Figure 25.1.3). As dissection continues inferiorly, Cooper's ligament and the iliopubic tract are exposed laterally (Figure 25.1.4). The dissection is completed by mobilizing the cord structures away from the peritoneal flap. Indirect hernias are clearly more difficult to deal with. If the sac is small it can be mobilized from the cord structures and reduced back into the abdomen. However, if it is large, extending into the scrotum, complete mobilization of the sac may result in an increased incidence of spermatic cord or testicular complications. In this situation, the hernia is best treated by dividing the sac at the internal ring, leaving the distal sac in situ, with dissection of the proximal sac away from the cord structures.

After completely dissecting the preperitoneal space and identification of the critical anatomical structures, the repair is commenced. First a decision must be made whether the cord structures are to be encircled with the prosthetic material or simply covered (Figure 25.1.4). If a direct inguinal hernia defect is quite large, extending to the internal ring, or if an indirect inguinal hernia has caused destruction of the internal ring (Nyhus type 3), we prefer to place a slit to accommodate the cord structures. This will require additional mobilization of the cord structures posteriorly to accommodate the mesh. In other cases, the mesh is simply laid over the cord structures, avoiding this dissection. Most surgeons prefer the latter as this avoids a dissection that increases the incidence of cord or testicular problems. Proponents of the former argue that this maneuver adds stability to the prosthesis, and in effect, creates a new internal ring. The controversy will not be settled until longer follow-up data are obtained.

Polypropylene is currently the most popular mesh but other materials are occasionally used (see previous chapter). The size of the prosthesis used is important as many of the earlier recurrences with laparoscopic herniorrhaphy have probably been due to inadequate coverage of all of the potential sites of recurrent groin herniation.[5] As an absolute minimum, it is important that the size of the prosthesis be no less than 10×5 cm. It must be sufficiently large to cover the defect and provide an extensive overlap. This allows the intra-abdominal pressure to act on an area of the patch overlying strong health tissue, thus tending to keep the patch in position rather than encouraging it to herniate through the defect.

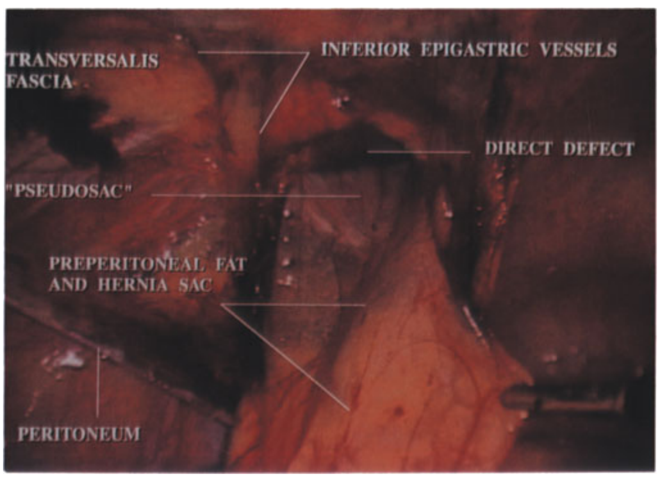

FIGURE 25.1.3. Initial mobilization of the peritoneal flap for the TAPP procedure, with exposure of the preperitoneal space.

The next step is to staple the prosthesis. Some surgeons actually suture the prosthesis in place, but it would appear that they are in the minority, as suturing in this area is quite difficult. The recently developed stapling devices facilitate the stabilization of the prosthesis and are preferable. Stapling is begun along the upper border to the posterior rectus sheath and transversalis fascia, at least 2 cm above the defect. If a slit has been placed in the prosthesis, it is repaired around the cord. The inferior edge is stapled to the symphysis pubis and Cooper's ligament medially, and the iliopubic tract laterally (Figure 25.1.5). When stapling the inferior edge, care must be taken not to place staples below the level of the iliopubic tract when lateral to the internal spermatic vessels, or an inordinately high incidence of neuralgias involving the lateral cutaneous nerve of the thigh or the femoral branch of the genitofemoral nerve will be observed.[31,32] A helpful maneuver in this situation is to use a bimanual technique. Staples are not placed without being able to palpate the head of the stapler (Figure 25.1.6). This assures the surgeon that he or she is above the iliopubic tract.

Finally, the lateral edge is stapled at a point approximately 1 cm medial to the anterior superior iliac spine. During the course of staple placement, excess mesh is trimmed *in situ* so that the prosthesis is perfectly tailored to the preperitoneal space. The final step is to close the peritoneum with staples, thus isolating the prosthetic

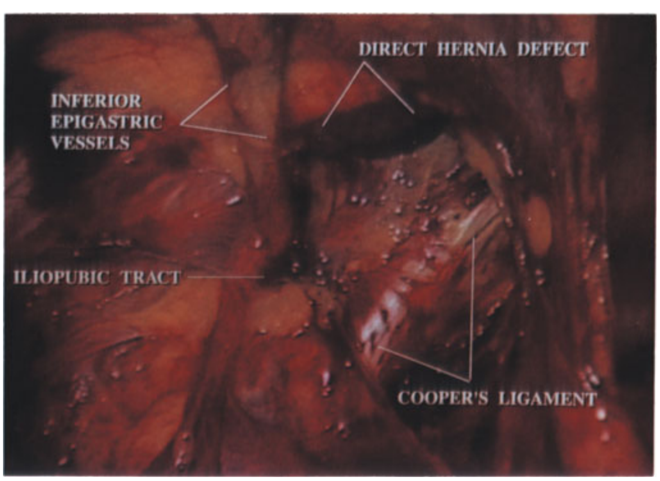

FIGURE 25.1.4. Completed dissection of the preperitoneal space for the TAPP laparoscopic herniorrhaphy.

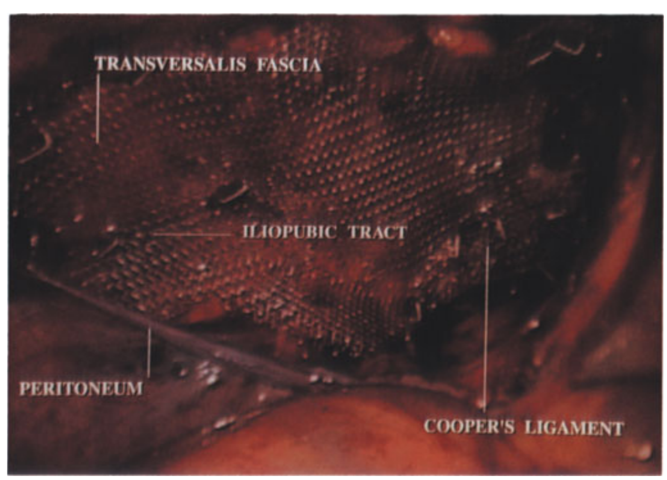

FIGURE 25.1.5. Mesh in place for a TAPP procedure.

FIGURE 25.1.6. Bimanual technique for staple placement.

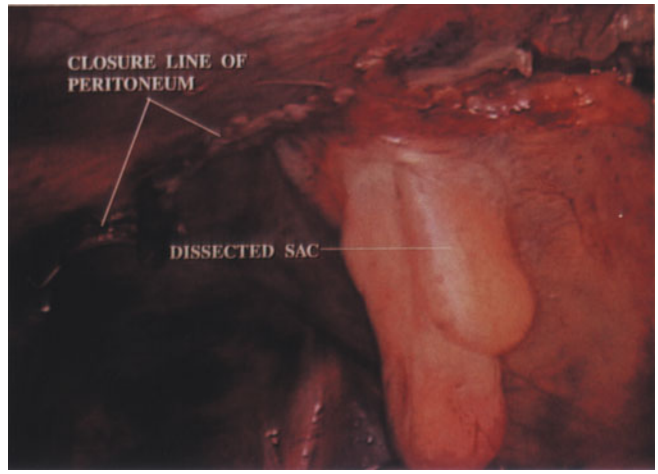

FIGURE 25.1.7. Peritoneum closed, isolating the prosthetic patch from the abdominal contents.

patch from the abdominal contents (Figure 25.1.7). It is important not to leave gaps between the staples because the bowel sometimes slips between these gaps causing obstruction.[31] Peritoneal closure is facilitated by reducing the pneumoperitoneum. A long-acting local anesthetic can be injected into the preperitoneal space at this stage to reduce postoperative discomfort.

Bilateral hernias can be repaired using one long, transverse peritoneal incision. A single piece of mesh, at least 20×6 cm, can be used for both defects. It is fashioned similarly to that described by Stoppa for a conventional repair. However, two separate pieces of prosthetic material are preferred by some surgeons because it is easier to manipulate the smaller prostheses. This may avoid a complication that might be encountered if the urachus was patent and an incision made across it and not recognized.

This approach to herniorrhaphy has now been established, at least on short-term follow-up, to have an acceptably low recurrence rate and good patient acceptance. Considerable dissection is required, but with experience, the operating time is similar to that for a conventional herniorrhaphy. The peritoneal dissection leads to some pain but the tension-free nature of the repair means this is not prolonged and most patients return to normal activities within a week.

IPOM

The reason for the peritoneal dissection described in the previous technique is threefold. To allow for ligation or reduction of the sac as classically required for herniorrhaphy, to allow for fixation of the prosthesis directly to the transversalis fascia, and to provide a covering for the mesh to minimize the risk of adhesion formation between the prosthetic patch and the bowel. However, the radical dissection of the preperitoneal space does result in perioperative discomfort and complications such as hematoma and seroma formation. Investigators questioned whether the same result could be obtained if the prosthesis was placed on the intra-abdominal side of the peritoneum, provided the same landmarks for staple placement were maintained.[10] The major theoretical disadvantage would be that the prosthesis would be placed intra-abdominally, potentially in contact with intra-abdominal viscera.

The IPOM procedure was investigated in the Laboratory for Experimental Laparoscopic Surgery at Creighton University. Yorkshire cross-feeder pigs, with either unilateral or bilateral indirect inguinal hernias, underwent intraperitoneal hernia repairs. One group of pigs had their hernias repaired using a polypropylene mesh prosthesis (Prolene) placed over the defect, overlapping it significantly, and then suturing it in place at the time of a laparotomy. This was the control group. A second group underwent an identical operation, except that the prosthesis was placed laparoscopically and it was stapled in place instead of being sutured. All hernia repairs in both groups were successful. Interestingly, the percentage of the prosthetic patch covered by adhesions as well as the tenacity of adhesions was significantly less in the laparoscopy group when compared to those animals having their prostheses placed at laparotomy. Examination of these patches at sacrifice, six weeks after operation, revealed complete coverage by a thin layer of tissue in most animals (Figure 25.1.8). Histologic examination disclosed that the thin layer was peritoneum. The staples had be-

FIGURE 25.1.8. Intraperitoneal polypropylene mesh prosthesis in a swine model six weeks after surgery, covered by a thin layer of tissue (peritoneum).

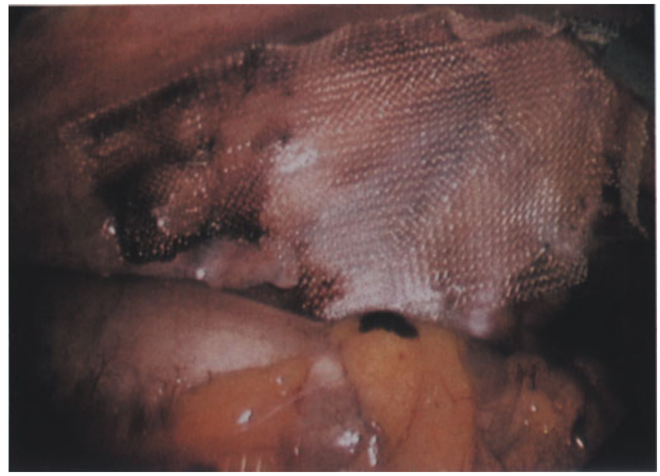

FIGURE 25.1.9. Prosthesis in place for the IPOM procedure.

come flush with the new surface and were also covered by peritoneum.[10]

Encouraged by these results, the Human Research Committee was petitioned and permission was obtained to perform the intraperitoneal operation in patients with indirect inguinal hernias. Operating ports were placed as for the TAPP procedure. The site of the hernia was inspected to ensure its suitability for this type of repair. Critical anatomical landmarks (i.e., the inferior epigastric vessels, symphysis pubis, Cooper's ligament, vas deferens, and internal spermatic vessels) were identified and a prosthesis placed into position and stapled at 1-cm intervals (Figure 25.1.9). Landmarks used for stapling were the same as in the TAPP procedure described above. Between May 2, 1991 and October 1, 1992, a total of 59 IPOM procedures were performed in 56 patients with indirect inguinal hernias. The mean follow-up is now two years. One recurrence has been observed. It is asymptomatic and the patient has refused further treatment. Interestingly, the patient also had a direct inguinal hernia on the opposite side that was repaired with the TAPP procedure at the same time. It has also recurred.

A frequent complication in the IPOM group has been neuralgia, usually resulting from injuries to the lateral cutaneous nerve of the thigh or the femoral branch of the genitofemoral nerve. The majority of these neuralgias have been transient and have resolved spontaneously. However, one patient required a second laparoscopy to remove a staple. The incidence of neuralgia has decreased drastically since the adoption of the policy of never placing staples below the iliopubic tract when stapling lateral to the internal spermatic vessels.

A single patient developed infection in his prosthesis 18 months after his IPOM procedure. He underwent a second laparoscopy and was found to have dense adherence of the cecum to the hernia repair. An abscess was drained extraperitoneally, and the mesh removed. His appendix could not be identified, and he never developed a fecal fistula. A barium enema three months postoperatively failed to visualize the appendix. Thus, it was unclear whether the prosthesis eroded into the cecum or the infection was secondary to appendicitis. He has not developed a recurrent hernia. These results suggest that the IPOM procedure is an effective method for correcting an indirect inguinal hernia.

Other investigators have used the technique to manage direct hernias with success. Franklin performed a series of 257 inguinal herniorrhaphies (110 direct and 127 indirect) in 197 patients, using a modified IPOM technique. His procedure differs in that he stabilizes the mesh, using sutures in addition to staples, to prevent migration. This is done by placing a straight needle into the abdominal cavity through a 2-mm incision in the skin over the prosthesis. The needle is brought through the mesh and then brought back out through a separate fascial sight but the same skin incision. The suture is then tied over the fascia, and the skin is closed.[33] In addition, Dr. Franklin feels that the hernia sac should always be reduced or removed. He also stresses the importance of keeping the prosthesis flat without rolled edges, as he feels this will decrease the rate of adhesion formation. There was one recurrence reported, with a mean follow-up of 22 months. Among the complications are three seromas, two neuralgias, two instances of testicular pain, one intraoperative laceration of an inferior epigastric artery, and one hematoma. There were no complications related to the intra-abdominal mesh placement.

Toy and Smoot also use an IPOM technique to repair both direct and indirect hernias. They prefer expanded polytetrafluoroethylene (ePTFE) rather than polypropylene as the prosthesis. Dissection is done to identify the pubic tubercle and Cooper's ligament, but the hernia sac is left in place. The 8 × 12-cm prosthesis is stapled to the transversalis fascia, pubic tubercle, Cooper's ligament, and iliopubic tract. The authors have performed 232 hernioplasties using this technique. Six recurrences have been reported with a maximum follow-up of 35 months.[34]

Dr. Zucker has been experimenting with the use of ePTFE after it has been placed in a skin graft meshing device. By doing this, a sheet of ePTFE can be converted to a mesh (so-called "Gore-mesh"). The theoretical advantage is that inflammatory tissue can grow into the mesh, re-enforcing the strength of the repair with minimal adhesion formation because of the nonreactive characteristics of ePTFE. However, some authors argue that when ePTFE is converted into a mesh, it should lose its nonreactive properties because inflammatory tissue forms in the mesh interstices, and adhesions will be the result. One hundred patients with 121 hernias underwent the procedure, with a mean follow-up of 11 months. Complications included two instances of urinary retention, two transient neuralgias, and one trocar site infection. One recurrence has been identified to date.[35]

The major appeal of the IPOM procedure is its speed and simplicity. However, this technique must be considered an experimental operation, and patients must be so informed. This is because of the intra-abdominal location of the prosthesis. Although there is data which suggests that the laparoscopically placed prosthesis is associated with decreased incidence of adhesions, these findings have not been verified in long-term studies.[10] Thus, surgeons must remain cognizant of the possibility of complications related to adhesion formation or erosion of the prosthesis into intra-abdominal viscera because of the direct contact with a foreign body.

EXTRA Laparoscopic Herniorrhaphy

To avoid the possible complications of entering the peritoneal cavity, and in an attempt to adopt a similar approach to the preperitoneal dissection described by Nyhus, McEvedy, and Henry for the management of femoral hernias, McKernan has championed the extraperitoneal approach. This employs the principles of minimal access surgery and is performed using laparoscopic instrumentation, and therefore is appropriate for this discussion.[11]

To utilize this technique, it is necessary to use a modified open laparoscopic approach. After the fascia is incised, the peritoneum is left intact and dissection begun inferiorly, in the plane above the peritoneum, towards the groin. An operating laparoscope is particularly useful for this procedure. It allows the surgeon to introduce optics and an initial dissecting instrument through the same umbilical cannula. Once a sufficiently sized space is created, accessory cannulae can be placed; the operating laparoscope is then replaced by a conventional 10-mm instrument. The dissection of the preperitoneal space is completed in an identical fashion to that described for the TAPP procedure. Similarly, prosthetic and staple placement is performed using the same landmarks as those that were described for the TAPP procedure.

The dissection of the preperitoneal space required for this procedure has been greatly facilitated with the advent of the air- or water-filled balloon dissectors. These devices are placed at the umbilical incision. The anterior rectus sheath is opened on the ipsilateral side, and the rectus muscle is retracted laterally. The dissector is then inserted above the posterior rectus sheath and directed toward the symphysis pubis. After the balloon has been inflated and deflated, it is replaced with an insufflation cannula, creating a "pneumoextraperitoneum."

Theoretically, the extraperitoneal approach avoids the risk of injuring intra-abdominal organs, adhesion formation, and erosion of the prosthesis. However, the procedure is difficult primarily because of the small working space, and orientation can be confusing. Surgeons should not attempt to perform this procedure until they are completely familiar with the TAPP operation so that they understand the anatomy of the preperitoneal space (Figure 25.1.10). Inadvertent perforations of the peritoneum are common, especially in patients who have had previous lower abdominal surgeries, an appendectomy, for example. This results in a competing pneumoperitoneum, further limiting the operating space. In addition, the perforations can be difficult to close and, sometimes, impossible to even identify. This may result in exposing the prosthesis, which defeats the purpose of the EXTRA operation. However, as the surgeon gains experience with the TAPP procedure, the EXTRA becomes more appealing.

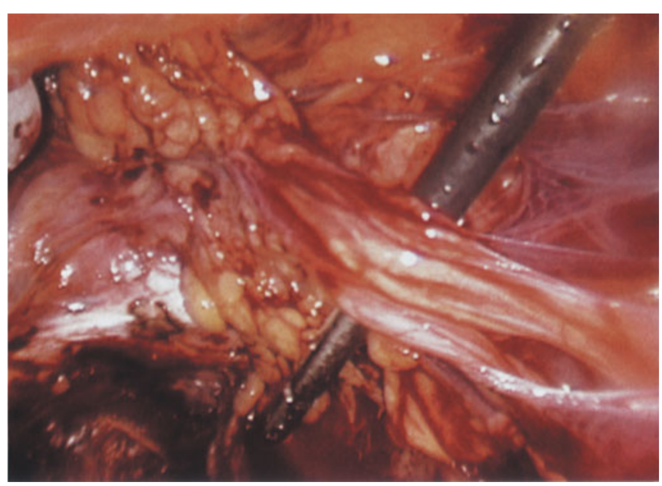

FIGURE 25.1.10. Typical appearance of the preperitoneal space after an EXTRA dissection.

Clinical Experience with the TAPP, IPOM, and EXTRA Procedures

A multicenter trial for laparoscopic herniorrhaphy was initiated in April of 1991 to study the TAPP, the IPOM, and the EXTRA procedures. Institutions in North America and Europe participated. Results of 869 herniorrhaphies in 686 patients revealed a recurrence rate of 4.5%, with a minimum follow-up of 15 months. Sixty-one patients had additional abdominal procedures performed at the time of laparoscopy without adversely affecting the herniorrhaphy.

Perhaps the most distressing complication has been neuralgia, resulting in transient or persistent leg or groin pain or numbness. This can be minimized once surgeons understand the anatomy of the nerves in the region, especially the lateral cutaneous nerve of the thigh and the femoral branch of the genitofemoral nerve. Six patients or 0.87% required a secondary abdominal procedure for complications, which included painful adhesion, infected mesh, trocar site bleeding, bowel obstruction, bowel perforation, and bladder perforation. Of these six patients, two required laparotomy and four required laparoscopy to repair the complications. Fifty-seven percent of the patients were discharged the day of surgery, and another 37% were kept overnight; 7% stayed two days or more, usually as the result of a complication or severe underlying medical illness. The recurrence rate was examined according to the type of laparoscopic inguinal herniorrhaphy performed (i.e., TAPP versus IPOM versus EXTRA) and no significant difference was demonstrated. The data suggested that the learning curve for this new procedure is significant, as the recurrence rate for individual surgeons was higher in their first 10 cases.[31]

Miscellaneous Repairs

Some authors advocate closure of the internal ring only for small, indirect hernias. Rosin simply inverts the sac and highly ligates it. If the defect is particularly large, he closes the ring with sutures.[26] Dion has performed deep inguinal ring closures for indirect inguinal hernias too, with no recurrences. For all other types of hernia, the author follows the TAPP approach.[27]

Spaw uses a technique for direct and indirect hernias that incorporates features of both the TAPP and the IPOM procedures. He performs a limited dissection of the preperitoneal space to expose Cooper's ligament to facilitate staple fixation of the prosthesis. He also dissects the cord structures to remove lipomas so that they will not be confused with a postoperative recurrence. A 7.5 × 10-cm expanded polytetrafluoroethylene (ePTFE) prosthesis is stapled to Cooper's ligament inferomedially, the iliopubic tract inferolaterally, and the transversalis fascia superiorly. The limited dissection of the preperitoneal space makes coverage of the prosthesis impossible in some cases. However, he does not consider this to be

TABLE 25.1.1. Three most commonly performed laparoscopic inguinal herniorrhaphies.

Name	Critical features	Major advantages	Major disadvantages
Transabdominal preperitoneal (TAPP)	1. Radical preperitoneal space dissection after it is entered through a peritoneal incision. 2. Sac reduced or divided at the internal ring. 3. Large prosthesis placed in the preperitoneal space. 4. Peritoneum closed over the prosthesis.	1. Essentially identical to conventional preperitoneal procedures. 2. Prosthesis is covered by peritoneum.	1. Morbidity increased because of radical preperitoneal dissection. 2. Potential for adhesive complications or herniation at sites where peritoneum has been breached.
Interpreperitoneal onlay mesh (IPOM)	1. Prosthesis placed intra-abdominally with no attempt to cover it. 2. Landmarks for prosthesis placement are: symphysis pubis medially; anterior abdominal wall at least 2 cm above the defect superiorly; Cooper's ligament inferomedially; the iliopubic tract inferolaterally and a point medial to the anterior superior iliac spine laterally.	1. Minimal dissection. 2. Minimal perioperative pain.	1. Prosthesis potentially in contact with intra-abdominal organs that may result in erosion or fistula formation. 2. Potential for adhesive complications or herniation at sites where peritoneum has been breached or prosthetic material has been placed.
Totally extraperitoneal (EXTRA)	1. The dissection of the preperitoneal space begins at the umbilicus, avoiding the need for a peritoneal incision. 2. Once the preperitoneal space in the vicinity of the groin is entered, the dissection is identical to the TAPP.	1. Peritoneal cavity is never entered.	1. Technically difficult. 2. Peritoneal breach common, especially for the inexperienced.

of particular concern because of the nonreactive properties of ePTFE. For small and medium indirect inguinal hernias, he performs simple ring closure. In his series, over 100 procedures were completed with one recurrence. He has not reported complications related to the placement of the prosthesis.[36]

Summary

Laparoscopic inguinal herniorrhaphy is an investigational procedure and the best technique and the exact indications are presently unclear. The most commonly performed laparoscopic inguinal hernia repairs are summarized in Table 25.1.1.

Laparoscopy affords an excellent exposure of the preperitoneal space that can be quite useful in repairing many inguinal hernias, especially those that are recurrent or otherwise complicated. It seems that laparoscopy will certainly have a place in the armamentarium of general surgeons caring for inguinal hernias. It is unlikely that laparoscopy will be indicated for every inguinal hernia. However, preliminary results would suggest that further investigation is indicated.

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25.2
Anatomical Considerations for Laparoscopic Inguinal Herniorrhaphy

Riccardo Annibali, José Camps, Robert F. Nagan, Thomas H. Quinn, Maurice E. Arregui, and Robert J. Fitzgibbons, Jr.

Most anatomical descriptions of the inguinal region begin with the anterior layer and proceed to deeper structures, like a cadaver dissection. For laparoscopic inguinal herniorrhaphy, the surgeon should understand the anatomy from the deeper to the more superficial layers. What follows is a detailed description of the anatomy of the inguinal region seen from this perspective. It is based on a review of the literature, and the study of videotapes from laparoscopic inguinal herniorrhaphies performed on patients and cadaver dissections.

Surface Characteristics of the Lower Abdominal Wall Peritoneum

Thirty or 45° angle view laparoscopes provide a well-lighted view of the posterior surface of the anterior abdominal wall. They allow superb detail and magnification not appreciated at laparotomy or during conventional cadaveric dissections (Figure 25.2.1). Initial inspection reveals five peritoneal folds or ligaments below the umbilicus. The *median umbilical ligament* (or *median umbilical fold*), represents the obliterated urachus and is not always obvious. This midline structure extends from the fundus of the bladder to the umbilicus. Laterally, on either side, are the *medial umbilical ligaments (medial umbilical folds)*. The size of the medial umbilical ligaments varies, ranging from a minor fold in the peritoneum to a fatty, imposing structure that actually interferes with visualization of other important landmarks. This variability exists not only from patient to patient, but sometimes in individual patients from side to side. The medial umbilical ligaments represent the obliterated portion of the umbilical arteries. Thus, the superior vesicular branches arise from the patent portion of the umbilical arteries. Lateral to the umbilical ligaments, the inferior epigastric vessels arise from the external iliac arteries; they provide blood to the anterior abdominal wall. The peritoneal folds in which they are found are termed the *lateral umbilical ligaments.* There is some confusion regarding the correct terminology of these folds, as some authors define the fold outlined by the umbilical artery as the *lateral umbilical ligament,* while the fold associated with the inferior epigastric vessels has been called the *plica epigastrica.*[1] For this chapter, the more consistent terminology described in the preceding paragraph, which conforms with that found in *Nomina Anatomica,* will be used.[2–4]

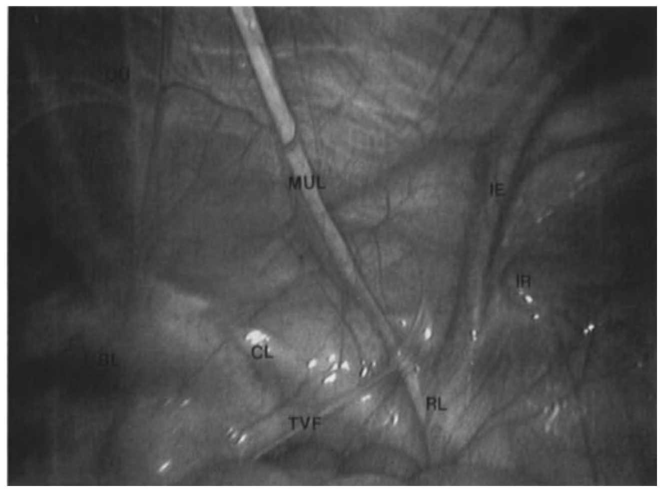

FIGURE 25.2.1. Laparoscopic view of right inguinal area in an elderly, thin female. Note small indentation lateral to the inferior epigastric vessels. This is the site of the internal ring where the round ligament enters the inguinal canal. OU (obliterated urachus or median umbilical ligament), MUL (medial umbilical ligament), IE (inferior epigastric vessels or lateral umbilical ligament), TVF (transverse vesicular fold), BL (bladder), CL (Cooper's ligament), IR (internal ring), RL (round ligament).

Lateral to the inferior epigastric vessels lies the *internal inguinal ring* where the vas deferens and spermatic vessels converge and penetrate the transversalis fascia (Figure 25.2.2). Just medially, a thickened band of peritoneum and subperitoneal fibrous tissue can be seen extending from the abdominal wall to the bladder on its posterior and medial side; this is the *transverse vesicular fold* (Figures 25.2.1 and 25.2.2). Between this fibrous band and the cord structures, a dimpling of the peritoneum or a patent processus vaginalis may be seen in some cases. This area marks the site of firm attachment or fusion of the peritoneum, preperitoneal fascia, and transversalis fascia sling (Monk's Hood), and is the site of the true internal ring.

The medial and lateral umbilical ligaments delineate three fossae on either side of the midline (Figure 25.2.3). The *lateral fossa* lies lateral to the inferior epigastric vessels and is the site of indirect hernias. It also contains the internal inguinal ring. The *medial* (or *middle*) *fossa* is defined as the space between the inferior epigastric vessels and the medial umbilical ligament and corresponds to the site of direct inguinal hernias. Finally, the *supravesical* (or *internal*) *inguinal fossa* lies between the medial and the median umbilical ligaments. The rectus abdominis muscle and rectus sheath confer a greater strength to this area, making supravesical hernias rare.[3] The smooth peritoneal lining of the abdominal wall has a rich blood supply that can be clearly visualized with the laparoscope. On the anterior surface of the lower abdominal wall, the blood vessels emerge from below and travel toward the umbilicus (Figure 25.2.4).

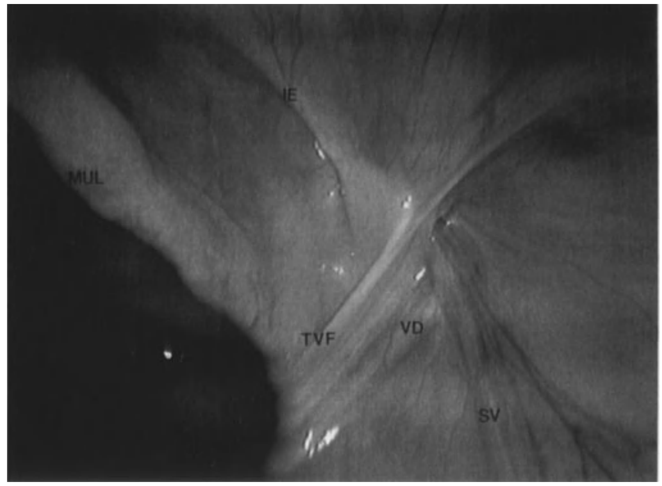

FIGURE 25.2.2. Laparoscopic view of the right inguinal area in a male with a small patent processus vaginalis. This is the site of the true internal ring. MUL (medial umbilical ligament), IE (inferior epigastric vessels or lateral umbilical ligament), TVF (transverse vesicular fold), VD (vas deferens), SV (spermatic vessels).

The Preperitoneal Fascia

At the internal ring, just superficial to the peritoneum, is a thin but clearly discrete fascia called the *preperitoneal fascia*.[5–8] This structure, also identified as the posterior layer of the transversalis fascia by other authors (see next section), is not always easily identified during anatomical dissections on an embalmed cadaver, but is readily apparent during laparoscopic preperitoneal dissection[9] (Figures 25.2.5 and 25.2.6).

The preperitoneal fascia forms a conical sheath around the cord structures and an indirect hernia sac, if present. This continues as the internal spermatic fascia as the cord structures enter the inguinal canal.[8] At this location there is very little fat between the peritoneum and the preperitoneal fascia. By staying between the peritoneum and the preperitoneal fascia and dissecting medially, a loose amorphous fibroareolar space will be encountered. This matrix of fat and loose fibrous tissue contains the residual of the umbilical artery, the inferior epigastric vessels (that produce the two peritoneal folds on either side of the midline) and, at a lower level, the bladder. When this plane is mistakenly entered either during a transabdominal preperitoneal or extraperitoneal dissection, bleeding can result. There is a risk of injuring the bladder if dissection is carried medial to the medial umbilical ligament in this plane. This space is bordered anteriorly by the thin, discrete preperitoneal fascia named the *umbilical prevesicular fascia.* Superficial to this fascia is the true preperitoneal plane of the inguinal area which is in continuity with the *space of Retzius* of the pelvis. External to the true preperitoneal inguinal space is an often thicker fascia with frequent transverse bands extending from the linea semilunaris. This layer is more prominent cranially. Caudally, it seems to thin out. It represents either the posterior lamina of the transversalis fascia as described by Read,[11] or more likely, a continuation of a variably attenuated posterior rectus sheath (see next section).[25]

The peritoneum can be easily distinguished from the preperitoneal fascia in the central aspect of the lower anterior abdominal wall where these fascial planes can be recognized by the relatively generous fatty tissues separating them. Near the umbilicus and lateral to the median umbilical ligament, the peritoneum, preperitoneal fascia, and posterior rectus sheath are intimately fused and intervening fatty tissue is sparse or nonexistent. This plane is poorly developed and dissection is quite difficult. Lateral to the longitudinal semilunar line, the extraperitoneal fat remains sparse until the retroperitioneal flank is reached. Here, as near the midline, the space between the preperitoneal fascia is better developed. Lateral and posterior to the cord structures and preperitoneal fascia, as they enter the internal ring, is the extraperitoneal space of the flank containing varying amounts of fatty tissue. Blunt dissection can be easily carried out around the conical preperitoneal fascia surrounding the cord structures. This fascial layer has been described by Tobin (1946) as the ventral lamina of the retroperitoneal fascia:[8]

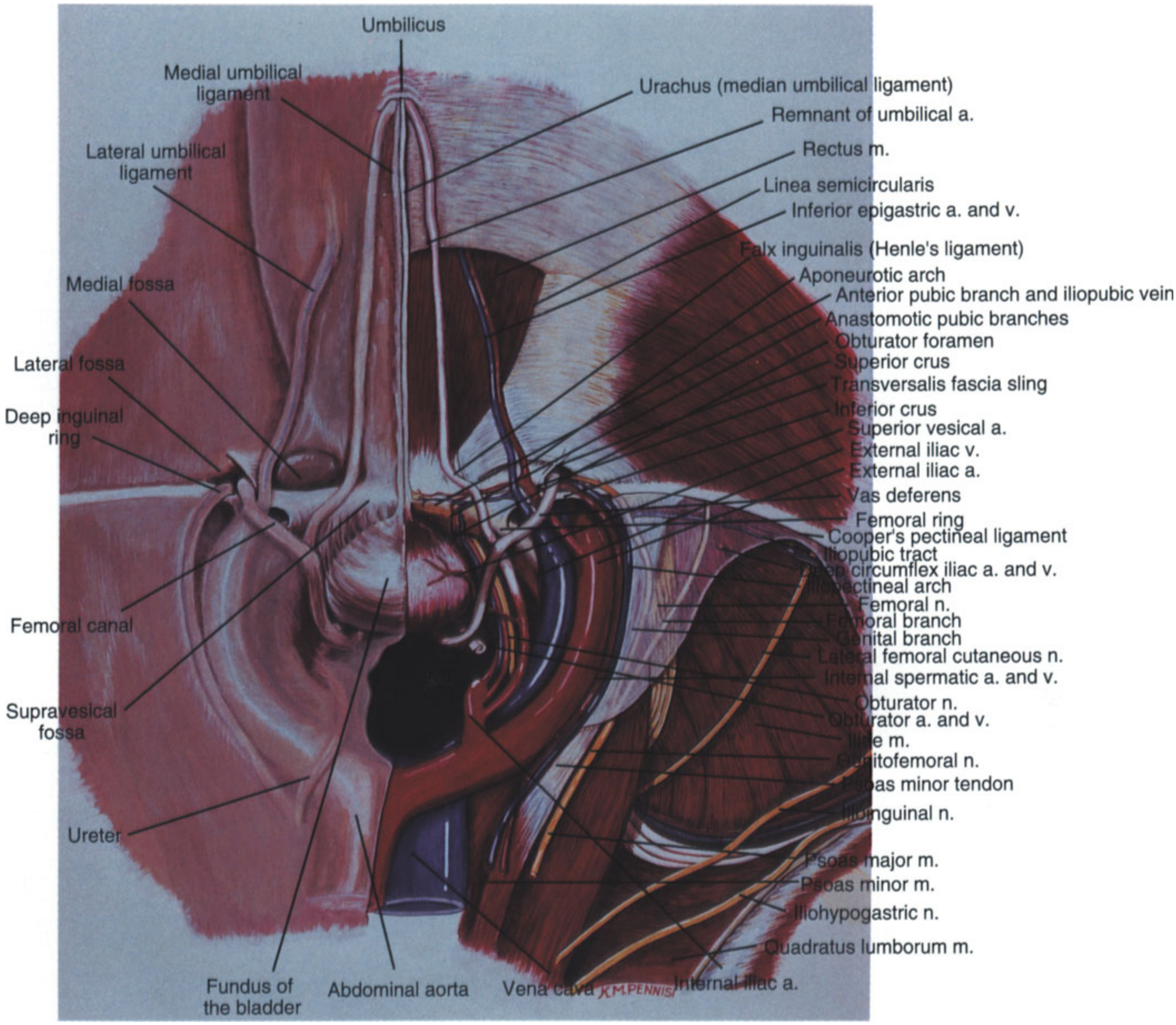

FIGURE 25.2.3. Anatomy of the internal surface of the lower abdominal wall, inguinal region, and lower trunk. (From Annibali R, Fitzgibbons RJ Jr, Filipi CJ, Litke BS, Salerno GM. Laparoscopic hernia repair. In: FL Green and JL Ponsky eds. *Endoscopic Surgery.* Philadelphia, WB Saunders, 1994:352–386; with permission.)

> At the abdominal inguinal ring, the ventral lamina, surrounding the spermatic vessels from the kidney on, and part of the intermediate stratum around the vas deferens, from the bladder region, fuse with the dorsal lamina and continue as the innermost layer, internal spermatic fascia, of the spermatic cord.

This is the preperitoneal fascia associated with the umbilical cord structures and contents of the spermatic cord, which serves as a mesenteric analogue. When performing an extraperitoneal approach, either by open or laparoscopic technique, in order to excise the peritoneal indirect hernia sac, this enveloping conical preperitoneal fascia must be entered by incision or blunt separation of its fibers (Figures 25.2.6 and 25.2.7). Once the peritoneal hernia sac is circumferentially cleared from surrounding structures, it can be proximally ligated and then distally transected (Figures 25.2.8 and 25.2.9). Posteriorly and proximally, the peritoneum remains quite intimate with the cord structures. Significant effort is required to separate the peritoneum from the vas deferens. Posterior to the cord structures and the preperitoneal fascia lies the retroperitoneal fascia. Underlying this are the iliacus, iliopsoas, lateral femoral cutaneous nerve, genitofemoral nerve, external iliac vessels, and femoral nerve (Figure 25.2.3).

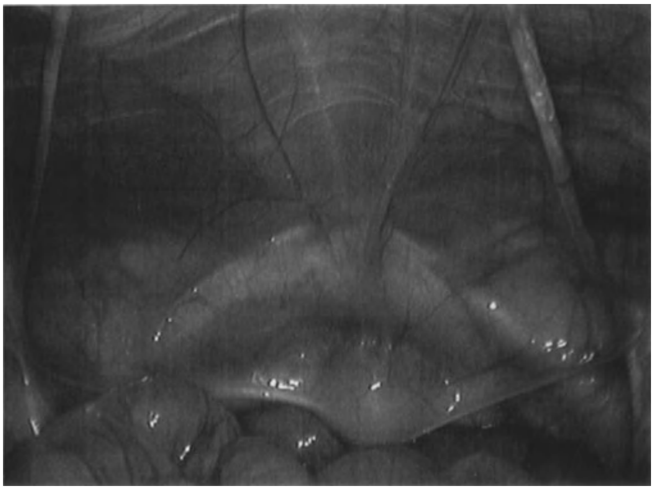

FIGURE 25.2.4. Thin, elderly female. A Foley catheter is in the bladder. Note the rich blood supply to the peritoneum and preperitoneal tissues arising from the deep pelvis. These are branches from the vesicular arteries originating from the internal iliac artery.

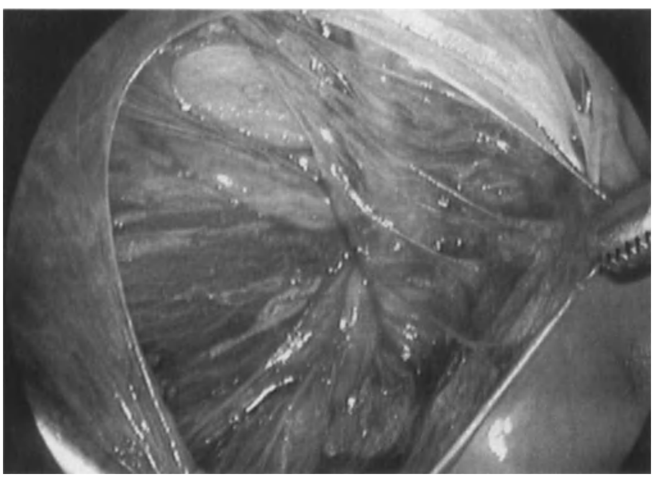

FIGURE 25.2.5. Transabdominal preperitoneal repair of inguinal hernia. Incision of the peritoneum at the orifice of the internal ring reveals the underlying preperitoneal fascia. (From Arregui ME, Davis CJ, Castro D, et al: Laparoscopic inguinal herniorrhaphy: transabdominal preperitoneal approach, fig. G.1. In *Inguinal Hernia—Advances or Controversies,* Radcliffe Medical Press, 1994; with permission.)

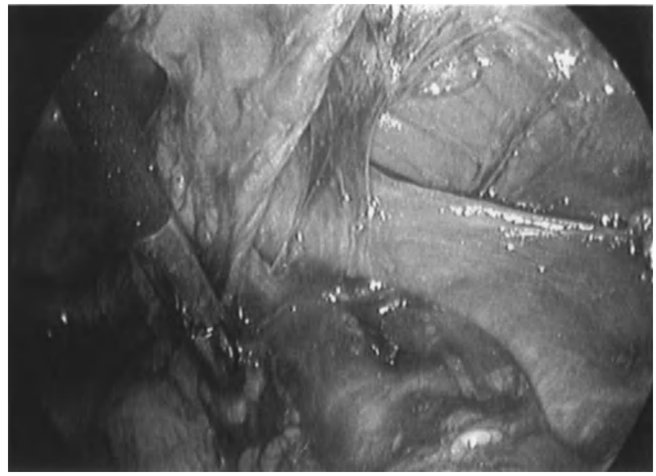

FIGURE 25.2.6. Extraperitoneal repair of direct right inguinal hernia. This view shows dissection of the internal ring. Note the preperitoneal fascia forming a conical sheath around the vas deferens and spermatic vessels. This preperitoneal fascia is quite discrete from the fibers of the transversalis fascia sling. (From Arregui ME, Dulucq JL, Tetik C, et al: Laparoscopic inguinal hernia repair with preperitoneal prosthetic replacement, fig. 18. In *Prostheses and Abdominal Wall Surgery,* R.G. Landes Co., 1994; with permission.)

FIGURE 25.2.7. The preperitoneal fascia has been opened to reveal the vas deferens and spermatic vessels. If present, an indirect hernia sac would also be contained within the preperitoneal fascia. (From Arregui ME, Dulucq JL, Tetik C, et al: Laparoscopic inguinal hernia repair with preperitoneal prosthetic Replacement, fig. 19. In *Prostheses and Abdominal Wall Surgery,* R.G. Landes Co., 1994; with permission.)

Transversalis Fascia

The layer immediately external to the preperitoneal space is called the *endoabdominal fascia.* It has different names, depending upon the specific structure covered at a certain location (e.g., transversalis f., psoas f., obturator f., iliac f., etc.), but is actually a single fascial sheath that invests the entire inner surface of the abdomen.[1]

Sir Ashley Cooper coined the term *transversalis fascia* to indicate that portion of the endoabdominal fascia that covers the internal surface of the transversus abdominis muscle.[10,11] According to Cooper's original description, the transversalis fascia consists of an anterior (or outer), and a posterior (or inner) lamina.[12] Cleland and Mackay also reported this bilaminar arrangement,[13] but McVay,

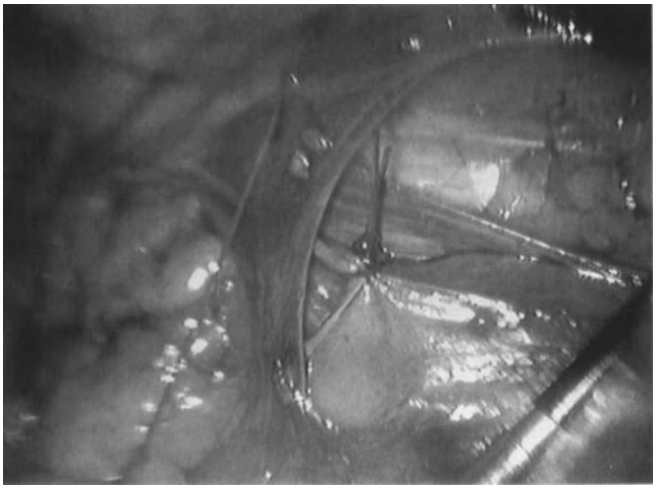

FIGURE 25.2.8. Extraperitoneal repair of indirect right inguinal hernia. Preperitoneal fascia has been opened and high ligation of indirect inguinal hernia sac has been carried out.

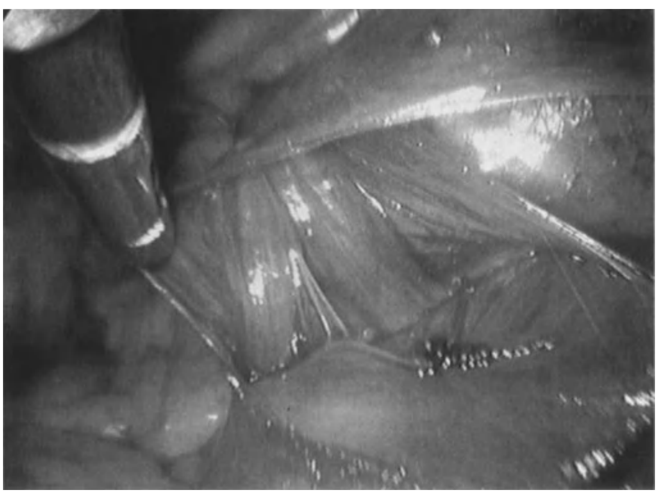

FIGURE 25.2.9. Transection of the ligated hernia sac reveals the vas deferens and spermatic vessels enveloped by the preperitoneal fascia.

Anson, and Condon argue against it.[2,14] Those who propose a bilaminar transversalis fascia describe the anterior layer as closely investing the aponeurosis of the transversus abdominis, inserting inferiorly to Cooper's ligament, and medially to the rectus sheath. The posterior layer merges superiorly with the linea semicircularis (of Douglas), medially with the linea alba, and inferiorly, inserts on the superior ramus of the pubis.[15] According to this theory, the inferior epigastric vessels do not lie within the preperitoneal space, but instead are enveloped within the two layers of the transversalis fascia.[11]

The structure described as the posterior layer of the transversalis fascia has also been identified as the *preperitoneal fascia.* The precise role that the transversalis fascia plays in the origin and repair of inguinal hernias is a matter of considerable debate.[12,16] The transversalis fascia is depicted by some authors as a thin, weak layer with no intrinsic strength,[2,10,16] whereas others feel that a strong transversalis fascia is essential for the avoidance of herniation.[3] Griffith once stated that "the fact that transversalis fascia may be destroyed by large direct hernias in obese, elderly men has led to the concept that the transversalis fascia is unimportant. Nothing could be further from the truth."[17]

Despite uncertainty about the intrinsic tensile strength of the transversalis fascia, there is general agreement that the combined deep elements of the abdominal wall (the transversus abdominis muscle, its aponeurosis, and the transversalis fascia) represent the structure that supports the pressure of intra-abdominal organs and prevents herniation.[3,18–20]

The Transversalis Analogues

The transversalis fascia has various thickenings and condensations, the so-called *transversalis fascia analogues,*[2,19] that delineate important landmarks to the laparoscopic surgeon. The *internal* (or *deep*) *inguinal ring* is the internal opening of the inguinal canal, located in the lateral peritoneal fossa. In conventional anatomical descriptions, it has been reported as being approximately 2 cm in circumference. However, when viewed laparoscopically it appears nearly closed (Figure 25.2.1). The inferior epigastric vessels can consistently be seen on the medial side of the internal ring. The iliopubic tract can be appreciated even with the peritoneum intact as it crosses the inferior surface of the internal ring. In a male subject, the vas deferens and testicular vessels pass through the ring to enter the inguinal canal and are usually accompanied by the genital branch of the genitofemoral nerve (Figure 25.2.3).

The internal ring results when the testicle migrates from its intra-abdominal position to the scrotum. During its descent, in the course of normal fetal maturation, the testicle pulls with it a funnel-shaped, truncated cone of transversalis fascia that angles obliquely and is oriented inferomedially. The transversalis fascia is, however, less oblique than the direction of the cord.[2,16,17] The fascial layer is, therefore, redundant on the medial side of the cord and forms a sling-shaped, thickened condensation in the transversalis fascia that reinforces the medial aspect of the deep ring.[20,21] This thickening of the transversalis fascia is called the *transversalis fascia sling* (Figure 25.2.10). The transversalis fascia sling has superior and inferior extensions known as the *superior* and *inferior crura.*[1,2] This anatomical arrangement plays a key role in the *sphincteric* or *valvular mechanism* of the internal inguinal ring: when the muscular fibers of the transversus abdominis contract during straining, the transversalis fas-

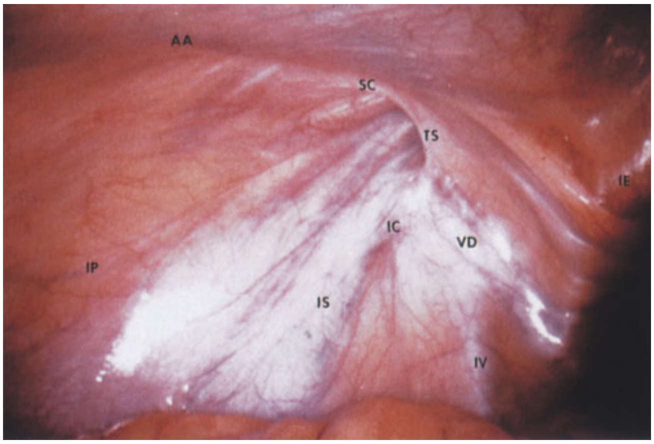

FIGURE 25.2.10. Laparoscopic view of a left inguinal hernia. TS (Transversalis Fascia Sling), SC (Superior Crus of the transversalis fascia sling), IC (inferior crus of the transversalis fascia sling), IS (internal spermatic or testicular vessels), VD (vas deferens), IV (external iliac vein), IP (iliopubic tract), IE (medial umbilical ligament), AA (aponeurotic arch of the transversus abdominis muscle). (From Annibali R, Fitzgibbons RJ Jr, Filipi CJ, Litke BS, Salerno GM. Laparoscopic hernia repair. In: FL Green and JL Ponsky eds. *Endoscopic Surgery.* Philadelphia, WB Saunders, 1994:352–386; with permission.)

cia moves along with them, displacing the internal ring laterally and cranially under the muscular edge of the internal oblique.[6,22] This results in approximation of the superior and inferior crura, thereby closing the internal ring.[2,19,23] This mechanism is felt by many authorities to be important in the prevention of indirect inguinal hernias.

The *iliopubic tract* (also referred to as the "bandelette of Thompson," the "bandelette iliopubienne," and the "deep femoral arch" in European medical terminology), is a condensation of the transversalis fascia. It originates laterally at the inner lip of the iliac crest, the anterior superior iliac spine, and the iliopectineal arch (Figure 25.2.11). It courses in a deep plane to the inguinal ligament, but parallel to it, crosses the external iliac vessels anteriorly while bordering the deep inguinal ring inferiorly, and finally, fans out to attach to the medial portion of Cooper's ligament.[10,16,19,20,24] Here, again, there is controversy: some authors feel the iliopubic tract is a substantial structure and, therefore, useful to the surgeon performing an inguinal herniorrhaphy.[20,25] Lichtenstein, however, has found it to be of significant strength only in a minor number of cases (25%), and does not regard it as a supportive structure.[26,27] An objective study has been conducted simultaneously, in the United States and China, to investigate the effective reliability of the iliopubic tract for hernia repair. In a series of 151 dissections of embalmed inguinal regions and in serial sagittal sections of four body halves, Gilroy and coworkers could identify a "substantial structure" corresponding to the iliopubic tract, and useful for hernia repair, in only 42% of the specimens.[28]

Cooper's (or *pectineal*) *ligament* (Figure 25.2.12) is easily identified during laparoscopic surgery and in the anatomical dissecting room, but the numerous modifications of Sir Astley Cooper's original description make it difficult to precisely define it anatomically.[12] It has been described as the fusion of the transversalis fascia and the iliopubic tract with the periosteum, covering the superior ramus of the pubis lateral to the pubic tubercle.[2,10,19,25,29] Others have simply referred to it as a lateral extension of tendinous fibers of the lacunar ligament. Still others have questioned whether it is even appropriate to refer to it as a separate ligament.[10] For the purposes of a surgeon intending to perform a laparoscopic herniorrhaphy, Cooper's ligament is the shiny, fibrous structure covering the superior pubic ramus.[30]

Another condensation of the transversalis fascia on the medial side of the iliac fascia is the *iliopectineal arch* (Figures 25.2.11 and 25.2.13). It is attached laterally to the anterior superior iliac spine, and medially to the iliopectineal eminence. Along its course, it intersects the lateral aspect of the femoral sheath, and also gives origin to part of the fibers of the external oblique, the internal oblique, the transversus abdominis muscles, and the iliopubic tract. The iliopectineal arch is also an important landmark because it divides the medial vascular compartment (*lacuna vasorum*) and the femoral canal from the lateral muscular compartment (*lacuna musculorum*) (Figures 25.2.11 and 25.2.13). The former includes the femoral vessels and the femoral canal; in the latter, the iliopsoas muscle, together with the femoral nerve and the lateral femoral cutaneous nerve, are found (see following).

Transversus Abdominis Muscle

The *transversus abdominis muscle* is the deepest of the three muscular layers that envelop the abdominal cavity. It originates from the lower six ribs, the lumbodorsal fascia, the iliac crest, the iliopubic tract, and the iliopsoas fascia. Its fibers travel transversely around the lateral aspect of the abdomen to reach the midline. Lateral to the rectus muscle, the fibers of the transversus abdominis make a transition into a tendinous aponeurosis. The aponeurotic fibers of the transversus abdominis cranial to a line located approximately midway between the umbilicus and the symphysis pubis (called the *linea semicircularis*),[3,31,32] pass posterior to the rectus abdominis muscle, thus contributing to the posterior rectus sheath. Caudal to that level, they usually cross anteriorly as part of the anterior rectus sheath, leaving only the transversalis fascia and the peritoneum to cover the posterior portion of the rectus muscle. The lower part of this aponeurosis

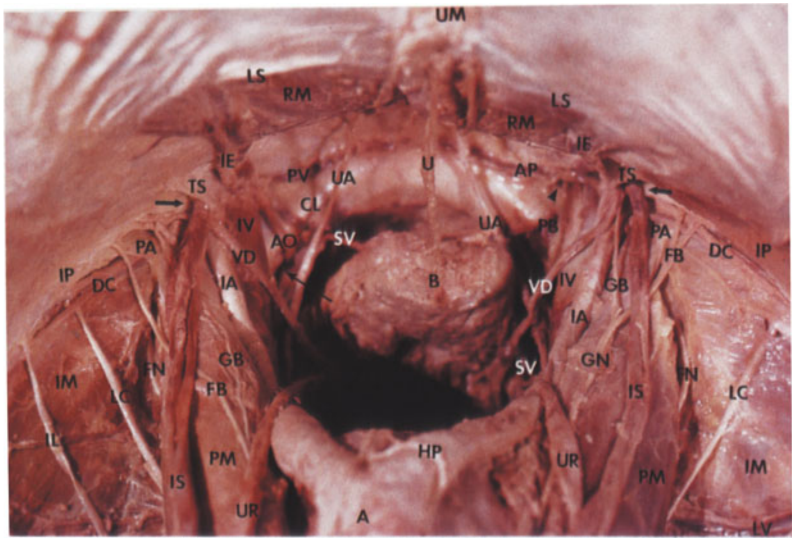

FIGURE 25.2.11. Panoramic view of the internal surface of the anterior lower abdominal wall, inguinal regions, lower trunk, and pelvis in a cadaver dissection. UM = umbilicus; LS = linea semicircularis; RM = rectus abdominis muscle; IE = inferior epigastric vessels; AP = anterior pubic branch and iliopubic vein; TS = transversalis fascia sling; U = urachus; CL = Cooper's ligament; UA = umbilical artery; AO = anomalous obturator artery; SV = superior vesical artery; PB = anastomotic pubic branches; IV = external iliac vein; IA = external iliac artery; VD = vas deferens; PA = iliopectineal arch; IP = iliopubic tract; DC = deep circumflex iliac vessels; GN = genitofemoral nerve; GB = genital branch of the genitofemoral nerve; FB = femoral branch of the genitofemoral nerve; FN = femoral nerve; LC = lateral femoral cutaneous nerve; IL = ilioinguinal nerve; IM = iliacus muscle; PM = psoas major muscle; IS = internal spermatic (testicular) vessels; UR = ureter; A = abdominal aorta; LV = iliolumbal vessels. Thick black arrow = deep inguinal ring; white arrow = obturator foramen; short arrow = femoral ring. (From Annibali R, Fitzgibbons RJ Jr, Filipi CJ, Litke BS, Salerno GM. Laparoscopic hernia repair. In: FL Green and JL Ponsky eds. *Endoscopic Surgery.* Philadelphia, WB Saunders, 1994:352–386; with permission.)

crosses downward and medial to form the *aponeurotic arch* (Figure 25.2.3). This makes up the superior margin of the internal inguinal ring before inserting at the pubic tubercle and the medial side of Cooper's ligament.[3] Occasionally, the fibers of the aponeurotic arch merge with parallel lower fibers of the internal oblique before the insertion on the pubic tubercle and superior ramus of the pubis, forming the so-called *conjoined tendon.*[2,23] This seems to be a rare combination, however, as it has been reported in only 3 to 5% of cases.[13,19,34] Indeed, according to some authors the conjoined tendon does not exist and it is only an artifact of dissection.[25,33]

The aponeurotic arch of the transversus abdominis plays an important role in a second physiologic system (known as the *shutter mechanism*). It helps to prevent both indirect and direct herniation. When the internal oblique and the transversus abdominis muscles contract simultaneously during straining, they approximate the transversus aponeurotic arch to the inguinal ligament, producing a reinforcement of the posterior wall of the inguinal canal.[2,22,23] In approximately 25% of the subjects, the aponeurotic arch is poorly developed or cannot descend enough to effectively approximate the inguinal ligament.[23,34] The result is that a portion of the lower deep abdominal wall lacks reinforcement during straining. In this circumstance, prevention of an inguinal hernia depends solely on the integrity of the transversalis fascia. In some instances, the aponeurotic lower portion of the transversus abdominis muscle does not terminate at the rectus sheath, but arches down to insert onto the superior ramus of the pubis.[2] This results in formation of a band of aponeurotic tissue referred to by some as the *falx inguinalis.*[19–21] This is confusing, however, because others use the term to describe a vertical extension of the sheath of the rectus muscle that attaches to the symphysis pubis and Cooper's ligament. Finally, in Europe, the term falx inguinalis is usually used to indicate the conjoined tendon.

Hesselbach's Triangle

A critical area included within the inguinal region is the *inguinal triangle* (or *Hesselbach's triangle*). Its boundaries are described in most anatomical and surgical textbooks as the inferior epigastric vessels superolaterally, the rectus sheath medially, and the inguinal ligament inferiorly. These boundaries represent a modification of Hesselbach's original description, where Cooper's ligament had been defined as the inferior margin.[3,10,20,21] This change

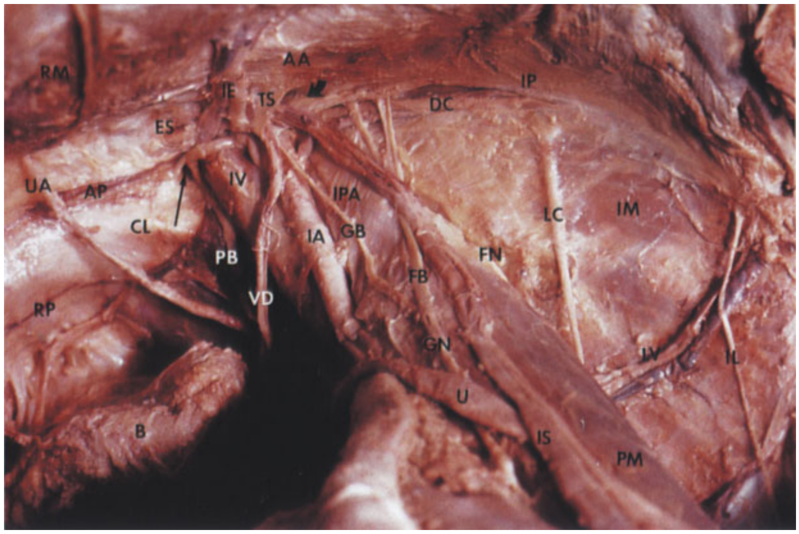

FIGURE 25.2.12. Photograph of a cadaver preparation (right side) showing the preperitoneal space at level of the inguinal area, after removal of the peritoneum and preperitoneal adipose tissue (the urachus has been resected and the bladder retracted posteriorly). RM = rectus abdominis muscle; IE = inferior epigastric vessels; AP = anterior pubic branch and iliopubic vein; AA = aponeurotic arch of the transversus abdominis muscle; TS = transversalis fascia sling; U = ureter; CL = Cooper's ligament; UA = umbilical artery; PB = anastomotic pubic branches; RP = retropubic vein; IV = external iliac vein; IA = external iliac artery; ES = external spermatic vessels; VD = vas deferens; IP = iliopubic tract; IPA = iliopectineal arch; DC = deep circumflex iliac vessels; GN = genitofemoral nerve; GB = genital branch of the genitofemoral nerve; FB = femoral branch of the genitofemoral nerve; FN = femoral nerve; LC = lateral femoral cutaneous nerve; IL = ilioinguinal nerve; IM = iliacus muscle; PM = psoas major muscle; IS = internal spermatic (testicular) vessels; LV = iliolumbal vessels; B = bladder (retracted posteriorly). Thick arrow = deep inguinal ring; thin arrow = femoral ring. (From Annibali R, Quinn T, Fitzgibbons J Jr.: Surgical anatomy of the inguinal region and lower abdominal wall: the laparoscopic perspective. In Bendavid R: *Prostheses and Abdominal Wall Hernias,* Landes Medical, Austin, TX, in press 1994.)

was suggested to correspond to the site of direct hernias observed by surgeons when performing a conventional inguinal herniorrhaphy.[2] For laparoscopic herniorrhaphy, however, it would seem more appropriate to go back to Hesselbach's original description, since the inguinal ligament is not visible laparoscopically and Cooper's ligament is a constant landmark. No matter which definition is used, Hesselbach or the inguinal triangle includes in its inferolateral portion the weak area previously discussed in the section defining the medial umbilical fossa. This triangular weak zone delimited by the aponeurotic arch superiorly, iliopubic tract inferiorly and inferior epigastric vessels laterally, is the site where direct hernias originate (Figures 25.2.14 and 25.2.15).

Internal and External Oblique Muscles

The other two outer muscular layers that contribute to the anterior and the lateral abdominal wall are the *internal and external oblique muscles.* Their role in the process of inguinal hernia formation is minimal, probably limited to modification of the direction of a hernial bulge only.[10,18] The *inguinal* (*Poupart's*) *ligament* (Figure 25.2.13) is formed by the thickened, most inferior portion of the aponeurosis of the external oblique, and extends from the anterior superior iliac spine laterally to the pubic tubercle medially. Some of its medial fibers twist to insert on Cooper's ligament, thereby forming the *lacunar ligament* (or *Gimbernat's*).[2,21]

Inguinal Canal and Spermatic Cord

The inguinal canal originates at the internal inguinal ring and follows an inferomedial oblique course through an aperture in the transversus abdominis and internal oblique muscles (Figure 25.2.16). It is approximately 4 cm in length and its outer limit is the *external* (or *superficial*) *inguinal ring,* which is located above the inguinal ligament and immediately lateral to the pubic tubercle. The external ring is made up of the lateral fibers of the aponeurosis of the external oblique where the aponeurotic structure folds under itself to form the inguinal ligament.

The inguinal canal is bordered inferiorly by the inguinal ligament, inferomedially by the lacunar ligament, anteriorly by the aponeurosis of the external oblique muscle, laterally and superiorly by the fibers of the internal oblique muscle and the aponeurotic arch of the transversus abdominis.[21] The posterior wall, between the aponeu-

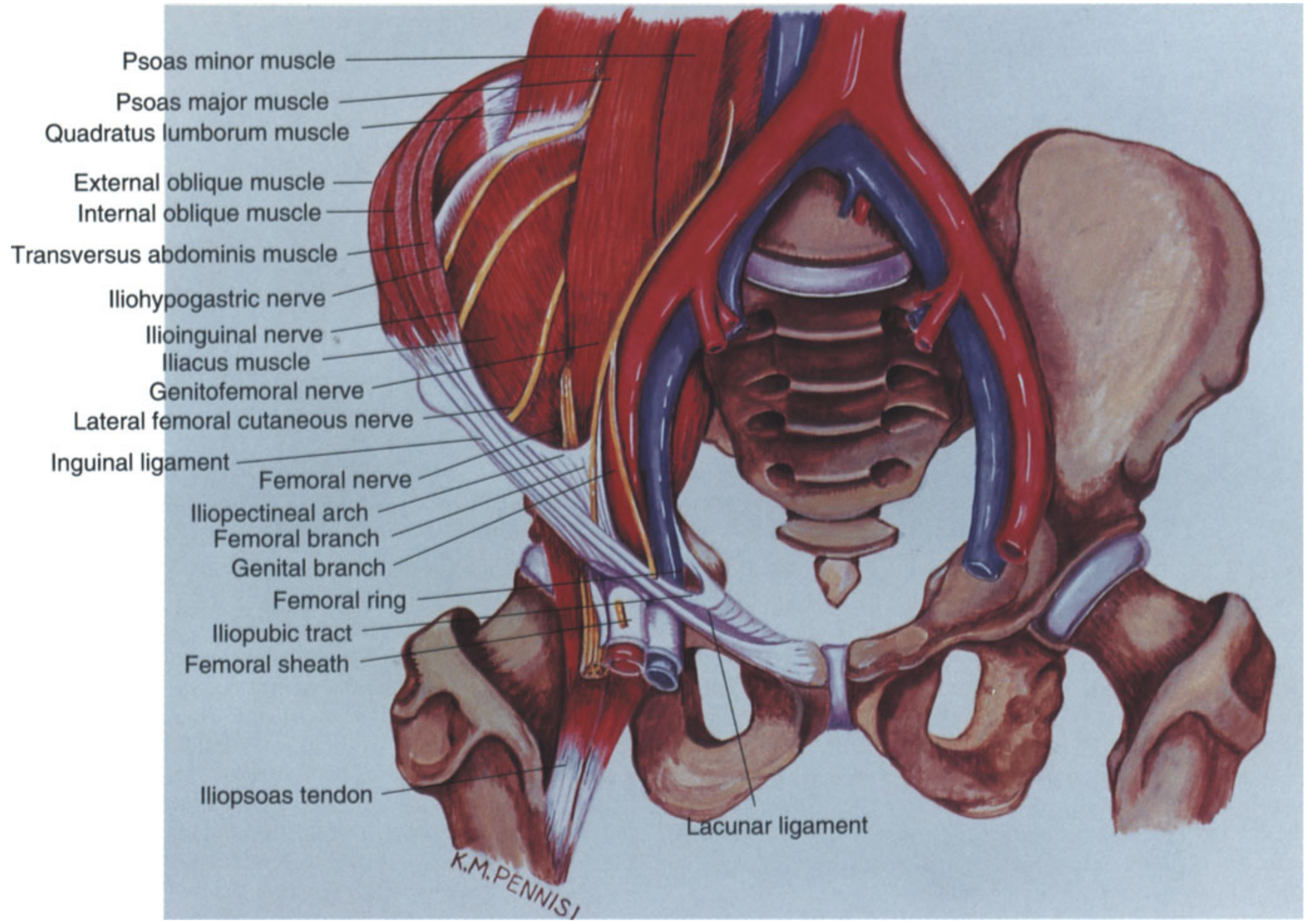

FIGURE 25.2.13. Important anatomical structural groin hernia repair. (From Annibali R, Fitzgibbons RJ Jr, Filipi CJ, Litke BS, Salerno GM. Laparoscopic hernia repair. In: FL Green and JL Ponsky eds. *Endoscopic Surgery*. Philadelphia, WB Saunders, 1994:352–386; with permission.)

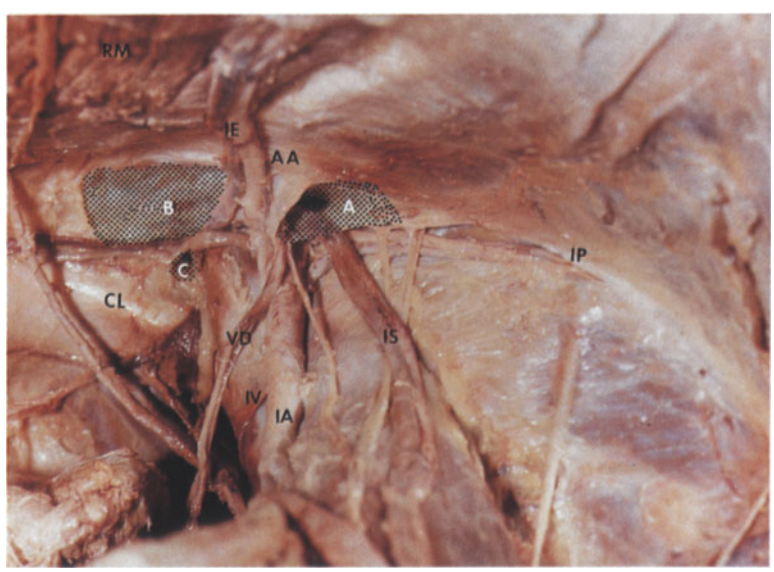

FIGURE 25.2.14. The weak areas of the inguinal region where hernias may occur. The white arrows correspond to: A: internal inguinal ring (indirect hernias); B: weak area within Hesselbach's triangle (direct hernias); C: femoral ring (femoral hernias).

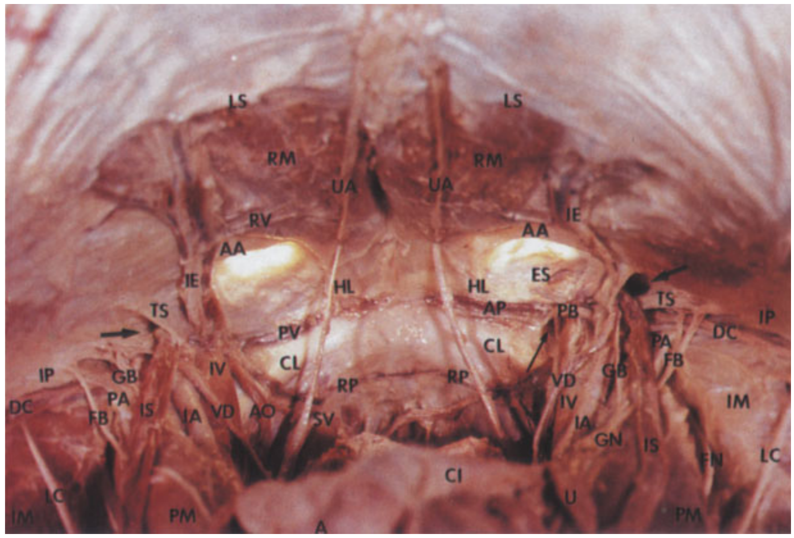

FIGURE 25.2.15. The internal surface of the lower anterior abdominal wall prepared in a cadaver. The urachus and the bladder have been reflected posteriorly. The weak areas inside the inguinal triangles through which direct herniations occur between the aponeurotic arch of the transversus abdominis muscle superiorly and Cooper's pectineal ligament inferiorly, are better demonstrated here by transillumination of the lower anterior abdominal wall. RM = rectus abdominis muscle; LS = linea semicircularis (of Douglas); IE = inferior epigastric vessels; ES = external spermatic (cremasteric) vessels; RV = rectusial vein; CL = Cooper's ligament; IP = iliopubic tract; DC = deep circumflex iliac vessels; UA = umbilical arteries; SV = superior vesical artery; HL = falx inguinalis (or Henle's ligament); AA = aponeurotic arch of the transversus abdominis muscle; VD = vas deferens; IS = internal spermatic (testicular) vessels; PB = anastomotic pubic branch; AP = anterior pubic branch and iliopubic vein; PV = iliopubic vein; RP = retropubic vein; AO = anomalous obturator artery; GB = genital branch of the genitofemoral nerve; FB = femoral branch of the genitofemoral nerve; LC = lateral femoral cutaneous nerve; TS = transversalis fascia sling; CI = common iliac artery; IA = external iliac artery; IV = external iliac vein; PA = iliopectineal arch; FN = femoral nerve; PM = psoas major muscle; IM = iliacus muscle; A = abdominal aorta. The thick arrows point to the deep inguinal ring. The thin arrow indicates the femoral ring. (From Annibali R, Fitzgibbons RJ Jr, Filipi CJ, Litke BS, Salerno GM. Laparoscopic hernia repair. In: FL Green and JL Ponsky eds. *Endoscopic Surgery.* Philadelphia, WB Saunders, 1994:352–386; with permission.)

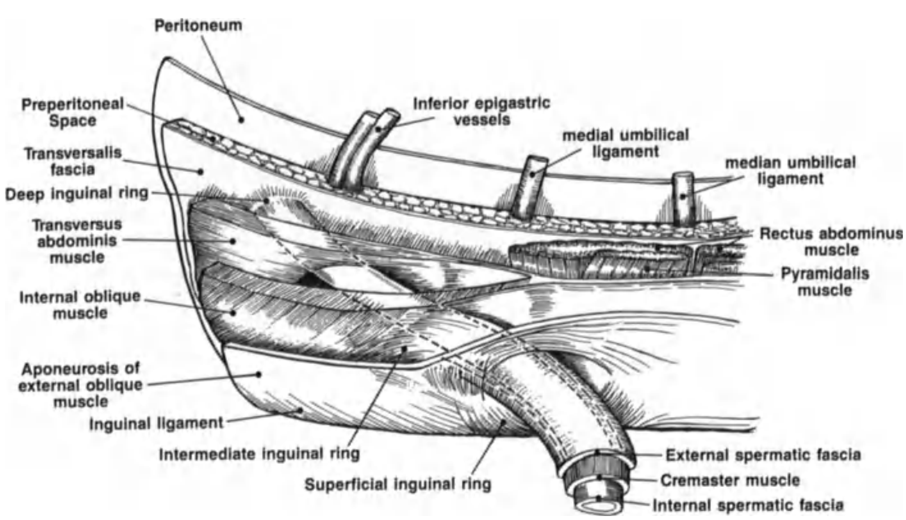

FIGURE 25.2.16. The inguinal canal. (Modified from Yaeger WL: Intermediate inguinal ring. *Clin Anat.* 1992; 5:289–295. Reproduced by permission of John Wiley & Sons, Inc.)

rotic arch superiorly and the iliopubic tract inferiorly, is formed only by transversalis fascia.

The *spermatic cord* is formed at the internal ring by the junction of the vas deferens and the internal spermatic (testicular) vessels, together with a matrix of connective tissue in continuity with the preperitoneal connective tissue. The testicle, during its descent towards the scrotum in embryonic life, invaginates the posterior wall of a tube-like extension of the peritoneum called the *processus vaginalis*.[3,16,19] The proximal processus usually becomes obliterated while the most distal, testicular portion remains patent and constitutes the *tunica vaginalis testis.* The proximal processus vaginalis fails to obliterate in a substantial percentage of patients. For example, 30 to 40% of children, three to four months old can be shown to have patent processus vaginalis.[35] According to Russell, all indirect inguinal hernias have a congenital origin due to patency of all or part of the processus vaginalis.[36] Also included in the cord are the *external spermatic (cremasteric) vessels,* the *artery of the ductus deferens,* the ilioinguinal nerve and the genital branch of the genitofemoral nerve. Venous blood from the testicle and cord structures collects in the *pampiniform plexus,* a network of small veins inside the cord itself, which in turn drains into the *internal spermatic vein* (there may be more than one). This midsize vessel empties into the renal vein on the left and into the inferior vena cava on the right.

These cord structures are covered by three layers derived from the anterior abdominal wall through which the testicle has to pass during descent. The inner layer is derived from the transversalis fascia, and is called the *internal spermatic fascia.* The middle layer is made up of muscle fibers and fascia from the internal oblique muscle and is called the *cremaster muscle.* Yeager has proposed the use of the term *intermediate inguinal ring* to indicate the oval area from which the lower fibers of the internal oblique evaginate to form the cremaster layer[37] (Figure 25.2.16). Finally, the external *spermatic fascia,* the outermost layer, is created at the external inguinal ring, by the reflection of the external oblique muscle fascia onto the cord.[19,21,23]

Femoral Sheath and Femoral Canal

The *femoral sheath* is derived from the endoabdominal fascia where it enfolds the femoral artery, femoral vein, and the femoral canal (Figure 25.2.13). It is usually described as a tubular, funnel-shaped structure. However, the funnel is not perfectly shaped, as the lateral wall is almost vertical, whereas the medial wall points obliquely inferolaterally.[1,16] The inguinal ligament is not in direct contact with the anterior surface of the femoral sheath, since the iliopubic tract is interposed between the two structures.[3,16] The lateral wall is in contact with the iliopectineal arch and is pierced distally by the *femoral branch* of the genitofemoral nerve.[1,16] Two septa divide the femoral sheath into three compartments: the *femoral artery* and the femoral branch of the genitofemoral nerve lie in the lateral compartment; the *femoral vein* lies in the middle compartment, while the medial compartment is the *femoral canal.* The femoral canal is a conical-shaped structure approximately 1.25 to 2 cm long. Its apex extends into the thigh to approximately the level of the fossa ovalis. Its base is a rigid ring, approximately 0.5 to 1 cm in transverse diameter and is known as the *femoral ring* (or *crural ring*).[16,23] The anterior border of the femoral ring has been reported to be made up of the iliopubic tract or the inguinal ligament, or both, according to various authors.[1,3,16,23] The superior ramus of the pubis, the pectineus muscle and fascia, and Cooper's ligament delimit the canal posteriorly. Laterally it is bordered by the femoral vein. The medial boundary is controversial: traditionally it has been considered to be the lacunar ligament.[1] Some authors, however, believe that the reflected aponeurotic arch of the transversus abdominis onto the pecten pubis,[3,25] or the fan-shaped medial insertion of the iliopubic tract onto Cooper's ligament actually forms the medial edge.[2,19] Our experience with cadaver dissections in our laboratory has convinced us of the latter.

The femoral ring is the proximal opening of the femoral canal; normally it is closed by a layer of connective adipose tissue, the septum femorale.[34] Within the canal some connective tissue, small lymph nodes, and lymphatic vessels are found. A large lymph node, known as the *node of Cloquet,* is commonly present inside the femoral triangle of the thigh at the end of the femoral canal. The femoral canal is where femoral hernias develop (Figure 25.2.13).

Vessels of the Retroperitoneal and Preperitoneal Space

There is a great need for the surgeon who dissects and staples prosthetic materials within the preperitoneal space to thoroughly understand its vasculature. The vascular structures are easily damaged, often resulting in the formation of a serious hematoma. The *external iliac vessels* run on the medial aspect of the psoas muscle over its investing fascia, before passing under the iliopubic tract and the inguinal ligament to become the femoral vessels, within the femoral sheath (Figure 25.2.3). The *inferior epigastric vessels* normally originate from the external iliac; they course superiorly and medially towards the umbilicus from a point midway between the anterior superior iliac spine and the symphysis pubis, ascend obliquely along the medial margin of the internal ring between the transversalis fascia and the peritoneum, and finally pierce the transversalis fascia to enter the sheath of the rectus muscle.

The inferior epigastric arteries usually give rise to two branches in the inguinal region: the *external spermatic artery,* or *cremasteric artery,* and the *anastomotic pubic branch.* The external spermatic artery runs upward from its origin along the medial aspect of the internal inguinal ring, pierces the transversalis fascia, and crosses the preperitoneal space to join the spermatic cord. The public branch courses inferiorly toward the obturator foramen, where it anastomoses with the obturator artery. The anastomotic pubic artery sometimes gives rise to an inconstant small branch, called the *anterior pubic branch,* as it crosses the superior ramus of pubis. This anastomotic ring of arteries, together with their corresponding veins, are sometimes referred to as the *corona mortis* ("crown of death") because of the bleeding that occurs if they are injured while suturing or applying staples to Cooper's ligament. An obturator artery originating from the inferior epigastric or external iliac has been observed in approximately 30% of the specimens studied.[38–41] When the obturator artery is anomalous in its origin, it usually appears as a considerably large branch from the inferior epigastric vessels. Damage to these branches during surgical repair could lead to disturbing hematomas in the preperitoneal space.

The *iliopubic vein* courses deep to the iliopubic tract, together with the anterior pubic branch, when this is present. It either empties directly into the inferior epigastric vein, or joins the venous anastomotic pubic branch to form a common trunk that drains into the inferior epigastric vein.[42] Another tributary of the inferior epigastric vein, the *rectusial vein,* runs along or within the lower lateral fibers of the rectus muscle. Bendavid, who first described this vessel, states that it consistently forms a venous anastomotic ring by joining the iliopubic vein above the pubic crest.[42] We were able to demonstrate this connection in most of our cadaver dissections; however, this venous anastomosis is better identified at the operating table as these small veins are often darkened and engorged when compared to the cadaver. Finally, a small, but constant, collateral branch of the anastomotic pubic vein is commonly observed on the lower posterior aspect of the pubic ramus, beneath Cooper's pectineal ligament, and has been termed the *retropubic vein.* Again, the importance of becoming familiar with the deep inguinal venous circulation for laparoscopic surgeons interested in laparoscopic hernia repair is evident, as damage to these structures usually leads to hematoma formation.

The *deep circumflex iliac artery and vein* also originate from the external iliac vessels. They transverse laterally over the femoral sheath, continue between the iliopubic tract and the iliopectineal arch, pierce the transversalis fascia to finally end in the space between the transversus abdominis and the internal oblique muscle. Here, they fully anastomose with the *iliolumbar vessels.*[2,21]

Innervation

Five major nerves derived from the lumbar plexus (T12, L1, L2, L3, L4) innervate the lower abdominal wall, the inguinal and genital region, the thigh, and the leg. The ilioinguinal, the iliohypogastric, the genitofemoral, the femoral, and the lateral femoral cutaneous are found in the extraperitoneal space after removal of the peritoneum covering the lower portion of the posterior abdominal wall.

The *iliohypogastric nerve* (Figures 25.2.3 and 25.2.13) becomes evident at the lateral margin of the psoas muscle and traverses obliquely on the quadratus lumborum, crosses beneath the inferior pole of the kidney to pierce the transversus abdominis muscle, and then divides into two branches. The most important one is the hypogastric, which lies between the external and the internal oblique muscle at the level of the anterior superior iliac spine. It pierces either the external oblique aponeurosis or the anterior rectus sheath to innervate the suprapubic skin of the anterior abdominal wall above the pubis[2,16,21] (Figure 25.2.17).

With a course similar to the iliohypogastric, but more inferior, the *ilioinguinal nerve* crosses the quadratus lumborum and the iliacus muscles before piercing the transversus abdominis just above the anterior half of the iliac crest (Figures 25.2.3 and 25.2.13). After penetrating the fibers of the internal oblique, it travels along the inguinal canal, over the cremasteric muscle, to finally exit through the external inguinal ring. This nerve innervates the skin of the superomedial portion of the thigh, the root of the penis, the pubic region, and the scrotum or labium majus (Figure 25.2.17).

The *genitofemoral nerve* emerges from the fibers of the psoas muscle, more often as a single trunk, at the level of the third or fourth lumbar vertebra. It usually crosses behind the ureter to divide into two terminal branches, the genital and the femoral, at a variable distance from the iliopubic tract (Figure 25.2.18). Sometimes the genital and the femoral branches appear as two separate trunks from the fibers of the psoas major. The *genital branch,* located medially, intersects the iliac vessels before reaching the internal inguinal ring, to finally run along the inguinal canal together with the spermatic cord. The genital branch of the genitofemoral nerve provides motor innervation to the cremaster muscle and sensory innervation to the skin of the penis and scrotum[2,21,32] (Figure 25.2.17). The *femoral branch* is commonly identified on the lateral edge of the psoas muscle, under the psoas fascia. Occasionally it may bifurcate before crossing the deep circum-

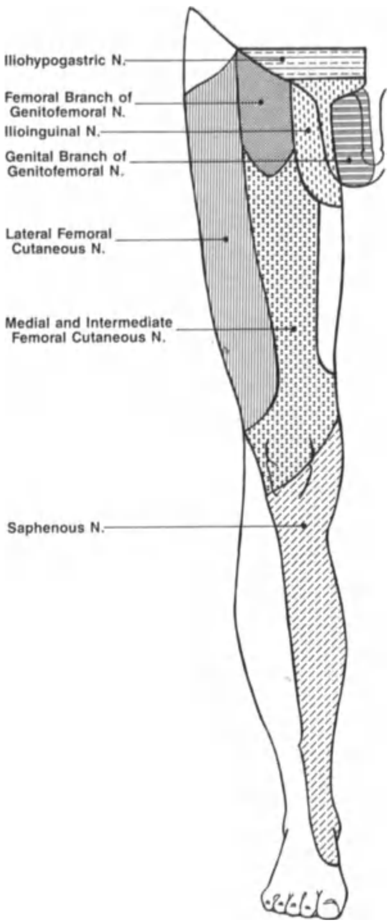

FIGURE 25.2.17. Areas of sensory innervation in the lower limb where pain occurs if the corresponding nerve is injured. (From Annibali R, Fitzgibbons RJ Jr, Filipi CJ, Litke BS, Salerno GM. Laparoscopic hernia repair. In: FL Green and JL Ponsky eds. *Endoscopic Surgery.* Philadelphia, WB Saunders, 1994:352–386; with permission.)

flex iliac artery to pass under the iliopubic tract just lateral to the testicular vessels. In the femoral sheath, it lies lateral to the femoral artery, and it has also been named the *lumboinguinal nerve.* After piercing the anterior wall of the femoral sheath and the fascia lata, it emerges in the upper portion of the femoral triangle, and provides sensory innervation to the anteromedial surface of the upper thigh (Figure 25.2.17).

The *lateral femoral cutaneous nerve* can often be seen under the peritoneum and iliac fascia, after emerging from the lateral margin of the psoas muscle (Figure 25.2.18). It lies on the iliacus muscle, which it traverses obliquely to pass below the iliopubic tract medially to the anterior superior iliac spine. It then reaches the thigh and divides into two branches. Approximately 10 cm below the anterior superior iliac spine, the anterior branch becomes superficial and innervates the skin of the anterior and lateral surfaces of the upper thigh as far as the knee. The posterior branch appears from the fascia lata at a level higher than that of the anterior one, and courses posterior to provide sensory innervation to the skin of the lateral aspect of the thigh. The innervated area extends from the greater trochanter to the midcalf level (Figure 25.2.17).

The *femoral nerve* is the largest of all the nerves originated from the lumbar plexus (Figure 25.2.13). It comes out deep to the psoas muscle, passes along its lateral border, and then it either courses in the slit between the iliacus and psoas muscles, or it lies on the surface of the iliacus muscle covered by a layer of fascia. After passing below the iliopubic tract and inguinal ligament, it reaches the femoral triangle within the "lacuna musculorum," to divide into anterior and posterior branches. The *anterior branch* arises approximately 8 cm distal to the inguinal ligament and, in turn, provides the *intermediate femoral cutaneous* and the *medial femoral cutaneous* nerves to innervate the skin of the lower anteromedial thigh. The *saphenous nerve* is the largest sensory branch of the femoral nerve, and continues to the leg, in proximity and parallel to the saphenous vein, to innervate the medial aspect of the leg and the great toe (Figure 25.2.17). The posterior branch contains *muscular branches* for the motor innervation of the pectineus, sartorius, and quadriceps.

Critical Anatomical Areas for Laparoscopic Hernia Repair

In 1991, Spaw pointed out the importance of the triangular space included between the vas deferens medially and the internal spermatic vessels laterally, which he named the "triangle of doom"[30] (Figure 25.2.18). The name was coined to warn the laparoscopic surgeon of the dangers related to this area, as the external iliac vessels lie on its floor, covered by the peritoneum and the transversalis fascia. In order to avoid injury to these important structures, suturing or stapling should be done only medial to the vas deferens or lateral to the spermatic vessels.[30]

Our own experience, and that of other laparoscopic surgeons, has proved that these precautions, although appropriate, are not enough to avoid neuralgia when performing a laparoscopic hernia repair. The borders of the "dangerous area" should be extended to include another extremely important landmark for safe staple placement, the iliopubic tract. The genital and femoral branches of the genitofemoral nerve, the femoral nerve, and the lateral femoral cutaneous nerve, all lie lateral to the spermatic vessels and immediately below (or, in some instances, directly through) the fibers of the iliopubic tract (Figure 25.2.19). Consequently, staples placed caudal to the iliopubic tract and lateral to the testicular vessels can cause transient or permanent neuralgias due to injury of one or more of the aforementioned nerves or branches.

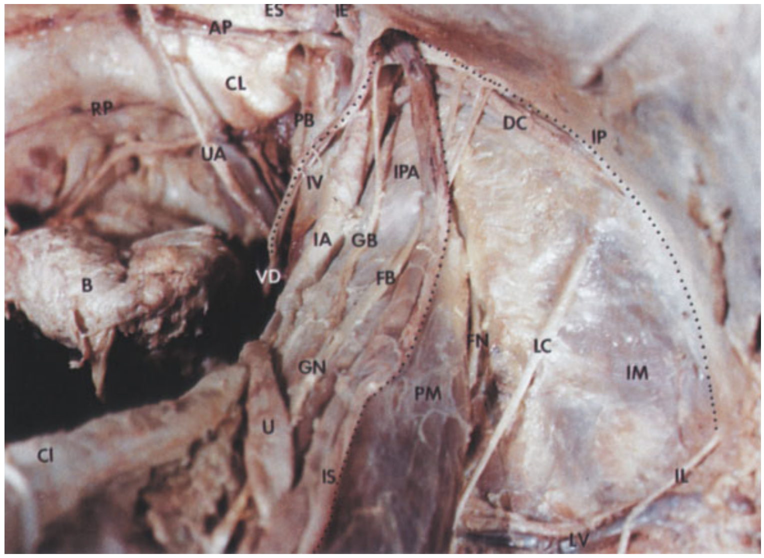

FIGURE 25.2.18. Cadaver preparation (right side) that shows the structures included within the "triangle of doom" (medial triangle) and the dangerous area beside it, bordered by the internal spermatic (testicular) vessels inferomedially and the iliopubic tract superolaterally (lateral triangle), where no staples or sutures should be placed. B = bladder (reflected posteriorly); CI = common iliac artery; UA = umbilical artery; CL = Cooper's ligament; PB = anastomotic pubic branch; AP = anterior pubic branch and iliopubic vein; RP = retropubic vein; ES = external spermatic (cremasteric) vessels; IE = inferior epigastric vessels; VD = vas deferens; IV = external iliac vein; IA = external iliac artery; GN = genitofemoral nerve; GB = genital branch of the genitofemoral nerve; FB = femoral branch of the genitofemoral nerve; IPA = iliopectineal arch; U = ureter; IS = internal spermatic (testicular) vessels; DC = deep circumflex iliac vessels; IP = iliopubic tract; FN = femoral nerve; LC = lateral femoral cutaneous nerve; IL = ilioinguinal nerve; PM = psoas major muscle; IM = iliac muscle; LV = iliolumbal vessels. (From Annibali R, Fitzgibbons RJ Jr, Filipi CJ, Litke BS, Salerno GM. Laparoscopic hernia repair. In: FL Green and JL Ponsky eds. *Endoscopic Surgery.* Philadelphia, WB Saunders, 1994:352–386; with permission.)

Damage of the *ilioinguinal* or the *iliohypogastric nerve* results in pain in the groin or lower abdomen.[16] Injury of the iliohypogastric and ilioinguinal nerves is much less frequent during laparoscopic hernia repair than with conventional anterior inguinal herniorrhaphy, since they lie in a plane superficial to the preperitoneal space and are not encountered during the dissection. At times, however, they can be compromised by staples placed too deep, especially if a strong bimanual technique is used. The *genital branch of the genitofemoral nerve* is not encountered commonly in the area in which staples are usually applied. However, maneuvers used to reduce the sac of an indirect hernia might damage this branch, resulting in pain along the cord and scrotum. Moreover, in some patients the genital branch passes below the iliopubic tract and enters the inguinal canal from below, instead of through the deep inguinal ring. This variation might explain some of the incidences of damage to the genital branch. A damaged genital branch is probably responsible for the painful sensation known as dysejaculation. This complication, recently described in 17 patients undergoing conventional herniorrhaphy, is a painful, burning or searing sensation experienced during ejaculation.[43] The onset of the condition is noted at varying times after surgery, and is probably triggered by distention of the vas deferens by the ejaculate.

The *femoral branch of the genitofemoral nerve* and the *lateral cutaneous nerve* lie on the anterior surface of the psoas and iliacus muscles, respectively. They are quite superficial along the course where staples are usually applied to tack the inferior lateral border of the prosthesis to the iliopubic tract (Figures 25.2.20 and 25.2.21). If staples are placed below the iliopubic tract when stapling lateral to the internal spermatic vessels, these nerves can be damaged. The *femoral nerve* is normally located in a relatively deeper position, between the psoas major and the iliacus muscle. Occasionally, however, it is found more superficially, and becomes more vulnerable to staples placed medially and close to the iliopectineal arch. Its injury may involve sensory (usually pain in the anteromedial region of the thigh) or functional consequences (inability to extend the leg, quadriceps atrophy).

For these reasons, when lateral to the vas deferens, staples should be placed only above and parallel to the iliopubic tract, if a totally safe laparoscopic hernia repair is to be performed (Figures 25.2.20 and 25.2.21). This precaution allows the surgeon to prevent damage to the nerves, as well as to the external iliac and deep circumflex iliac vessels (Figure 25.2.18). Moreover, care should also be taken on the lateral aspect of Cooper's ligament when tacking the inferomedial corner of the mesh, just medial to the vas deferens. This will enable the surgeon to avoid

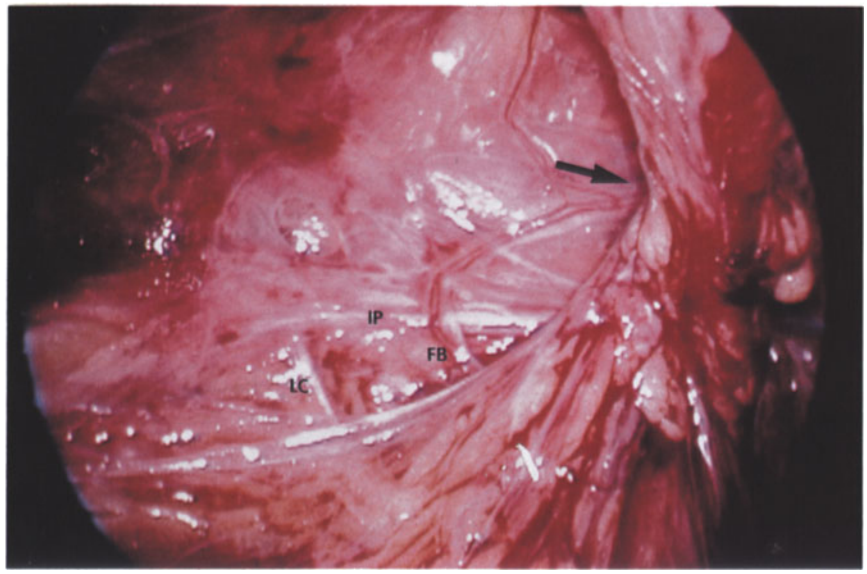

FIGURE 25.2.19. After surgical dissection, the femoral branch of the genitofemoral nerve and the lateral femoral cutaneous nerve have been identified during a laparoscopic hernia repair as they approach and pass below the iliopubic tract. IP = iliopubic tract; LC = lateral femoral cutaneous nerve; FB = femoral branch of the genitofemoral nerve. The arrow indicates the enlarged deep inguinal ring of an indirect inguinal hernia. (From Annibali R, Fitzgibbons RJ Jr, Filipi CJ, Litke BS, Salerno GM. Laparoscopic hernia repair. In: FL Green and JL Ponsky eds. *Endoscopic Surgery*. Philadelphia, WB Saunders, 1994: 352–386; with permission.)

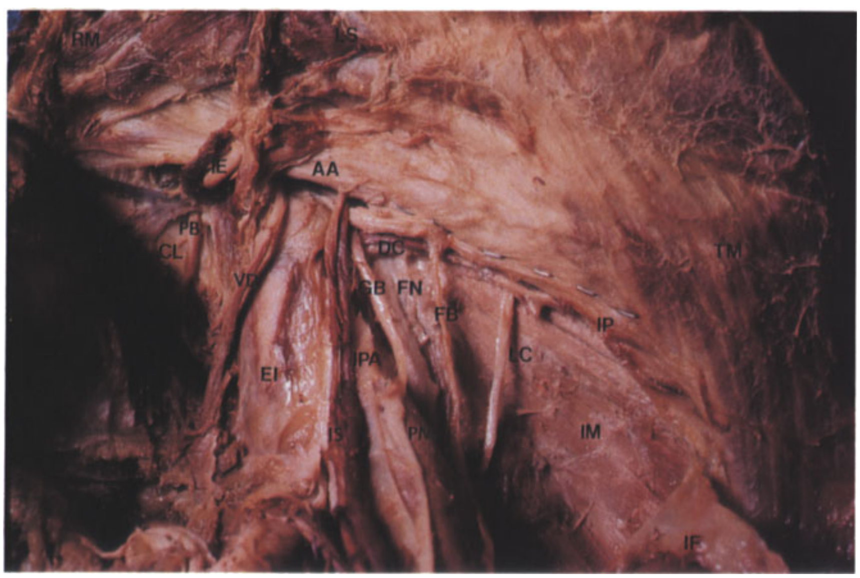

FIGURE 25.2.20. Cadaver preparation demonstrating correct placement of staple just above the iliopubic tract, to secure the inferior lateral border of the prosthesis. The internal spermatic (testicular) vessels have been moved slightly laterally to show the external iliac vessels on the floor of the "triangle of doom." RM = rectus abdominis muscle; IE = inferior epigastric vessels; IP = iliopubic tract; CL = Cooper's ligament; VD = vas deferens; EI = external iliac vessels; GB = genital branch of the genitofemoral nerve; FB = femoral branch of the genitofemoral nerve; FN = femoral nerve; LC = lateral femoral cutaneous nerve; DC = deep circumflex iliac vessels; PB = anastomotic pubic branch; AA = aponeurotic arch of the transversus abdominis muscle; UR = ureter; IM = iliacus muscle; PM = psoas major muscle; IF = iliac fascia (reflected); TM = transversus abdominis muscle; LS = linea semicircularis. (From Annibali R, Fitzgibbons RJ Jr, Filipi CJ, Litke BS, Salerno GM. Laparoscopic hernia repair. In: FL Green and JL Ponsky eds. *Endoscopic Surgery*. Philadelphia, WB Saunders, 1994:352–386; with permission.)

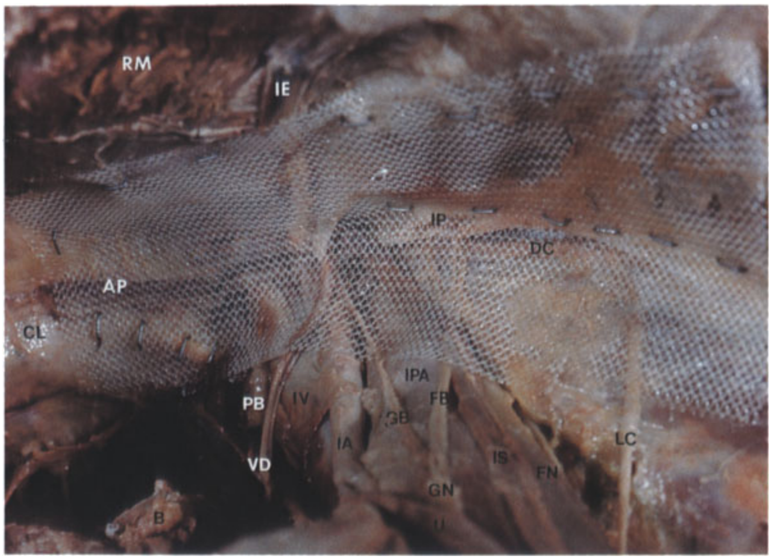

FIGURE 25.2.21. Mesh correctly positioned and tacked with staples to cover the three weak areas corresponding to the deep inguinal ring, the inguinal triangle, and the femoral ring. VD = vas deferens; IS = internal spermatic (testicular) vessels; IV = external iliac vein; IA = external iliac artery; IP = iliopubic tract; IE = inferior epigastric vessels; RM = rectus abdominis muscle; PB = anastomotic pubic branch; AP = anterior pubic branch and iliopubic vein; IPA = iliopectineal arch; CL = Cooper's pectineal ligament; DC = deep circumflex iliac vessels; GN = genitofemoral nerve; GB = genital branch of the genitofemoral nerve; FB = femoral branch of the genitofemoral nerve; FN = femoral nerve; LC = lateral femoral cutaneous nerve; U = ureter; B = bladder (reflected posteriorly). (From Annibali R, Fitzgibbons RJ Jr, Filipi CJ, Litke BS, Salerno GM. Laparoscopic hernia repair. In: FL Green and JL Ponsky eds. *Endoscopic Surgery.* Philadelphia, WB Saunders, 1994:352–386; with permission.)

the anastomotic pubic branch, which usually lies on the medial portion of Cooper's ligament (Figure 25.2.21).

Summary

Due to recent interest in open preperitoneal repairs, the anatomy of the inguinal area described from the posterior or preperitoneal approach has become better understood. This information is not always appreciated by all general surgeons as evidenced by the alarming number of neuralgias during the early stages of the development of laparoscopic inguinal herniorrhaphy.[44] Similarly, the incidence of hematoma due to accidental injury of blood vessels whose locations were poorly understood has been a concern. A thorough understanding of the anatomy of the inguinal region and lower abdominal wall from the unique perspective of the laparoscopic surgeon is essential before a surgeon performs a laparoscopic hernia repair.[45–47]

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25.3
Prosthetic Materials and Adhesion Formation

Riccardo Annibali, José Camps, Nam Nguyen, and
Robert J. Fitzgibbons, Jr.

> Surgeons are usually reluctant to use a prosthesis for fear of wound complication and a natural disinclination to use foreign materials
>
> F. C. Usher

Prosthetic materials have been used for almost a century to repair abdominal defects, but the importance of the type of material is still debated. Adhesions are observed following conventional hernia repair, but the potential risk of development is increased by the presence of a foreign body, such as a prosthetic graft. Extensive ventral hernias sometimes require direct contact of a prosthesis with intra-abdominal viscera. Moreover, the advent of laparoscopic hernia repair has made the intraperitoneal placement of a prosthesis appealing. In this review, the relationships between placement of a prosthetic patch and development of intraperitoneal adhesions will be examined. A survey of the possible methods for prevention of adhesion formation will also be included.

Foreign Bodies and Adhesion Formation

Fibrovascular adhesions are found in 50 to 95% of patients who have undergone conventional abdominal surgery.[1–3] Mechanical trauma, thermal injury, infection, tissue ischemia, and foreign materials are most often responsible for adhesion formation.[4] Foreign bodies have been reported in 61 to 69% of postoperative adhesions. In 50 to 68% of cases, the foreign material was talc; other materials included sutures, cotton lint, filaments of dressings, starch, extruded gut contents, and prosthetic grafts. A combination of different materials has also been noted (usually talc and thread).[2,5]

The common pathway leading to adhesion formation (Figure 25.3.1) is inflammation. It produces exudates containing large quantities of fibrinogen.[6–8] Fibrin clots develop between otherwise unattached surfaces, causing temporary adherence. Granulation tissue results after colonization of the fibrin network by fibroblasts, macrophages, and new blood vessels. A healthy, well-vascularized peritoneum (even with a defect) has an effective fibrinolytic system, because a form of plasminogen activator is able to completely absorb the newly developed fibrinous attachments.[4,9] Prosthetic materials can considerably impair the fibrinolytic activity by two different mechanisms:

1. Tight suturing and grafting induce peritoneal ischemia. Ischemic tissue is a potent stimuli for adhesion formation, actively inhibiting fibrinolysis in adjacent peritoneal surfaces.[6,8–11] Thus, maintaining adequate blood flow is essential for proper, adhesion-free peritoneal healing.[6,12,13]
2. Mesothelial cell proliferation is another important factor for adhesion prevention.[14,15] In a comparative study conducted by Law, adhesion formation was inversely related to the number of mesothelial cells; its reduction, observed in infected wounds and in those where a prosthesis was present, resulted in decreased fibrinolytic activity.[15]

A number of experimental and clinical studies have been conducted to better understand the mechanism of adhesion formation and prevention. One of the major difficulties encountered has been the development of an animal model that is reproducible, quantifiable, and reliable. The rabbit uterine horn model has emerged as the most popular system for the study of adhesions.[16] In this model, a traumatic deperitonealization of the rabbit uterine horn is accomplished. The resulting raw surface will

Inflammation → Exudates rich in fibrinogen →
Fibrin clots → Adherence → Granulation tissue

FIGURE 25.3.1. Common sequence started by different etiologic factors leading to adhesion formation.

develop adhesions with other raw surfaces within the abdominal cavity in a predictable fashion. However, data from any animal model for studying adhesion formation must be interpreted cautiously as there are significant variations in adhesion formation, not only from species to species, but even among members of the same species.

Prosthetic Materials

A variety of different, nonabsorbable and absorbable prosthetic materials has been used for the repair of abdominal wall defects (Table 25.3.1). Most have been manufactured in the form of a mesh or screen to promote the ingrowth of vascularized tissue into the open spaces, resulting in incorporation of the prosthesis. The notable exception is *expanded polytetrafluoroethylene* (ePTFE, Gore-tex). This material is a solid sheet grossly, but is microporous under light microscopy.

Nonabsorbable *silver wire prostheses* were first employed at the beginning of the century in Germany[17] and came to the United States in 1903. Silver wire was shaped into a variety of frameworks that could be used to bridge abdominal wall defects. The results were less than satisfactory, as the metal was found to have limited tensile strength.[18] It would corrode and oxidize when in contact with tissue fluids, resulting in a tendency to fracture with migrating fragments, causing fistulas.[19]

Tantalum mesh, first reported by Burke in 1940, and Koontz and Lam in 1948,[20–22] solved the problem of corrosion and oxidation, but still tended to fragment with repeated flexion within the tissues, and the same complications related to the silver wire prosthesis were reported.[19]

Stainless steel mesh also does not oxidize and was used in the middle of this century to repair defects in the abdominal wall. It has been recently reintroduced in Europe as an improved, pliable, and solid mesh, named Toilinox.[23] Stainless steel, like tantalum, is resistant to infection. Fibrous ingrowth within the mesh is extensive, as evidenced by the need for body wall resection when it has to be removed for recurrence, infection, or other problems.[19] Subsequently, synthetic meshes derived from carbon polymers became available. The initial experience with nylon was not satisfactory, as this material tended to dissipate after implantation. Mesh made from other materials such as polyethylene, acrylic cloth (Orlon), polyester sheeting (Mylar), polyvinyl cloth (Vinyon-N), and sponge (Ivalon) for abdominal wall defects were associated with an unacceptably high rate of infection. *Carbon fibers* dissolve in a relatively short time, and fragments are removed by macrophages. They stimulate a considerable ingrowth of dense collagen fibers that tend to orient themselves along lines of stress. They have not gained wide usage however, because of a concern for potential carcinogenicity.

Absorbable meshes have been recently proposed for temporary peritoneal coverage after extensive sepsis.[19,24] Favorable results with implantation of a *polyglactin 910* (Vicryl) *mesh* for inguinal hernia have been reported by Brenner.[59] In 1983, however, Lamb had previously reported that a polyglactin 910 mesh resulted in hernias 12 weeks after abdominal wall replacement in 4 of 10 rabbits; at 3 weeks, there was an intense inflammatory process around the mesh, but there was no demonstrable fibrous tissue ingrowth into the mesh. The material was considered unsatisfactory for safe and successful hernia repair by the author.[26] Also, *polyglicolic acid mesh* (Dexon) did not induce a strong fibrous response, and was consequently an adequate support for the abdominal wall, in the previously mentioned study conducted by Law.[15] Although there has been some enthusiasm for absorbable meshes in Europe, they have not been well accepted in the United States.

Perhaps the most important development in the history of prosthetic mesh occurred in 1958 when Usher reported good results with the use of woven polypropylene in incisional hernias.[27] The original product was modified in 1962, with the construction of a knitted mesh that was more malleable and could be stretched along both its axes to better fit a hernia defect. In addition, the problem of unraveling after cutting, observed with the first prototype, was eliminated.[19] Usher felt it was particularly useful for extensive abdominal wall defects.[28] The use of this material subsequently gained popularity in Europe.[29] Today polypropylene mesh (Marlex, Prolene) is the most widely used prosthesis for the repair of hernias.[19,26,30,31] It is composed of monofilament fibers (140 μm in diameter) arranged in a network with large, square pores of about 620 μm per side. This allows the infiltration of fibroblasts and production of dense collagen fibers as

TABLE 25.3.1. Different prosthetic materials available for hernia repair.

Nonabsorbable
• Silver
• Stainless steel
• Tantalum
• Nylon net
• Polyester fiber sheeting (Mylar)
• Polyvinyl cloth (Vinyon-N)
• Acrylic cloth (Orlon)
• Carbon fibers
• Polypropylene (Marlex, Prolene)
• Polyester fiber cloth (Dacron, Mersilene)
• Expanded polytetrafluoroethylene (ePTFE, Teflon, Gore-tex)
Absorbable
• Polyglactin mesh (Vicryl)
• Polyglicolic acid (Dexon)

a result of a mild foreign body reaction. Its intrinsic strength is reinforced when fibrous ingrowth takes place. A 20-year follow-up in patients with conventional preperitoneal inguinal hernia repairs suggests that the material is durable.[32] Polypropylene mesh, however, is not perfect. Inflammatory reaction is responsible for dense scar formation, with distortion of the prosthesis in some cases.[33–35] Complications such as wound sepsis, mesh extrusion, erosion into intra-abdominal organs, refractory seromas requiring operative debridement, and bowel fistulas have also been reported.[36–40]

These considerations have stimulated a search for other prosthetic materials. Two of them became competitive with polypropylene mesh: the polyester fibers and the expanded polytetrafluoroethylene (ePTFE, Gore-tex). *Polyester fiber mesh* (Dacron, Mersilene) is thin and pliable, with wide interstices that result in rapid incorporation by connective tissue. It is well tolerated by the body, with a moderate inflammatory reaction and a strong fibrotic response.[19,41,42] Some surgeons feel that its handling characteristics are superior to polypropylene.[42]

Dacron has been used both in the United States and in Europe, especially in France by Rives and Stoppa.[42,43] Hanson, after comparing abdominal wall implants of polydimethylsiloxane-Dacron and Marlex in rats whose peritoneal cavity had been contaminated with feces, reported a significantly lower incidence of infection in the Dacron group (17% in front 88%, respectively). He attributed this result to the different host response toward the two meshes: Dacron was encapsulated, while Marlex was characterized by tissue ingrowth. He felt that this was the reason for the different response to infection. He also felt that fibrous ingrowth was not a sign of biocompatibility, but a factor promoting bacterial proliferation and adhesion formation.[44]

Initial clinical experience with mesh woven from solid *polytetrafluoroethylene (PTFE, Teflon)* was unfavorable, with infection and seroma being a frequent complication.[45] The discovery in the 1970s of a new process for producing this material in an expanded microporous form *(ePTFE, Gore-tex),* with a variety of pore sizes, opened new possibilities.[46] The pore size of $< 10\ \mu m$ reduced cellular penetration and fibrous tissue ingrowth. The first applications were in the cardiovascular field when ePTFE was used as a pericardial membrane substitute and for vascular grafts. In the last decade, ePTFE has been widely used as a replacement for abdominal wall defects.

Recently ePTFE has been reintroduced in a mesh form by Dr. Zucker and his colleagues. They have transformed solid sheets of ePTFE into a mesh, using a meshing device used for skin grafts in laparoscopic inguinal herniorrhaphy. The objective is to maximize the minimally adhesive characteristics of ePTFE and at the same time maintain the advantages of the simple intraperitoneal onlay mesh (IPOM) procedure for laparoscopic inguinal hernia repair. Some argue that by converting ePTFE to a mesh form, its nonreactive properties are lost and it will take on adhesive characteristics similar to other mesh protheses. Long-term follow-up data will be required to confirm the theoretical advantages.

Prosthetic materials have improved dramatically over the last several decades, but the ideal prosthesis still does not exist. Characteristics associated with such an ideal prosthesis would be strength, pliability, durability, hypoallergenicity, and resistance to infection (Table 25.3.2).[22] In addition, the material should be inert, noncarcinogenic, stable in body fluids, and easily sterilized. It should not stimulate foreign body reaction, but should allow rapid host tissue infiltration and ingrowth to create a strong tissue prosthetic aponeurosis. Finally, when the prosthesis is used intra-abdominally, it should not be associated with adhesions between its abdominal surface and intra-abdominal organs. It should be permeable to body fluids to prevent seroma formation.[19,47–49]

A number of single and comparative studies that analyze the outcome of different prosthesis have been reported. Most studies compare the use of polypropylene and ePTFE for the repair of abdominal wall defects.[15,24,26,31,35,50] Three main parameters have been commonly evaluated: (1) patterns of fibrous ingrowth and development of adhesions; (2) resistance to infection; and (3) the incidence of seroma formation.

Table 25.3.3 summarizes the particular features of the two different materials, on which most authors agree. The literature that contains these comparative reports is often contradictory, with similar studies commonly having completely different conclusions.

TABLE 25.3.2. Characteristics of an ideal prosthetic mesh.

• Strong	• Stable in body fluids
• Pliable	• Resistant to infection
• Durable	• No foreign body reaction
• Hypoallergenic	• No adhesions
• Noncarcinogenic	• Permeable
• Sterilizable	• (Transparent)

TABLE 25.3.3. Parameters of fibrous ingrowth: polypropylene versus ePTFE.

	Polypropylene	ePTFE
Foreign body reaction	+ + or + + +	+
Fibroblasts ingrowth	Extensive	< 10%
Host tissue incorporation	Complete, with dense collagen fibers	Encapsulated by regular and evenly distributed collagen
Mesothelial cell growth pattern	Irregular	Continuous layer
Surface (electronic microscopy)	Rough	Smooth

Patterns of Fibrous Ingrowth and Adhesion Formation

Wagner studied puppies in which diaphragmatic defects were created and replaced with various materials. He determined the polypropylene (Marlex) resulted in the least granulomatous response when compared to two other protheses (Teflon and Mersilene). None of the prosthetic materials were as effective as an autogenous graft made of skin harvested from the abdominal wall of the animals. The epidermis and superficial dermis were removed with a dermatome[50] (Cutis graft). Usher also published a report concerning Marlex showing it to be completely intact when examined four years after implantation.[51] Elliott and Juler compared Marlex with the newly developed, expanded Teflon (ePTFE), which was gaining popularity for vascular applications. Data presented by Elliott and Juler were highly critical of Marlex. One and one-half centimeter triangular-shaped pieces of either ePTFE (Gore-tex) or polypropylene (Marlex) were placed between the transversalis fascia and the peritoneum in the groins of rabbits. Marlex mesh engendered dense scar tissue with marked inflammatory tissue response. Grossly, the Marlex appeared "crumpled into a wadded ball" of scar tissue. This was felt to be secondary to contraction of scar tissue causing complete distortion of the graft. ePTFE, on the other hand, excited only a mild inflammatory response. However, fibroblastic cellular ingrowth resulted in complete incorporation into host tissue. There was minimal distortion of the graft material, presumably because of the milder inflammatory response. The authors also noted an orderly orientation of scar tissue adjacent to the prosthesis, suggesting that the material stimulated the host to produce "neofascia."[35]

Amid came to a completely different conclusion based on experimental studies in the rabbit. Polypropylene patches retained their original shape because of rapid fixation by host tissue; ePTFE, on the other hand, showed incomplete fixation and became "wrinkled and curled on itself." The observed penetration of fibroblasts from the host tissue into the depth of ePTFE was less than 10% four years after implantation; with a superimposed infection, this was further decreased.[24]

Law and Ellis[15] found that penetration of fibroblasts from the host tissue into the depth of ePTFE was poor. They also observed that polypropylene (Marlex) mesh was incorporated by dense collagen fibers in a mild foreign body reaction, while collagen penetration of the interstices of ePTFE was regular and evenly distributed. Mesothelial cells were observed in an irregular pattern over polypropylene, but were observed as a continuous layer after four weeks with ePTFE. This has resulted in a different appearance of the two protheses, as seen in low-power scanning micrographs: the peritoneal surface of polypropylene mesh was irregular, but that of ePTFE was smooth. Taylor and Gibson have noted that a round, smooth surface stimulates encapsulation, whereas a rough one prevents it.[52] Lamb reported a better fibrous tissue ingrowth with ePTFE when compared to polypropylene, and a more complete incorporation into a healing wound.[26,33] Bauer, in a clinical trial of ventral hernia repair using ePTFE, noted outstanding results when compared to historical experience.[19] However, what seems to be an adverse factor of polypropylene for proponents of ePTFE, namely roughness of the surface or the weave of the fabric, is according to Amid, a positive aspect that increases fibroblastic reaction and host tissue incorporation.[24]

To summarize, the technique of expanding PTFE into a sheet of nodes interconnected by tiny fibrils allows fibroblasts to infiltrate tiny spaces or pores and synthesize collagen. The question is whether this fibrous ingrowth is sufficient. For example, Van der Lei and Monaghan have independently noted that poorly secured ePTFE patches show a decreased collagen ingrowth, with an increased incidence of "buttonhole" hernias between sutures at the prosthesis fascia interface.[53,54] Both authors recommend either a double layer, a running suture, or a wide overlap of the fascia, to try to prevent recurrent herniation. Thus, a concern with ePTFE patches is that they are based entirely on the strength of the prosthesis because of reduced fibrous ingrowth.[54]

An advantage advocated by some authors in favor of ePTFE, when compared with polypropylene, is a lower rate of adhesion formation.[31,33,55] Again, however, there is not complete agreement in the literature. In Goldberg's experimental study using the rabbit uterine horn model, ePTFE increased postoperative peritoneal adhesion formation when either cut or scrape lesions were produced on one uterine horn and then covered by ePTFE, when compared to the opposite uterine horn with the same cut or scrape lesion left uncovered.[56] Finally, in a comparative study, Jenkins noticed exactly the same rate and density of adhesions to both ePTFE and Marlex, when these prostheses were used to repair abdominal wall defects in rats.[57]

Resistance to Infection

Polypropylene has been regarded as the prosthesis of choice in contaminated wounds,[36,58] primarily because its wide pores do not harbor bacteria. Law and Ellis performed a comparative study in rats between polypropylene and ePTFE in wounds contaminated with *Staphylococcus aureus.* They found a substantial strength advantage with polypropylene.[59] They conclude that polypropylene is the "material of choice over ePTFE" in wounds contaminated by *S. aureus.* Some authors state that the chance of infection is increased with material such as ePTFE or Dacron that has pores 10 μm in size, as bacteria averaging 1 μm in size can hide in such small spaces and proliferate, sheltered from granulocytes.[24] Indeed, DeBord in a clinical study, has reported a high incidence (9.6%) of infection following repair of large ventral incisional hernias with ePTFE.[47] Brown's opinion is contrasting. His group compared polypropylene and ePTFE in a guinea pig model in which reconstructed abdominal wounds were contaminated with *S. aureus*. Although all protheses had grossly purulent material surrounding them at sacrifice, bacterial count per square centimeter was significantly less with ePTFE. They also noted fewer adhesions to underlying viscera and easier prosthesis removal in the ePTFE animals.[31] Law and Ellis, on the other hand, observed the same maximum adhesion formation stimulated by the combination of infection and either ePTFE or polypropylene mesh, two and four weeks after implant.[15] To summarize, there is no consensus of opinion in the literature as to whether ePTFE or polypropylene performs better in the presence of infection.

Seroma Formation

Proponents of mesh materials feel that open spaces allow better access to the peritoneal cavity so that macromolecular substances can flow freely back into the peritoneal cavity, decreasing the chance of seroma formation.[60] The microporous nature of ePTFE does not allow such an egress of fluid back into the peritoneal cavity. Indeed, a high incidence (42%) of seroma formation after repair of inguinal and incisional hernias has been reported by Monaghan.[53] There is evidence, however, that the peritoneal cavity seals within 12 hours, even when a mesh has been used, and no drainage should be possible after that time.[31,61]

Miscellaneous Considerations

There is general consensus in the literature that the use of polypropylene (Marlex) placed in direct contact with interabdominal viscera involves a high risk of fistula formation.[24,36–39] Since ePTFE has not been used clinically as long as polypropylene, it remains to be seen if the rate of fistulization will be less with this material, especially when used in infected wounds. Finally, from the standpoint of the laparoscopic surgeon, polypropylene offers the advantage that one can see through it to allow for safe staple placement under direct vision. Since ePTFE is not transparent, it does not offer this advantage.

Laparoscopy versus Laparotomy

In 1990, Luciano completed a randomized study comparing postoperative adhesions in rabbits subjected to laser incisions (over one uterine horn and over the peritoneal surface or either lower quadrant), done by laparotomy or laparoscopy.[62] He demonstrated that in the laparotomy group, postoperative adhesions were not only present on the tissues involved with initial injury, but also at the laparotomy incision. In addition, adhesions were often found where no apparent injury had been inflicted. No adhesions were observed in the laparoscopy group. Filmar, on the other hand, reported no significant difference between the two procedures in an animal model analogous to the one used by Luciano.[63] However, Filmar inflicted the injury with sharp scissors, causing subsequent bleeding that was not immediately controlled. According to several authors, the presence of intraperitoneal blood, associated with drying of the serosal surface, dramatically increases subsequent adhesion development.[64,65] However, large volumes of fresh and clotted blood, without the simultaneous presence of serosal injury, do not promote adhesion formation and are completely absorbed by normal peritoneum within two days.[65,66]

The results in favor of laparoscopic surgery support a number of clinical observations in which the incidence of adhesion formation was over 50% following open laparotomy for infertility (discovered at a second-look operation). When the procedure was accomplished laparoscopically, the incidence was considerably lower.[62] These conclusions were confirmed in an experimental study of the swine model conducted by our group at Creighton University.[67] In conclusion, laparoscopic surgery decreases the incidence of adhesion formation by avoiding incisions, reducing the amount of blood loss, preventing talc shed in the abdominal cavity, allowing precise dissection with magnification, and eliminating traumatic microinjuries due to the use of sponges and lint (Table 25.3.4).

Prevention of Adhesion Formation

Several types of adjuvants have been tried to decrease adhesion formation. They belong to different classes. The **high viscosity instillates** recall fluids into the peritoneal cavity, creating a sort of "hydroflotation bath." They reduce the apposition of the serosal and peritoneal surfaces, thus decreasing adhesion formation during the period of epithelial regeneration. They may also prevent fibrin deposition.[68] In this class, 32% Dextran 70 (mol. wt. 70,000

TABLE 25.3.4. Advantages presented by laparoscopic surgery in preventing adhesion formation.

Avoid incisions
Less blood loss
Magnification: precise dissection
No talc shed
No sponges or lint: less microinjuries

Daltons), or Hyskon, is the substance most commonly employed. It proved to be effective at high dosage in animal studies;[69] in human studies, however, results were contradictory. Both a prospective, randomized multicenter trial[70] and an additional retrospective study[71] demonstrated beneficial effects of 32% Dextran 70, but two other human studies failed to reveal any advantage.[72] Various allergic reactions following peritoneal instillation of Hyskon, although rare, have been reported as side effects and have prevented widespread use of this drug.[68]

Mechanical barriers represent another class of adjuvants. These materials are interposed between surfaces to impede their adherence. Fascia, peritoneum, omentum, tunica vaginalis, vena cava, cellophane, Teflon, silastic, and nylon are only some of the various kinds of barriers employed. To reduce the potentiating effect of foreign bodies on bacterial virulence, reabsorbable materials have usually been preferred. Among them, two have gained popularity: *oxidized cellulose* (Surgicel) was first tested in two experimental studies in laboratory animals, and did not promote adhesions when left in the abdominal cavity after surgery.[73,74] However, in another laboratory study utilizing trauma to the fimbria and ovary in the rabbit, Hixson and colleagues found that adhesion formation was increased by oxidized cellulose.[75] Subsequently, modifications to the degree of oxidation, porosity, and density led to the development of a new reabsorbable and biocompatible barrier called *Interceed* (TC7).[76,77] It has a finer knit. After the fibers swell, within a few hours after insertion, pores in the fabric close. In two rabbit studies, a significant reduction of adhesion formation was achieved after the use of Interceed; these good results were subsequently confirmed in a human study. In 74 infertility patients treated with laparotomy adhesiolysis for bilateral pelvic sidewall adhesions, and followed-up by second-look laparoscopy, the deperitonealized area of one side had been covered with Interceed, and was compared to the other side, which served as a control. The covered area showed a 90% improvement over control sidewalls in preventing adhesion formation. In our experience, Interceed has not been highly effective in preventing adhesion formation at laparoscopy. In a swine study conducted at Creighton University, the average surface area of prosthetic patches covered by adhesions was not significantly different, when comparing a composite patch of oxidized regenerated cellulose and polypropylene (Prolene, Interceed) with one of polypropylene alone.[67] Finally, it is interesting to note that an increase in *de novo* intraperitoneal adhesion formation caused by Interceed in a murine model has also been reported.[78]

Pharmacological methods have also been experimentally employed in an effort to reduce adhesion formation. However, the difficulty of delivering the drug in an effective concentration at the potential site of action has often jeopardized the potentially good results. *Calcium channel antagonists,* such as nifedipine, verapamil, and diltiazem, have been used. The hypothesis is that adhesion formation can be prevented by blocking the intracellular mechanisms involved in the action of peritoneal repair (fibroblasts, platelets, phagocytes, and endothelial cells). Promising results have been noted in the rabbit model after treatment with verapamil.[79]

The assumption that *heparin* could reduce fibrin deposition and initiation of adhesion formation led to its clinical employment, both via an intravenous route and as an instillate to irrigate the peritoneal cavity, with little success when used alone.[80] However, heparin, and its derivations such as dermatan sulphate, low molecular weight heparin, and hexuronyl hexosaminoglycan sulphate (HHS), have increased the effectiveness of Interceed in preventing adhesions when directly applied on the fabric.[68] *Tissue plasminogen activator (t-PA)* converts plasminogen to plasmin and specifically acts on the fibrin surface without activating the liquid-phase plasminogen. Recombinant genetic technology has recently made t-PA available in pharmacological quantities (rt-PA). Applied topically as a gel formulation in the rabbit uterine horn model, it was effective in reducing both the number and density of adhesion formations and reformations.[81]

Sodium tolmetin in a hyaluronic acid carrier administered intraperitoneally at the end of surgery reduced adhesion formation in a study conducted in rabbits. In addition, tolmetin significantly reduced the number of red blood cells recovered from peritoneal lavage postoperatively. Different mechanisms have been proposed to explain the preventive action of tolmetin: (1) mechanical separation of the wounded serosa from the other normal serosa by viscous macromolecules; (2) suppression of bleeding, with consequent reduction of the number of blood clots; and (3) pharmacological effect by tolmetin on the function, migration, and proteolytic enzyme secretion of postoperative inflammatory cells, which may lead to an increased fibrinolytic activity.[82]

Carboxymethylcellulose (CMC) acts by coating the intraperitoneal surface to prevent direct apposition of injured structures. Its ability to decrease postoperative adhesion formation is prolonged, as it is very slowly absorbed.[68] CMC was effective in significantly reducing adhesion formation and reformation in three studies using the rabbit model.[72,83–86] In two of these studies, CMC was more effective than 32% Dextran 70 for preventing adhesion reformation.[72,83,84] In the other study, however, CMC not only increased adhesions in treated rats, but also promoted anastomotic leaks and a high mortality in the treated group.[87]

Nonsteroidal anti-inflammatory agents (NSAIDS) have also been tried. They reduce vascular permeability, histamine release, and stabilize lysosomes. In particular, oxyphenbutazone[88,89] and ibuprofen[90–92] seem to reduce the intensity of adhesion formation in animal studies. Iloprost, a *prostacyclin* analog, is effective in reducing postoperative primary posttraumatic adhesion formation in hamsters, when administered perioperatively.[93] The effectiveness of *steroids* in preventing adhesion formation is controversial. A beneficial effect of these drugs was demonstrated.[94,95] Swolin, and more recently Jansen, used hydrocortisone intraperitoneally before peritoneal closure, and subsequently reported that all patients showed a considerable reduction in adhesion formation at repeat laparoscopy a few months later.[96,97] Other authors, however, were not able to confirm the usefulness of glucocorticosteroids for preventing postoperative adhesions.[98–100] Moreover, increased postoperative morbidity is to be expected if immunological defenses are decreased with steroid use.[4]

The hypothesis that *antihistamines* decrease fibrin-rich inflammatory exudate in the abdominal cavity (and consequently limit adhesion formation) has also been promoted.[94,95,101] In a randomized, controlled, and laparoscopically monitored study conducted by Jansen among 90 patients, however, no beneficial or deleterious effect was reported on the extent of postoperative adhesions when antihistamines were used.[97]

Conclusion

Theodore Billroth is quoted as saying, "If we could artificially produce tissues of the density and toughness of fascia and tendon, the secret of the radical cure of hernia would be discovered."[19] A variety of safe materials are now available for closure of abdominal wall defects. However, a definitive solution to the problem of adhesion formation after intraperitoneal placement of synthetic prostheses has not yet been found. It is for this reason that most surgeons remain reluctant to position a prosthetic graft within the peritoneal space. This avoids the formation of adhesions directly to the prosthesis with possible intra-abdominal organ erosion. It seems, however, that technological developments will provide us with safer and more reliable materials for intraperitoneal placement in the future.

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25.4
Avoiding Complications of Laparoscopic Hernia Repair

Namir Katkhouda

After the initial enthusiasm, surgeons began to question the value of laparoscopy in some procedures. The main concern in laparoscopic hernia repair was the relative complexity of the operation when compared to the traditional open procedure. Some poor results based on inappropriate technique also contributed to the skepticism. Complications of laparoscopic hernia repair are usually related to avoidable errors in the indications, choice of procedure, and technique.

Incorrect Indications

Laparoscopic hernia repair is contraindicated in several situations. One of the most common is an operation performed on cardiac patients under CO_2 pneumoperitoneum and general anesthesia. There is a high risk of cardiac decompensation and myocardial infarction. Indeed, the few mortalities reported throughout the world are usually related to myocardial infarction. The best method of operation for these patients is probably a conventional anterior approach (Shouldice, Lichtenstein, or McVay) under local anesthesia. Incarcerated sliding scrotal hernias[1,2] containing bowel are another contraindication for laparoscopy. During the dissection, the risk of colonic perforation is great; if unrecognized, it can lead to major postoperative problems. The best approach for treating hernias in such patients is probably a simple anterior approach with an inguinal incision. Another contraindication for laparoscopy is the pediatric hernia (type 1 of Nyhus). It is best treated by a high ligation of the sack. There is no need to endanger babies with a CO_2 pneumoperitoneum and a major intra-abdominal operation. If there is some doubt as to whether there is an incarceration, then a diagnostic laparoscopy could be a reason to perform a laparoscopic high ligation of the sack. Otherwise, we do not see any rationale for treating hernias in babies and infants by using a laparoscope. A recent history of infection is a major contraindication to the use of mesh. The author prefers to wait for an infection-free period of more than one year to insert a mesh, when repairing a hernia.

Inappropriate Procedures

A major goal of laparoscopic hernia repair is to keep the procedure as simple as possible. The use of complicated techniques or procedures that have not been proven to be reliable leads to immediate complications. Among them are the stuffing of mesh into the hernia defect, sometimes of several layers, leading to a migration of mesh into the scrotum, necessitating additional surgery.

The closure of the internal ring only for a type 3 hernia with a defect in the posterior wall whether direct, indirect, or femoral (or a type 4 recurrent hernia) leads also to recurrence of the hernia soon after surgery. Using staples or sutures will not prevent recurrences, as the posterior inguinal wall is not repaired. An intraperitoneal onlay mesh for direct or femoral hernias has, at this point, been associated with a high recurrence rate, but several teams are using this technique and reporting better results.[3,4] Finally, high ligation of the sack alone without repair of the internal ring and the posterior wall is not sufficient for many patients and leads to a high rate of recurrence (except in pediatric patients, see previous section).

Technical Problems

Technical problems are usually the most frequent cause of recurrent hernias and postoperative complications. During CO_2 insufflation in the total extraperitoneal mesh repair, there is a risk of hypercarbia and a high blood diffusion of CO_2. This can be controlled by an anesthesiologist and requires a change in the mechanical ventilatory control parameters. The presence of subcutaneous emphysema is cause for concern; this is usually felt by most surgeons as meaningless, but in the experience of the author, this is an early sign of more problems that lead to sudden cardiac disorders. When using the total extraperitoneal mesh repair, the presence of a hole in the peritoneum during the dissection can lead to a competing pneumoperitoneum, rendering the dissection very difficult.[5–7] If the hole is small, a "valve system" results, decreasing the size of the preperitoneal space. One can enlarge the hole to equalize the pressure between the preperitoneal space and the intra-abdominal cavity, but the hole has to be sutured at the end of the operation. This is very difficult because of the small space and the awkward angle.

A low insertion of the trocars limits the lateral dissection, as the instruments are usually long. The same low insertion of the trocar in the thin patient can endanger the iliac vessels resulting in hemorrhage and/or limb ischemia. When using a transabdominal preperitoneal repair, a short peritoneal flap can be difficult to close. The best way to have an adequate amount of tissue is to incise the flap at the superior aspect of the internal ring. The use of noninsulated instruments out of the range of the telescope can induce small bowel burns that can go unnoticed and lead to postoperative complications. The injury of the vas or spermatic cord vessels during the operation can lead to scrotal or pelvic hematomas and epididymitis and even testicular ischemia. During the total extraperitoneal mesh repair, the dissection behind the rectus muscle can lead to severe hematomas under the anterior abdominal wall. This was reported recently by one author in a personal communication.

Closure of the peritoneal flap is of critical importance as it is to be considered as the "Achiles heel" of the tapp repair. It has to be performed in an overlap fashion if staples are used, otherwise the closure must be done with sutures. An incomplete closure leading to windows in the peritoneum can provoke adhesions of the bowel to the mesh, causing obstructions. A traumatic dissection of a large flap may theoretically induce peritoneal ischemia and necrosis of the flap, leading to small bowel adhesions, although this has not yet been reported. Therefore, this closure has to be performed very carefully and precisely and should not be considered as a minor step in the procedure. The author believes that the ideal closure of the peritoneum is a running suture of prolene 3–0 using the "LaparoTie device" (Ethicon Inc.) to start and finish the suture.

Complications of Lap Hernia Related to the Use of Mesh

The choice of material has to be very precisely assessed. Indeed, one should avoid using polypropylene mesh in the intraperitoneal onlay mesh technique, because this will lead to adhesions or small bowel obstructions. The use of expanded polytetrafluoroethylene (ePTFE) or Interceed in the intraperitoneal onlay mesh technique is currently under evaluation. Some feel that ePTFE induces fewer adhesions to the small bowel and therefore should be the recommended material when using the intraperitoneal technique.[8–10] The incomplete coverage of the hernia spaces leads to immediate recurrence, therefore an anatomical dissection of the area demonstrating the landmarks (Cooper's ligament, rectus muscle, and psoas muscle) is mandatory.[11] The mesh has to be tailored ideally according to Stoppa, and the shape has to follow the general configuration of the pelvic inlet.[12] When putting the mesh in place, one should avoid wrinkles in the mesh. Wrinkles are often found when repeat surgery is required for infection or recurrence of the hernia. A good way to avoid folds is to cut the tails of the mesh in a circular fashion. The fixation of the mesh has to follow very precise rules. One should have a functional stapler available, if staples are used. Currently, it is felt that few staples are necessary if there is fixation to the landmarks (Cooper's ligament, rectus muscle) and there is no need to place more than six staples for the mesh to be kept in place. If one uses a large mesh for the total extraperitoneal repair, no staples are probably necessary.[12]

The so-called triangle of doom should be enlarged and renamed "the square of doom" as a further precaution against surgical complications. The triangle of doom described initially by Spaw consists of a triangle between the vas deferens and the spermatic arteries and veins. In this space, there are iliac vessels, and Spaw recommended avoiding any staples or suturing material in this triangle. We recommend that this triangle be enlarged to a square. The borders of the square are the vas and the iliopubic tract. In this square the genitofemoral nerve runs medial to the psoas before its division into the genital branch and the femoral nerve branch. A lateral stapling in this square of doom can injure the nerve, leading to compression and early ischemia. Clinically, the patient will present with hypoesthesia of the groin, transient pain, and even a neuroma that would need removal of the staple. It is also mandatory to open the peritoneum when using the transabdominal preperitoneal repair above the internal ring, as the genital branch of the genitofemoral nerve runs with the cord along the superior aspect of the internal ring (Figure 25.4.1). The lateral femorocutaneous nerve can also be injured in this area by the same mechanism and by pushing on the abdominal wall during lateral stapling of the mesh.

Parietalization of the Cord

Parietalization of the cord is a very important concept that has been described by Stoppa and Rives. It consists of an atraumatic dissection and separation of the sper-

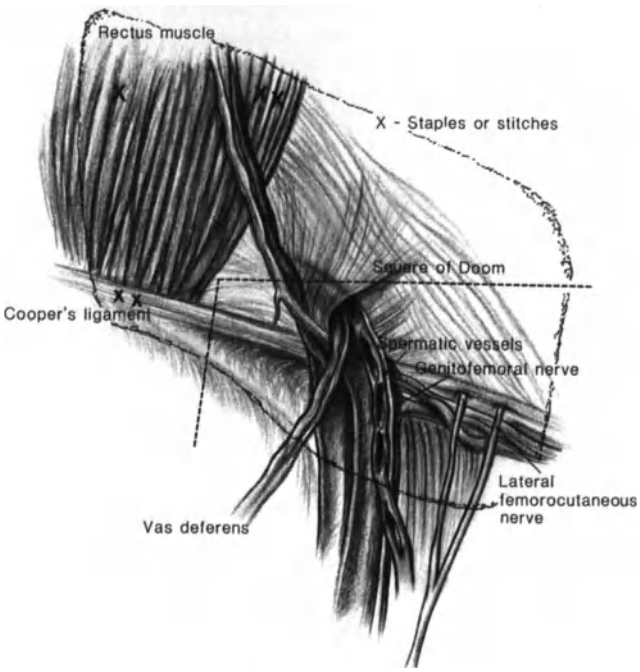

FIGURE 25.4.1. The square of doom.

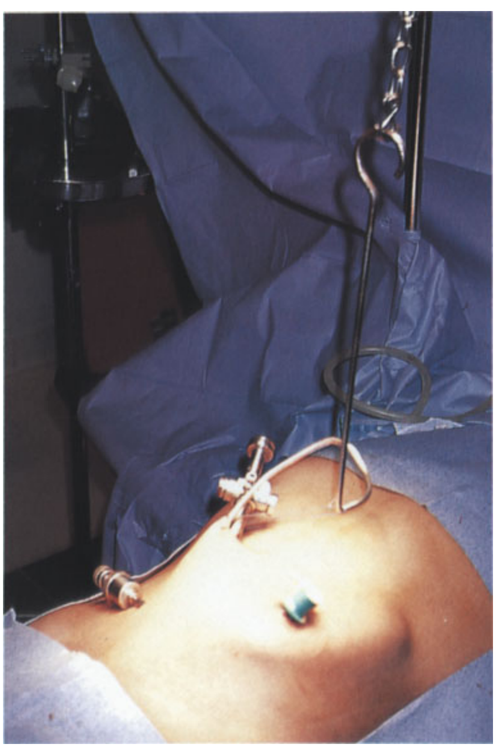

FIGURE 25.4.2. Gasless laparoscopy using a suspension device.

matic cord structures from the peritoneum. The elements of the spermatic cord can be moved laterally to the pelvic wall lying between the mesh and the pelvic wall.[12] Parietalization will avoid putting slits in the mesh for the passage of the cord. Slits have been described by several authors as inducing weakness in the mesh. When the cord is parietalized, the risk of inferior recurrence of hernias above the iliac vessels is eliminated.[12] Recurrences most commonly occur at this site.

Conclusion

Complications can be avoided by identifying high-risk patients (cardiac and pediatric patients) and tailoring the technique according to the Nyhus classification.[13] The pediatric type 1 patient needs only high ligation of the sack. A Nyhus type 2 hernia in the young adult with a strong posterior wall and a large internal ring can be treated by the closure of the ring, avoiding any mesh in young patients. Those patients can also benefit from a conventional open repair or a laparoscopic mesh repair decreasing the risk of future recurrences in the direct space. Mesh should only be used when there is a posterior wall defect (types III and IV).[13] Two techniques are widely accepted: the transabdominal preperitoneal repair and the totally extraperitoneal repair. The later procedure can be greatly improved by using a balloon dissection of the preperitoneal space.[14] The mesh can be placed without staples if it is big enough. Finally, the operation should be kept as simple and cost-effective as possible. Complicated and unproven techniques should be avoided. The suppression of CO_2 and general anesthesia, and the concept of gasless laparoscopic hernia repair under regional anesthesia, described elsewhere in this book, may be the answer to the major problems of hernia repair (cost, general anesthesia) and could also prove to be a better procedure in the future (Figure 25.4.2) if the preliminary results are confirmed.

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25.5
Prevention of Complications of Open and Laparoscopic Repair of Groin Hernias

Cihat Tetik and Maurice E. Arregui

Awareness of the types and mechanisms of complications associated with the laparoscopic repair of groin hernias is essential for their prevention. A clear understanding of the potential risks, coupled with mastering laparoscopic and open approaches will help the surgeon select the best operation for the individual patient. This decision should be based on the type of hernia, clinical condition of the patient, and particular needs of the patient with regard to demands on physical activity at work or home. In this chapter, we will analyze complications and recurrences associated with laparoscopic and open hernia repairs.

Preoperative Evaluation

To properly assess the risk-benefit ratio of hernia repairs, surgeons must be able to diagnose types of hernias, understand the mechanisms of formation, and know the complications associated with having hernias. Complications associated with unrepaired inguinal hernias include: intestinal obstruction, incarceration, strangulation, and problems associated with using a truss. Nonrepair of inguinal hernias increases morbidity and mortality. Undetected or misdiagnosis of hernias can lead to complications or inadequate preparation for surgery. The differential diagnosis of groin masses includes: hydroceles, lymph nodes, lipomas, saphenous varicosities, and psoas abscess. Ultrasound can be helpful in assessing abdominal wall masses of uncertain etiology, identifying occult femoral hernias, and differentiating indirect from direct hernias.[3,60] Herniography can identify nonpalpable inguinal hernias in patients with groin pain.[6] Obstructive uropathy, chronic pulmonary disease, cirrhosis, occult carcinoma of the pancreas or colon, and other intra-abdominal processes can be associated with, or predispose to, hernia formation. These should be evaluated prior to inguinal herniorrhaphy.

Intraoperative Complications of Traditional Inguinal Herniorrhaphy

Vascular Complications

Damage to the pubic branch of the obturator artery (corona mortis = crown of death), deep circumflex iliac vessels, inferior epigastric vessels, cremasteric artery, and external iliac vessels can lead to serious hemorrhage. Careful placement of sutures and staying parallel to the vessels avoids vascular injury. When a stitch is placed into the external iliac vessels, it should be removed and pressure applied. If pressure does not stop the hemorrhage, wider exposure will be necessary. This exposure is achieved by incising the posterior wall of the inguinal canal parallel to the inguinal ligament. This may allow more effective tamponade. A fine, vascular hemostatic suture without narrowing the lumen, a patch graft, or an interposition graft may be required to repair the defect. Other arteries may be ligated with impunity. The cremasteric artery is often a source of annoying scrotal hematomas.[60,74]

Nerve Complications

The ilioinguinal, iliohypogastric, and genitofemoral nerves extend into the operating field and can be unintentionally injured during traditional inguinal herniorrhaphy. The ilioinguinal nerve is in close relation to the spermatic cord. Therefore, it is particularly vulnerable when the external oblique aponeurosis is initially opened. The iliohypogastric nerve may be cut during a relaxing incision over the rectus sheath or in attempting medial exposure in preperitoneal herniorrhaphy. The genital branch of genitofemoral nerve is injured more often than the femoral branch because the genital branch penetrates the internal oblique muscle at the origin of the cremaster, and the femoral branch lies more deeply. Nyhus suggests that the posterior approach to inguinal hernia repair is much less likely to result in nerve injury.[53] If severance of ilioinguinal, iliohypogastric, and genitofemoral nerve does occur, the nerve ends should be ligated to close the neurolemmal sheath. This reduces neuroma formation.

Severance of Testicular Blood Supply

During the repair of a large or recurrent groin hernia, the major vessels of the spermatic cord may be damaged. The major blood supply to the testes is derived from the testicular artery. The external spermatic artery from the inferior epigastric artery, artery to ductus deference from the superior vesical artery, vesical branches, prostatic branches, and scrotal vessels from the internal and external pudendal arteries create a rich collateral network above the testes. If the vessels are cut, ligation is necessary. Repair is impractical. The important point is that the external collateral circulation must be undisturbed if the testicular artery is ligated.

Severance of Ductus Deference

The incidence of a cut ductus deference is 0.3%.[14] If severance of ductus deference occurs, the cut ends must be made smooth and approximated with interrupted sutures.[31] Even though there are two ducti deferens, because this complication carries serious implications, repair should be attempted. Repair increases the chances for normal function. Patency rates up to 50% are reported.[14]

Severance of Spermatic Cord

The spermatic cord can be cut as a maneuver allowing complete closure of the deep inguinal ring. This maneuver should be discussed with the patients, especially those who have recurrent hernias. Tenderness and swelling of the testis and fever does occur in two-thirds of patients. In one-third of patients with transection of spermatic cord, testicular atrophy or hydrocele is seen.[14,42]

Visceral Complications

The intestinal wall and its blood supply may be injured during high ligation of the hernia sac or repair of a sliding hernia. To prevent this injury, the stitches of high ligation must be put into place under direct vision. A sliding hernia must be considered in order to recognize it. When encountered, an incision of the peritoneum is made anteromedial to the sliding component to avoid damage to the intestinal blood supply. This incision allows direct visualization of the mesentery and blood supply. If the intestine is entered or its blood supply damaged, recognition and repair must be carried out prior to completion of the hernia repair.

During the repair of a strangulated hernia, ischemic intestine may have been returned into the peritoneal cavity. Careful observation for the return of good color, serosal shine, peristalsis, and pulsation in the mesenteric vessels is necessary. Injection of fluorescein and examination with ultraviolet light, or examination with Doppler can be helpful in assessing intestinal viability. If there is any doubt about viability, resection of the affected segment should be performed. The lymphatic and venous fluid of the necrotic intestine should not be allowed into the general circulation or endotoxic shock could result. Occasionally, questionable intestine is inadvertently returned to the peritoneal cavity. All attempts to assess viability must be made. The preperitoneal approach usually provides this without a new incision.[46] If the hernial sac is large and long-standing, reducing the intestine into the abdomen may be impossible. Induction of progressive pneumoperitoneum preoperatively may ensure the repair of these massive hernias without the loss of "Right of Domain."[47,59]

Injury to the urinary bladder may occur during the repair of the medial side of a direct inguinal hernia. The presence of perivesical fat should serve as a reminder of the location of the bladder during the operation. This complication can be avoided by inverting the hernia sac. If injury occurs, the bladder wall defect must be closed in two layers with interrupted chromic catgut or other absorbable fine suture material, and an indwelling urethral catheter inserted and maintained for four to six days.

Sometimes, the ureter is encountered during the repair of large, sliding inguinal hernias. The awareness of this complication and anatomy of retroperitoneal area is necessary to prevent it. A transected ureter must be repaired with fine interrupted chromic catgut or other fine suture materials, and a double "J" catheter from renal pelvis to bladder must be inserted. The ureter may require reimplantation into the bladder.

Postoperative Complications of Traditional Inguinal Herniorrhaphy

The rate of postoperative complications associated with open inguinal hernia repair has been reported as high as 15 to 19%.[16,67,88] Postoperative complications can be classified as early complications and late complications, or they can be classified according to systems.

Systemic Complications

Atelectasis, pneumonitis, thrombophlebitis, coronary occlusion, and miscellaneous complications such as acute gout, acute cholecystitis, intestinal obstruction, gastrointestinal hemorrhage, renal calculus, liver necrosis, herpes zoster, and acute psychosis are the systemic complications that can occur after inguinal herniorrhaphy. Rydell reported a 5.4% rate of systemic complications and a cardiopulmonary complication rate of 4.1%.[67] Although there seem to be no significant differences in hemodynamic parameters between local and general anesthesia, the use of local anesthesia decreases the rate of systemic complications.[7]

Urinary Complications

Urinary retention is a common complication. Ten to 30% of patients undergoing general and spinal anesthesia may encounter this. The rate is < 5% with local anesthesia.[22,60,62] It usually occurs in older men with prostatic obstruction and young muscular men. In young healthy men, reflex sphincter spasm associated with operative pain is the cause. It may be controlled by adequate use of analgesics. Pelvic dissection, postoperative pain, use of narcotics, and excessive intravenous hydration can cause bladder distention. Use of local (and if it is not possible, spinal) anesthesia, restriction of intravenous fluids, and early postoperative ambulation are the most effective ways to avoid postoperative urinary retention.[22,38,57] Upright posture and running water may be useful to overcome retention. Otherwise, catheterization of the bladder is necessary if patients are unable to void within eight hours or if they have symptoms of overflow incontinence. Alpha-adrenergic blockers such as phenoxybenzamine hydrochloride, administered preoperatively, may be useful in patients with urinary flow complaints.[30]

Femoral Vein Constriction

The femoral vein may be constricted, especially during McVay herniorrhaphy. Although rare, this complication can lead to significant morbidity. Nyhus and Condon suggest that the incidence of this problem is unknown because most patients have clinically unrecognizable constriction. However, in McVay herniorrhaphy, an incidence of 1.2% has been reported.[11] Venous stasis can predispose patients to deep venous thrombosis, postphylebitic syndrome, or pulmonary embolism. Tension with the placement of the transition suture in the medial portion of the femoral sheath must be considered. If this complication is suspected, venogram or venous duplex scanning must be obtained.[52] If the constriction is seen, the offending suture should be removed.

Scrotal and Testicular Complications

Scrotal ecchymosis as a consequence of dissection is not a serious complication. It disappears spontaneously. A hydrocele can also result from dissection that traumatizes lymphatic or venous drainage. Additionally, it may result from leaving the distal portion of the hernia sac. Hydroceles occur with a 0.5% incidence after traditional inguinal herniorrhaphy.[67] Treatment of this complication is aspiration of the fluid with a syringe. Hydroceles may also resolve spontaneously. Trauma from dissection can also result in testicular swelling. It may be created by thrombosis of the pampiniform plexus. However, closing the deep inguinal ring extremely tightly is believed by some to be the cause of testicular swelling.[64] The rate of marked swelling has been reported as 2.6% by Rydell.[67] Treatment consists of bed rest, scrotal support, and ice compresses. Testicular swelling, testicular pain, and tenderness may be an indication of ischemic orchitis. The incidence of ischemic orchitis is 0.03 to 0.65% after primary hernia repair, and 0.97 to 2.25% after recurrent hernia repair.[26] The pain usually subsides over time, and atrophy develops. Ischemic orchitis and testicular atrophy are a dreaded complication of inguinal herniorrhaphy. Color Doppler sonography, Doppler examination, ultrasonography, and radionuclide imaging are helpful in evaluating testicular viability. Rydell reported the rate of testicular atrophy after traditional inguinal herniorrhaphy as 1.8%.[67] Minimizing cord dissection by leaving the distal hernial sac, not dissecting beyond the pubic tubercle, employing a posterior preperitoneal approach to inguinal hernia, and giant prosthetic enforcement are techniques that may reduce the incidence of testicular complications.[26,48,53,92,93] The surgeon must explain to the patients with testicular atrophy that their remaining testes can maintain fertility and potency.

Wound Complications

Wound complications such as ecchymosis, hematoma, seroma, keloid formation, suture abscess, cellulitis, suppuration, induration, wound pain, and chronic sinus tracts require observation or outpatient management. Wound complications such as deep suture abscess, mesh extrusion, mesh infection, wound disruption, and peritonitis may require inpatient management. Ecchymosis is a common complication with use of local anesthesia. Because the needle can pierce small blood vessels in the subcutaneous tissues, local anesthetic agents containing epinephrine may be helpful. Of patients undergoing traditional inguinal herniorrhaphy, 0.7 to 7% will experience wound hematomas.[28,62,67] Preoperative family and personal coagulation history and attention to hemostasis is necessary to avoid hematoma formation. If a hematoma does occur, pressure or aspiration may be required. The incidence of seroma is high if the hernia repair is carried out with prosthetic grafts in recurrent repairs, and in older patients. It usually appears four to six days after the operation.[28] Aspiration is often necessary to resolve it.

Control of local dermatologic problems, shaving the patient just before operation, maintaining sterility, avoiding multifilament suture material, and proper surgical technique are necessary to prevent infection. Local antibiotic prophylaxis may help prevent infection.[40] The repair of recurrent hernias increases the incidence of wound infection to 3%. It is 1 to 1.3% after primary repair.[62,67] Recurrence is often a sequel to infection.[1,8] Reopening of the incision and systemic antibiotics help resolve this complication. Sinus tracts, as a result of using multifilament suture material and meshes, are rare. Sinus tracts must be removed when they occur.

Neurologic Complications

Although relatively infrequent (1 to 2%), postoperative neuralgia is difficult to resolve.[41,67,77] Careful identification of the nerves is the most important factor in avoiding this complication. After inguinal herniorrhaphy, the finding of typical burning pain that radiates to the area supplied by the iliohypogastric, ilioinguinal, and genitofemoral nerve; impairment of sensory perception of the nerve; and the disappearance of the pain after infiltration with a local anesthetic agent indicates diagnoses of either nerve entrapment or formation of a neuroma. Nerve entrapment can result from scar formation or placement of sutures through or around the nerve. A neuroma is rare and develops in the central part of the nerve. Pain in the skin of the anterior abdominal wall above the pubis associated with iliohypogastric neuralgia, pain in the lower abdominal wall, groin, scrotum, and back associated with ilioinguinal neuralgia; and in the groin, scrotum, and upper thigh associated with genitofemoral neuralgia is usually temporary and disappears or becomes minimal within six months. Using carbamazepine or nonsteroidal anti-inflammatory medication may relieve this complication. If not, a local nerve block must be applied. If this is unsuccessful, a diagnostic paravertebral block of L-1 and L-2 for the genitofemoral and L-2 and L-3 for the ilioinguinal nerve should be considered. If the symptoms do not disappear, the offending suture or neuroma should be removed by a surgical approach.[78,82] Femoral nerve entrapment after inguinal hernia repair has also been reported.[13]

Miscellaneous Complications

Pelvic granulomas after inguinal herniorrhaphy are rare complications, with a 0.04% incident. Paravesical granulomas are seen at a rate of 0.01%. Granuloma formation is a result of infected, nonabsorbable suture material. This complication may occur from several months to years postoperatively. It may simulate a bladder, pelvic, or urachal malignancy. Patients with this complication may have urinary symptoms and a palpable mass. For diagnosis, excretory urograms, computerized tomography scans, barium enemas, and cystoscopy may be useful. Sonographically guided biopsy of the mass is also useful. Nonabsorbable suture materials used to ligate the neck of the hernial sac have been implicated as a cause. Removing the source of the inflammation is necessary for both histological diagnosis and treatment.[10,44,94]

Osteitis pubis, another unusual complication of inguinal herniorrhaphy, is an inflammatory condition of the pubic bones. The reason for this complication may be the piercing needles or contaminated suture materials. Patients complain of pain over the symphysis pubis, ischial tuberosities, and in the adductor region of the thigh. X-rays show the characteristic changes of osteitis pubis—diffuse rarefaction, loss of the cortical margins, sclerosis of bone, and bony fusion of the symphysis. Anti-inflammatory agents are used to treat this complication.[34] Tubal occlusion and infertility may occur after inguinal herniorrhaphy as an uncommon complication. The surgically interrupted fallopian tube is highly amenable to microsurgical reconstruction.[83,89]

Recurrence

During inguinal herniorrhaphy an associated hernia can be missed. A missed hernia is one of the reasons for recurrent groin hernias. Associated hernias occur in 7 to 15% of cases.[28] Missing associated femoral hernias can be avoided by using preoperative ultrasound. Palpation of the femoral canal, Hesselbach's triangle, and the deep inguinal ring during herniorrhaphy is essential. Other reasons for recurrence are inadequate dissection of the indirect hernia sac, improper repair of the deep inguinal ring, and iatrogenic damage to the posterior wall. In addition, the repair of bilateral hernias simultaneously, repair in patients in poor general condition, elderly patients, abdominal wall weakness, obesity, or a large hernia create conditions for recurrence.[28,36,79] Nyhus and Condon emphasize that tension in a hernia repair is the essential reason for recurrence. They report recurrence rates from 1 to 7% for indirect inguinal hernias, 4 to 10% for direct inguinal hernias, 1 to 7% for femoral hernias, and 5 to 35% for recurrent hernias.[14] Preoperative and postoperative awareness of reasons for recurrence; a working knowledge of the anatomy; evaluation of the internal ring, hernia sac, and posterior wall of the inguinal canal; avoidance of general anesthesia; relaxing incisions in sutured repairs; use of prosthetic materials; and avoidance of the repair of bilateral hernias simultaneously, have all been reported to reduce the recurrence rate.[28,50] In addition, many authors report that the recurrence rate is much less after preperitoneal repairs. Recurrent hernias must not be repaired by the technique used in the initial operation.[9,20,73] Stoppa suggested that the placement of giant prostheses by the midline approach to treat recurrent and bilateral hernias reduces the recurrence rate to as low as 2.5%.[27,32,48,54,56,63,79–81,92] Nyhus likewise emphasizes the value of a buttressing patch to support the posterior repair of recurrent hernias.[53,54] Repair of recurrent hernias is associated with higher complication and recurrence rate.

Intraoperative Complications of Laparoscopic Inguinal Herniorrhaphy

Laparoscopic inguinal herniorrhaphy shares many of the same complications as traditional herniorrhaphy. However, a new list of complications has emerged as the laparoscopic technique has become widely used in inguinal hernia repair. Many of these complications are associated with the learning curve, an incomplete understanding of the anatomy, or evolving techniques. Different publications report intraoperative complication rates of 0 to 3.6%, and total complication rates of 5 to 13.6%.[51,55,84,85,91] The majority of intraoperative complications of laparoscopic herniorrhaphy are related to laparoscopic technique. Some are related to the hernia repair and anesthesia.

Complications Related to Laparoscopic Technique

Complications related to laparoscopic technique include injury to the intestine during the trocar placement, broken stapler, loss of needle, bleeding from a trocar port, trocar site hernia, hypercarbia, and equipment problems. Some of these complications have required conversion to open.[21,55,85] Their occurrences, prevention, and treatment are the same as for other laparoscopic procedures.

Complications Related to Laparoscopic Hernia Repair

The most common vascular injuries are injuries of inferior epigastric and spermatic vessels.[9,85] In addition, the external iliac, circumflex iliac profunda, and obturator vessels may be injured during laparoscopic herniorrhaphy. Anatomical variations and confusion during dissection, especially if in connection with previous surgeries, can predispose patients to these injuries. All the vessels in the inguinal region except for the external iliac vessels may be ligated when injuries occur. No suture or staple must be put in the triangular area between the ductus deferens medially and spermatic vessels laterally to avoid injury to the external iliac vessels.[75,90] Injury requires removal of the offending suture or staple and applying pressure to the vessels.

The nerves are often not visible during the laparoscopic herniorrhaphy and a neurologic injury may not be recognized intraoperatively. Therefore, these complications will be analyzed as postoperative complications. Intestinal injuries are related to laparoscopic technique, except when necrotic intestine is returned into the peritoneal cavity in an incarcerated hernia or if injury occurs when dissecting a sliding hernia. Laparoscopy allows excellent evaluation of the intestine. Bladder injury is a rare intraoperative complication with a rate of 0.06 to 0.47.[45,85] A urinary catheter is usually inserted just before the operation, and care must be taken during the dissection of a large direct hernial sac to avoid a bladder injury. If this complication does appear, the bladder injury must be repaired with two layers of absorbable suture and a urethral catheter continued for four to six days.

Severance of the vas deferens or cord structures is a rare occurrence during laparoscopic repair of groin hernia. It has been reported during laparoscopic high ligation with sac inversion[12] and preperitoneal mesh repair.[91] If transected, the cut ends of the vas must be made smooth and repaired with fine, interrupted sutures. With laparoscopic repairs, intentional transection of the cord is not necessary to ensure a good repair in recurrent hernias, as is often recommended with anterior repairs. The surgeon must carefully identify the ductus deferens to avoid transection.[75]

Complications Related to Anesthesia

The use of general anesthesia during laparoscopic procedures adds to the potential for complications such as bronchospasm and cardiac dysrhythmia.[85] Laparoscopic inguinal herniorrhaphy may be performed under regional anesthesia. Recently, local anesthesia has been employed with good results.[18,37]

Postoperative Complications of Laparoscopic Inguinal Herniorrhaphy

Postoperative complications are more common than intraoperative complications. The rate of postoperative complications range from 5 to 12.4%.[51,55,84,85,91] This includes both minor and major complications.

Local Complications

The most common postoperative complications of laparoscopic inguinal herniorrhaphy are local.[45,55,85] These include: trocar site, inguinal canal, and scrotal hematomas; seromas; subcutaneous emphysema; wound infection; anterior abdominal wall ecchymosis; hydrocele; and groin pain. Local complications are least common after the ring closure and most common after the total extraperitoneal mesh approach.[45,65,85] The reason for this disparity may be that ring closure requires no preperitoneal dissection and total extraperitoneal mesh repair requires extensive dissection. In different studies, local complication rates range from 1.6 to 5.6% for intraperitoneal onlay mesh technique, 3 to 5.3% for transabdominal preperitoneal mesh technique, and 6.6 to 12.4% for the total extraperitoneal mesh technique.[17,45,85] Subcutaneous emphysema, inguinal canal, and trocar site hematoma or seroma constitute the majority of local complications. Subcutaneous emphysema can extend into the scrotum. Laparoscopic inguinal herniorrhaphy without pneumoperitoneum is a means of avoiding emphysema.[19] The effects of subcutaneous emphysema are of questionable significance and its importance minimal. The cause of hematoma, seroma, ecchymosis, and hydrocele is likely due to interrupted lymphatics and blood vessels during tissue dissection. This is especially extensive with the extraperitoneal approach. In addition to leaving the distal portion of hernial sac, suture closure, or mesh narrowing of the deep inguinal ring may create conditions for a hydrocele to develop. The rates for hematoma or seroma formation are 2 to 7.5% and 0 to 0.6% for hydrocele.[23,45,55,64,85] They usually resolve spontaneously. Occasionally, simple aspiration is necessary. With large direct hernias, inversion of the outpouching transversalis fascia and anchoring to Cooper's ligament will eliminate the extra abdominal sac that allows pooling of serous and bloody fluids forced out by the intra-abdominal pressures. In our experience, this has greatly reduced inguinal canal hematomas. For large indirect hernias, a temporary drain may decrease the incidence of postoperative fluid collections. Because muscles or fascia of the inguinal canal are not divided during laparoscopic herniorrhaphy, postoperative groin pain is less than after open repairs. Greater tissue dissection seems to create more postoperative groin pain. Oral analgesics usually control the pain. Choosing the optimum technique by the type of hernia, and careful and limited dissection in the proper preperitoneal plane will diminish the rate of local complications.[75,90]

Neurologic Complications

The femoral branch of the genitofemoral nerve and the lateral cutaneous nerve of the thigh are the nerves most at risk during laparoscopic inguinal herniorrhaphy.[39,45] In addition, the intermediate cutaneous branch of the anterior branch of the femoral nerve is also at risk.[90] These nerves are not usually visible during the procedure. Therefore, they may be injured during the fixation of mesh by staple or suture. The genital branch of genitofemoral nerve may be injured during dissection of a large hernia sac or dissection of the cord structures in preparation for mesh placement. Neurologic complications are more frequently seen after large mesh repairs. The rate for this complication has been reported as 0.5 to 4.6%, 1.2 to 2.2%, and 0 to 0.6% after the intraperitoneal onlay, transabdominal preperitoneal, and total extraperitoneal mesh repairs, respectively.[15,23,45,85] These repairs require more dissection of preperitoneal space, and sutures or staples for fixation. Large mesh repairs without suture or staple fixation are being reported. Nonfixation of mesh, or suturing and stapling with excellent visualization and awareness of preperitoneal nerve anatomy (including the anatomy of the "triangle of doom," which contains the femoral nerve and external iliac vessels, and lateral to it, the "triangle of pain," which contains the genitofemoral nerve branches and lateral femoral cutaneous nerve) is essential for preventing these complications.[29,35,66,75,90,91]

Symptoms of neurologic complications include numbness and a burning pain. Patients are treated with nonsteroidal anti-inflammatory agents and observed. In general, the nerve irritation resolves in two to four weeks after surgery. If complaints continue, localization and removal of the offending staple or suture may be required. The iliohypogastric and ilioinguinal nerves are rarely encountered during the laparoscopic repair of groin hernias. However, injury to the ilioinguinal nerve has been reported, presumably due to deep anterior penetration of a staple placed in the preperitoneal space.[55]

Testicular Complications

The complication most often reported is testicular pain. It is transient and resolves in one to three weeks. The etiology of this pain is somewhat obscure. Perhaps the pain is due to trauma to the genitofemoral nerve or to the sympathetic enervation to the testis. The sympathetic testicular plexus may be traumatized during dissection around the cord structures or during separation of the peritoneum from the cord structures. Testicular swelling rarely accompanies this transient pain. Indeed with open hernia repairs, Wantz describes the preperitoneal approach as a way of avoiding the risk of orchitis and testicular atrophy in repair of recurrent hernias. He feels that the etiology of orchitis is due to the trauma associated with the extensive dissection required to remove a hernia sac completely. This is avoided with the preperitoneal approach.[26,92,93] With laparoscopic approaches, orchitis and epidydimitis is a rare cause of testicular and scrotal pain. An alternative explanation of swollen testis appearing with testicular pain may be due to suture or mesh narrowing of the deep inguinal ring, or from interrupted lymphatic and venous vessels resulting from attempts at complete removal of a large indirect inguinal hernia sac. The rate of testicular pain is 0 to 2% after laparoscopic inguinal herniorrhaphy. The rate of total testicular complications is 0.3 to 5%.[23,45,85] Careful technique for tightening the deep inguinal ring during ringplasty of indirect inguinal hernias, gentle dissection around the cord structures, and avoiding complete removal of large indirect hernia sacs is essential for reducing testicular complications. The majority of testicular complications resolve spontaneously. Most cases of orchitis likewise resolve without sequelae if adequate collateral lymphatic and venous drainage develops. Supporting the testis, limiting the activity of the patient, and use of nonsteroidal anti-inflammatory agents is helpful for pain control.

Urinary Complications

Urinary complications such as urinary retention, urinary tract infection, and hematuria can result from the urinary catheter, preperitoneal dissection, general anesthesia, or large volume of intravenous fluids administered during surgery. The most common complication is urinary retention. Although laparoscopic herniorrhaphy is usually performed under general anesthesia, the rate of urinary retention is not significantly higher than traditional herniorrhaphy. This is probably due to the decreased pain associated with this technique, and subsequent lower incidence of reflex spasm. The rate of urinary complications is 1.5 to 3.7% for all laparoscopic techniques.[23,85] This rate is 2 to 5% for preperitoneal laparoscopic techniques.[43,45] We have recently stopped using urinary catheterization for laparoscopic hernia repairs. It is too early to know if this will impact on the urinary complication rate.

Mesh Complications

Palpable mesh, migration of mesh, infected mesh, adhesion formation, and erosion of the prosthesis into intra-abdominal organs are potential complications.[1,2,8] Mesh complications associated with the plug and patch technique have been reported to occur at rates of 4.5 to 7.3%, while rates of 0 to 0.3% are reported after the large mesh repairs without using a plug.[5,23,45,85] Most of the reported complications associated with the plug and patch technique were related to the use of the plug. This technique has for the most part been abandoned. Mesh fixation may prevent migration of the mesh.[45,72] The need for fixation may not be necessary if a sufficiently large prosthesis is used. We no longer fix the mesh, but rely on the intraperitoneal pressures and the sandwiching of the mesh between the abdominal wall and peritoneum to hold the mesh in place. Infected mesh is an uncommon complication with reported rates of 0 to 0.06%.[45,68,72,85] Use of monofilamented biomaterials helps reduce the chances for the mesh to get infected.[1,8] Intravenous antibiotics and soaking the mesh in antibiotics may reduce the chances for mesh infection.

Adhesions of intra-abdominal organs to the hernia repair site may be less after the total extraperitoneal mesh repair, since the integrity of the peritoneal surface is not violated. Avoiding disruption of the peritoneum, meticulous complete closure of the peritoneum, and avoidance of intraperitoneal mesh may prevent this complication.[4,24] Animal studies suggest that adhesion formation is limited to the areas of the dissection.[61] Trauma, infection, ischemia, and foreign materials enhance adhesion formation by creating inflammation that produces a fibrinous exudate. The fibrinolytic mechanism of tissue is decreased by ischemia. Minimizing trauma, avoiding infection, supporting the blood supply, avoiding exposed mesh, and using expanded polytetrafluoroethylene (ePTFE) (if intraperitoneal mesh is used) reduces the chances for adhesion formation.[33,45,69,87]

Miscellaneous Complications

Small bowel obstruction and pubic and pelvic osteitis are miscellaneous complications occurring after laparoscopic inguinal herniorrhaphy. Small bowel obstruction is an uncommon complication related to adhesions or gaps occurring with poorly closed peritoneum after a transabdominal preperitoneal mesh repair. Therefore, avoiding this complication requires the same considerations as those mentioned for preventing adhesion formation. Small bowel obstruction can also result from trocar site hernias. All trocar sites $>$ 5 mm should be closed. Osteitis pubis may be avoided by staple placement on the anterior and superior portion of Cooper's ligament. Sutureless herniorrhaphy techniques will also avoid this complication.[29] If this complication does occur, anti-inflammatory agents and analgesics may be helpful.[34]

Recurrence

The incidence of recurrence following laparoscopic herniorrhaphy is low. The recurrence rate is higher, 6 and 22%, respectively, after transperitoneal suture repair, and the plug and patch technique than after other laparoscopic techniques. Limited preperitoneal dissection during the plug and patch technique may allow recurrences due to missed hernias as well as due to inadequate coverage of the defect.[45,49,58,70,71,85] Recurrence is lowest when a large mesh is used. The recurrence rate is 2.2 to 3.2%, 0.7 to 0.8%, and 0 to 0.4% after the intraperitoneal onlay mesh, transabdominal preperitoneal mesh, and total extraperitoneal mesh techniques, respectively.[15,25,45,51,76,86,91] MacFadyen reported on the complications of laparoscopic inguinal herniorrhaphy as a collective experience of 16 surgeons.[45] In this study, a total of 841 inguinal hernias were repaired on 762 patients. There were two (2.2%) recurrences in 87 patients who had repair of 89 hernias using the closure of internal inguinal ring, six (6.8%) recurrences in 74 patients who had repair of 87 hernias using plug and patch technique, two (6.6%) recurrences in 28 patients who had repair of 30 hernias with transperitoneal suture repair, and nine (1.4%) recurrences in 563 patients who had repair of 635 hernias with a large prosthesis. No recurrences were reported in 53 patients with 90 hernias repaired by a totally extraperitoneal approach. The reasons cited for recurrence include: inexperience, undersized mesh, and mesh without staple or suture fixation.

In Fitzgibbon's study, 736 hernias in 597 patients were repaired with three different laparoscopic techniques: transabdominal preperitoneal, intraperitoneal onlay mesh, and totally extraperitoneal. No recurrences have been reported in the totally extraperitoneal series; the recurrence rate in the intraperitoneal onlay mesh group was 4.6% and in the transabdominal preperitoneal group it was 3.5%.[23] Tetik and Arregui have reported recurrences in a retrospective analysis of 1,514 laparoscopic repairs on 1,288 patients (Table 25.5.1).[85] Recurrence rates were lowest with large mesh repairs, and highest after the plug and patch technique.

Because of a high early recurrence rate (6.8 to 22%), the plug and patch technique has been abandoned. Limited preperitoneal dissection has resulted in missing concurrent hernias, mainly direct defects. Complication rates of 13.4 to 13.5% are reported.[45,85] Most of these complications are due to palpable plugs and migration of mesh. Because a small mesh is used, migration into the hernia defect can occur. Transperitoneal suture repair of the transversalis fascia to the iliopubic tract or to Cooper's ligament has also been abandoned due to a high complication rate (19.8%) and a high recurrence rate (6.6%).[45]

With the ring closure technique, inspection of the inguinal floor is not carried out and a direct hernia or weak floor can be missed. With this technique, careful patient selection is imperative. Those best suited for this repair are young patients with type 1 and type 2 inguinal hernias who are unlikely to have a defect in the inguinal canal floor. Complication rates of 1 to 2.2% and recurrences of 2.2 to 3% have been reported.[45,85]

The intraperitoneal onlay mesh technique is associated with complication rates of 4.8 to 13.4% and recurrence rates of 2.2 to 4.6%.[23,45,85] Because a preperitoneal dissection is not performed, missed hernias can result. Adhesions to the intraperitoneal mesh can occur and there is a potential for erosion into the bowel and for bowel obstruction. A complication rate of 9.4 to 11% and a recurrence rate of 0.7 to 3.5% has been published for the transabdominal preperitoneal mesh repair.[23,45,85] During the transabdominal preperitoneal mesh repair, if the staple closure leaves too much of a space between staples, the exposed mesh can result in adhesion formation and associated complications or herniation into the preperitoneal space. This remains the major disadvantage of this repair over the totally extraperitoneal approach. Although the total extraperitoneal mesh repair has a higher complication rate (7.7 to 19.6%), it has the lowest recurrence rate (0 to 0.4%).[23,45,85] This technique reduces the risk of adhesion formation and associated complications. It is the more recently introduced technique and is more complicated to perform than other laparoscopic techniques.

Conclusion

Laparoscopic inguinal herniorrhaphy has been introduced as an attempt to reduce the pain and convalescence associated with open traditional hernia repairs. As with most techniques in evolution, numerous minor complications have occurred during the learning curve. Many of these problems will be eliminated by a better understanding of the anatomy of the area and the mechanisms of the complication. Many of the complications reported with the laparoscopic repairs are often not mentioned in reports of open anterior repairs. These minor problems of hematoma, seroma, and transient pain are disregarded

TABLE 25.5.1. Complications and recurrences after 1,514 laparoscopic inguinal herniorrhaphies.[85]

Types of complications		Laparoscopic Techniques					
		82 Plug and patch	102 Ring closure	320 Intraperitoneal onlay mesh	457 Total extraperitoneal	553 Transabdominal preperitoneal	Total
Intraoperative complications	Related to hernia repair	0	0	2	0	1	3
	Related to laparoscopy	0	1	1	9	3	14
	Related to anesthesia	0	0	0	0	1	1
	Total	0	1	3	9	5	18
Postoperative complications	Local complications	0	0	18	56	21	95
	Neurologic complications	0	0	15	3	7	25
	Testicular complications	1	0	0	11	11	23
	Urinary complications	0	0	4	7	12	23
	Mesh complications	6	0	1	0	3	10
	Miscellaneous complications	4	0	2	4	2	12
	Total	11	0	40	81	56	188
Recurrence		18	3	7	2	4	34

in these reports, so it is difficult to compare the complication rates between open and laparoscopic techniques. With major complications such as infections, orchitis, and bowel obstructions, the rates are quite low in both types of repairs. The laparoscopic approach is clearly more invasive, and most repairs are more complicated than open anterior approaches. Comparison with open repairs is further complicated by the fact that most of the laparoscopic repairs are in evolution and few techniques have been standardized. What seems to be evident so far is that laparoscopic repairs with a large mesh have a very low recurrence rate, even in the early learning curve. The long-term recurrence is not likely to change much, based on the long-term experiences with open preperitoneal repairs using a large mesh. These early, encouraging lower recurrence rates must be tempered with the occurrence of bowel obstructions, nerve entrapments, complications of general anesthesia, and laparoscopic techniques that are not seen with open anterior approaches using mesh. Higher costs are also incurred with the laparoscopic techniques. We must also objectively evaluate whether the laparoscopic approach indeed significantly reduces the pain and convalescence compared, not with traditional open repairs, but to more contemporary repairs using tensionless mesh techniques. To properly evaluate laparoscopic approaches, prospective studies will need to be performed comparing contemporary open repairs with well-established, standardized laparoscopic approaches.

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26
Pediatric Laparoscopy

26.1
Principles of Pediatric Laparoscopy

Joseph S. Sanfilippo and Thom E. Lobe

Introduction and Historical Review

Applications of operative laparoscopy in the pediatric and adolescent patient represent the "neophyte" of current technological advances. Operative laparoscopy has been successfully accomplished in preterm infants as well as neonates and young children, and the horizons appear to be on a continuum of unprecedented achievement. The first direct visual inspection of an internal organ (uterine cervix) appeared in the Babylonian Talmud (Niddah Treatise, Section 65b), in which a lead funnel with a bent mouthpiece equipped with a wooden drainpipe was introduced into the vagina. This is the foundation upon which modern surgical expertise was built. The use of light reflected from a mirror placed in front of the exposed vulva to illuminate internal body structures for inspection has been attributed to the Arabian physician Albukassim (912 to 1013 A.D.). The first endoscopic light source was attributed to Giulio Cesare Aranzi (1587), and the subsequent application of the *camera obscura* was invented by the Benedictine monk, Don Panuce. In 1805, Bozzani used a tube and candle light to examine the urethra of a patient. In 1901, Ott inspected the abdominal cavity by focusing a head mirror into a speculum introduced through a small incision—the appearance of the laparoscopic procedure. The introduction of the pneumoperitoneum by Kelling and Jacobaeus, followed by the introduction of the Nitze cystoscope, allowed further evolution of the technological advances that surgeons use on a daily basis. Carbon dioxide insufflation is attributed to Zollikofer, and the insufflation needle to the excellent work of Veress.[1] As the timeline continues, Hope, and subsequently Riddock, diagnosed an ectopic pregnancy via laparoscopy. The first textbook in English on laparoscopy has been attributed to Steptoe.[2]

Better instrumentation has made endoscopic operative intervention currently available for children. Steve Gans is given the major credit for convincing pediatric surgeons that laparoscopy could play a major role in the management of diseases in children.[3–5] In the mid- to late 1970s, shortly after the availability of pediatric-sized Hopkins Rod Lens telescopes, he traveled to Tutgarten, Germany, to the Storz research and development department and designed with them the first laparoscopies suitable for use in infants and small children. Since then, refinement of lightweight video cameras and development of better endoscopic instrumentation, including endoscopic surgical staplers, and devices for delivering various forms of thermal energy (e.g., lasers, and monopolar and bipolar electrosurgical tools), have facilitated the endoscopic performance of advanced operative procedures.

In any discussion of laparoscopy, two issues surface. First, one must consider procedural issues, for example, which procedures can be performed, and how they should be performed. Second, one must consider which of the procedures that can be performed is more efficacious than the conventional operative approach, to the extent that it should be performed preferentially because of its significant advantages. Accordingly, we will discuss how to perform laparoscopy on infants and children first, and then follow that with a discussion of the pros and cons of a laparoscopic approach in children.

Laparoscopy is now possible in infants and children because of several technological developments. As previously mentioned, the Hopkins Rod Lens telescopes have revolutionized all pediatric endoscopy. These instruments range in size from 2 to 10 mm in diameter and are used most often in 0 or 30° lens configurations. We prefer the 0° scopes because their use causes less disorientation for the operating surgeon, and they are the easiest to use for the novice. The 30° lenses are useful in specific instances where it is required to see around a corner or at an angle and a second trocar is not desired. The right angle or operating laparoscopes have very little use in most of our current operative laparoscopic procedures, and are probably not worth the additional expense if one is purchasing a new system. The Hydrolaparoscope (Circon/ACMI, Stamford, CT), an instrument designed with a forward irrigation channel and a side (lens) irrigation channel, is useful in situations where there is purulent material or hemorrhage that is likely to smear the end of the telescope and obscure the view. This instrument allows the surgeon to irrigate the end of the lens without having to remove the telescope from its cannula (Figure 26.1.1). This convenient feature saves time on lengthy procedures.

Another essential instrument is a lightweight video camera system. There is much discussion about the virtues of three-chip cameras and systems with the chip on the end of the scope. In all probability this is not germane to discussions of laparoscopy in children, as it is in adults. Because we tend to use the smaller scopes for many procedures, but often use the larger scopes on older children, the lightest camera available that is adaptable to all sizes of scopes seems ideal. The weight becomes more of an issue when the smaller telescopes (2 to 5 mm) are used. Heavy cameras weigh these scopes down and tend to bend the shaft of the shorter 2- and 4-mm telescopes. Another convenience, if one is concerned about image documentation, is a camera system with controls on the camera head. This is a convenient feature that allows the camera operator to control the video printer or video recorder.

Laparoscopy in infants and children requires smaller trocar/cannula sets and more delicate instrumentation. The ideal trocar for the infant or small child is one that is approximately 2.5 cm in length that will remain fixed in the peritoneal cavity until it is no longer required. There are several disposable devices that are shorter than most adult cannulae and have an expandable flange that will keep the cannula from slipping out of the abdomen after it is inserted. The screw-type fixation devices tend to tear the skin of the child and slip out easily because the child's abdominal wall is so thin. Newer adhesive rings to hold the cannulae in place show some promise. Alternatively, one may use Steri-strips (3M, St. Paul, MN) to help secure the cannulae in place after their insertion.

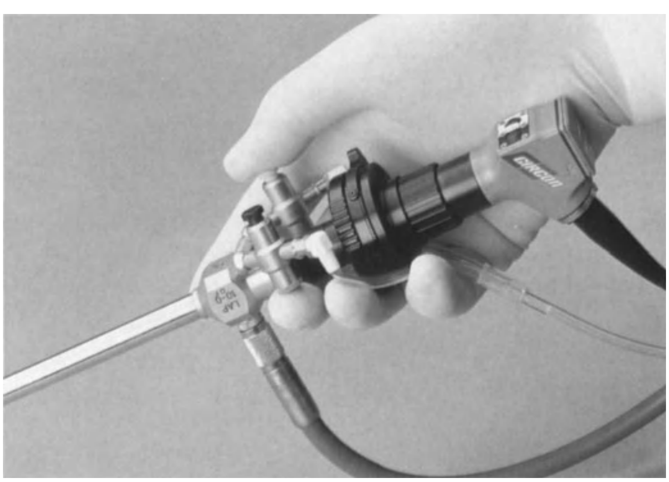

FIGURE 26.1.1. Hydrolaparoscope (Circon/ACMI, Stamford, CT).

There has been an explosion in the development of instrumentation for endoscopic surgery. Most of the disposable devices are still too crude in their design for use in small children. We prefer nondisposable instruments when delicate dissection is required, and usually use a combination of the two types of instruments, depending on the procedure. Ideally, one should try to use as many 5-mm instruments as possible, and avoid the larger clamps and staplers, except in procedures where they are essential. Most of the other instruments and accessory supplies are the same for children and adults.

Most laparoscopy in infants and children is performed under general anesthesia with endotracheal intubation. Prophylactic antibiotics (preoperative) are recommended to prevent trocar site infections. All infants and children have their stomach and bladder emptied just prior to beginning the procedure. The stomach can be emptied with a suction catheter and, in most instances, the bladder can be emptied sufficiently with the use of a Crede maneuver.

The abdominal wall of the child is thin and elastic. This presents two problems. First of all, it is easy to introduce a needle or trocar into the subcutaneous space and think you are well into the peritoneal cavity and, second, it is easy to injure abdominal viscera during secondary trocar introduction. Both these problems can be easily avoided. A Veress needle can be used to establish a pneumoperitoneum in even the smallest infant. First, a stab wound is made in the skin of the inferior rim of the umbilicus, the length of which equals the diameter of the cannula to be introduced. The abdominal wall is elevated by grasping it on either side of the umbilicus as the Veress needle is introduced. It is easier to introduce the needle perpendicular to the long axis of the patient and avoid inserting the needle into the loose areolar subcutaneous tissue. The needle is best held by its shaft like a dart, and the maneuver is a quick shallow thrust into the peritoneal cavity until the retractable blunt end of the needle is heard to "pop" free into the abdomen. When the insufflation tubing is connected, the flow of gas should be 0.5 L/min or greater; a lower rate of flow suggests that the needle is not in the proper location.

The exact total volume of gas introduced into the abdomen varies with the size of the patient. It is preferable to set pressure limits on pressure-regulated automatic insufflators. For infants, the pressure is set at 6 to 8 torr. For children, most procedures can be accomplished using pressures of 8 to 10 torr. Older children can better tolerate pressures of 10 to 12 torr. After the abdomen is insufflated, the umbilical trocar is introduced. Ideally, a 5-mm cannula is used. Caution should be exercised when introducing the trocar. Despite abdominal insufflation, the abdominal wall should be elevated as the trocar is introduced. A twisting motion for insertion of the trocar permits better control. Downward force (with the shoulder rather than the hand) is applied. This technique lowers the probability of injury to adjacent viscera. Insertion of secondary trocars can be more dangerous. One must always keep the tip in sight during the introduction, and elevate the abdomen instead of relying on the insufflation to keep the abdominal wall away from the viscera. This is necessary because of the thinness and greater flexibility of the child's abdominal wall.

Postoperatively, the trocar sites should be sutured in children. Because of the thinness of the abdominal wall, there is greater likelihood of a hernia in a trocar site. We therefore close both the fascia and the skin with interrupted absorbable sutures. A Steri-strip or transparent occlusive dressing is applied to each trocar site. Patients are placed on postoperative Reglan (A.H. Robins Co., Richmond, VA) to prevent nausea. In children older than 8 or 10 years of age, a patch of Transfer–Scope (CIBA Pharmaceuticals, Edison, NJ) behind the ear is useful. Children have fewer complaints of postoperative shoulder pain than adults. (We do not leave suction catheters in the peritoneal cavity for several hours to evacuate all the CO_2 gas, as has been done for some laparoscopy in adults.) Postoperative analgesic requirements are extremely varied and should be prescribed as necessary. A wide variety of laparoscopic procedures can be accomplished in infants and children as listed in Table 26.1.1.[6] Details of the more common procedures follow.

Appendicitis

As pediatric surgeons gain experience with laparoscopic techniques, it is apparent that one of its best applications is in treatment of appendicitis.[7,8] Most of the arguments against approaching this disease laparoscopically are by those unfamiliar with laparoscopic surgery. There are several advantages of laparoscopic appendectomy. These include a better cosmetic result, particularly in young females, and the early return to extracurricular activities after a brief recovery time (hours to days). In our experience, if the technique is performed properly, the complication rate of laparoscopic appendectomy is the same as in the open technique.[9] The complications of laparoscopic appendectomy include minor local wound infections that can be treated locally with antibiotics, and an occasional intra-abdominal abscess requiring draining, associated with a ruptured appendix. This latter complication can occur when a fecalith is left behind.

TABLE 26.1.1. Laparoscopic procedures in infants and children.

Appendectomy	Splenectomy
Cholecystectomy	Bowel resection
Trauma evaluation	Vagotomy
Undescended testes	Pull-through for Hirschsprung's disease
Varicocele	Lymphadenectomy
Small bowel obstruction	Staging laparotomy
Abscess	Vesicourethral reflux
Gallbladder shunts	Neonatal jaundice
Ventriculoperitoneal/Tenkoff catheters	Rectal prolapse
Inguinal hernias	Acute pelvic inflammatory disease
Pyloromyotomy	Chronic pelvic pain correlation
Nissen fundoplication	Lysis of adhesions
Tumor staging	Ovarian cyst
Brachytherapy	Adnexal torsion
Liver biopsy	Creation of neovagina
Nephrectomy	

After laparoscopic appendectomy for acute, uncomplicated appendicitis, patients are discharged between 6 and 36 hours postoperatively, and are allowed to return to unrestricted activity as soon as they are comfortable, usually within 72 hours. In cases of ruptured appendix requiring antibiotics, the advantages of laparoscopic appendectomy are not as great. However, in the young adult who would like to "return to normal as soon as possible," the laparoscopic technique offers the opportunity to treat the disease and, once antibiotic therapy is completed, return to one's normal level of activity without restriction. In our opinion, this is the main advantage of laparoscopy in cases of ruptured appendicitis. Approximately 40% of our cases have been ruptured at the time of laparoscopy. One good approach is to perform laparoscopy in patients who appear to have appendicitis uncomplicated by rupture or abscess formation. If laparoscopic appendectomy is begun and a ruptured appendix is discovered, we complete the laparoscopic appendectomy without laparotomy. There are several different laparoscopic approaches to appendectomy. The procedure can be performed using the laser, surgical clips, linear stapling devices, endoscopic loops, or sutures, depending on the preference and expertise of the surgeon. The linear tissue stapler is our method of choice.

The initial approach to laparoscopic appendectomy requires placement of a nasogastric tube and a bladder catheter. The patient is placed supine in Trendelenburg position for most of the procedure. A CO_2 pneumoperitoneum is established as described above and, depending on the size of the patient, a 5- or 10-mm laparoscope is introduced via the umbilicus into the peritoneal cavity. We generally use a 5-mm laparoscope for patients under 10 to 12 years of age and find it acceptable to use a 10-mm laparoscope for older children.

On inspection of the peritoneal cavity, it is usually immediately obvious that there is some inflammation in the right lower quadrant. Occasionally fluid is seen in the pelvis. We use two additional cannulae to complete the operation; their size and location depend upon the technique. We prefer to place symmetrical cannulae in the right and left lower quadrants below the "bikini line," lateral to the epigastric vessels on either side. One 5-mm cannula and one 12-mm cannula appear adequate (Figure 26.1.2). To use the Endo GIA (US Surgical Corporation, Norwalk, CT) stapler, insert a 12-mm cannula into the left lower quadrant to ensure ample room for proper instrument placement and function. To mobilize the appendix, a 5-mm reducing cap must be used when 5-mm instruments are used with the larger cannulae, so that the pneumoperitoneum will not be lost.

The surgeon may begin with two tissue graspers, at least one of which has a ratcheted handle. With these graspers, the tissues are mobilized so the tip of the appendix can be secured (in one of the graspers) (Figure 26.1.3). A closed grasper is helpful, serving as a blunt dissector in a manner similar to using a finger for blunt dissection in open cases. This technique enables separation of inflammatory adhesions and fluid loculations to completely mobilize the appendix. Occasionally there will be some adhesions that necessitate being taken down sharply. Alternatively, a Metzenbaum style scissors can be used. Bipolar electrosurgery enables careful division of the adhesions while cauterizing any blood vessels to minimize bleeding. Once the appendix is mobilized and its junction with the base of the cecum can be clearly identified, the mesoappendix and the appendix can be divided.

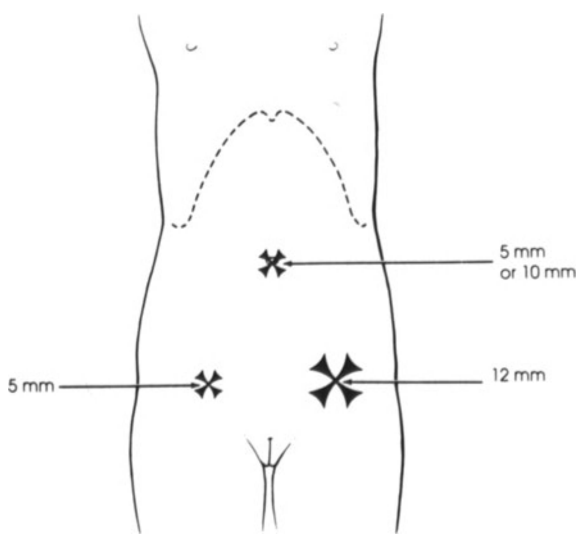

FIGURE 26.1.2. Trocar sites for pediatric laparoscopic appendectomy. (By permission of TE Lobe, KP Schropp (eds), *Pediatric Laparoscopy and Thoracoscopy,* Philadelphia: W.B. Saunders, 1993; p. 117.)

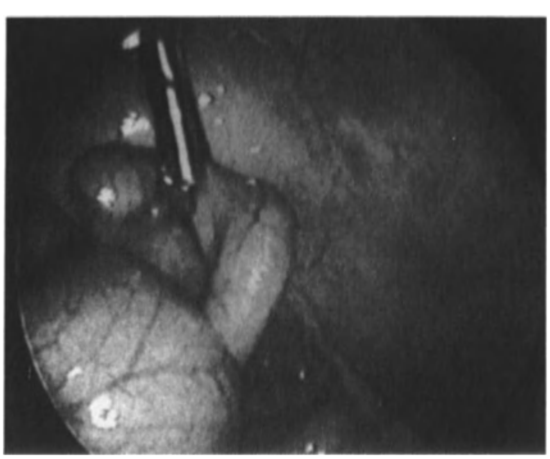

FIGURE 26.1.3. Appendix held by endoscopic grasper.

The Endo GIA stapler can be used to divide the mesoappendix and appendix individually. Use of vascular staples and replacement cartridges is feasible. The device is placed through a 12-mm left lower quadrant cannula and allows securing of the mesoappendix and appendix down to its junction with the cecum. At the same time, the tip of the stapler must be well identified and the line indicating the end of cut must be beyond the tissue (Figure 26.1.4). If the mesoappendix and the appendix are divided in one application of the stapler and the tissues are too thick or inflamed, there may be a leak at the junction of the mesentery and the appendiceal stump when the two structures are not divided separately. The jaws of the stapler are then closed; the surgeon must check to be certain of its position and be sure that there is no additional tissue or loop of bowel engaged in the device. Once the proper position is certain, the safety latch is released and the stapler fired.

With the appendix free, it can be extracted through the left lower quadrant 12-mm cannula so that the inflamed or contaminated tissue never touches the cannula tract to risk possible infection. If the inflamed appendix is so thick that it cannot be removed through the cannula, a tissue sac or sterile condom-like sac can be inserted through the

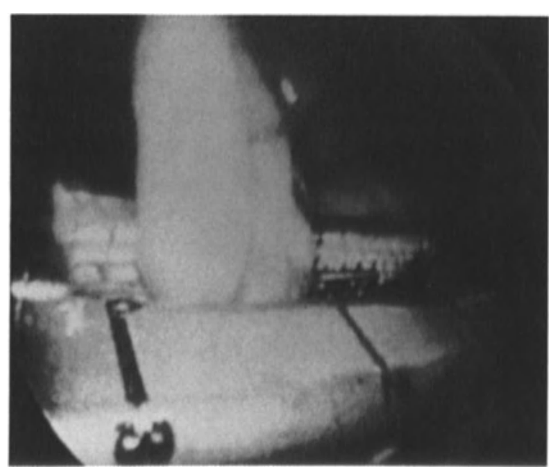

FIGURE 26.1.4. Laparoscopic view of Endo GIA applied to appendix showing the "cut" mark beyond the tissues to be divided. (By permission of TE Lobe, KP Schropp (eds), *Pediatric Laparoscopy and Thoracoscopy,* Philadelphia: W.B. Saunders, 1993; p. 118.)

right lower quadrant cannula, the appendix can be placed within it, and the sac or condom withdrawn into the cannula to its point of resistance (Figure 26.1.5). The cannula should be withdrawn completely so the neck of the sac or condom-like pouch is outside the abdominal wall. The sac or condom usually has enough lubrication from tissue fluids so that it can easily slip out through the incision, minimizing contamination of the cannula tract. After the sac is removed, the left lower quadrant trocar and cannula are reinserted, the surgical bed is inspected for hemostasis, and irrigated as necessary. If the surgeon feels uncomfortable leaving the appendiceal stump exposed, it can be inverted by placing a Z stitch or purse-string stitch, using standard laparoscopic suturing techniques. While this may be preferable to some surgeons, we have had no complications related to an exposed appendiceal stump when the procedures described previously have been carried out.

In cases of ruptured or gangrenous appendicitis, the surgeon must take care to watch for friable segments of the appendiceal wall through which a fecalith may extrude. A fecalith lost in the peritoneal cavity may be a nidus for abscess formation requiring subsequent intervention. In cases of ruptured appendicitis where an abscess is found, a Luken's trap is attached to the end of the suction device to obtain material for culture. At the end of the procedure, there must be copious irrigation of the peritoneal cavity with saline and then antibiotic solution. In cases of intra-abdominal inflammation, such as appendicitis, where frank pus is present, and irrigation is used to help cleanse the peritoneal cavity, the surgeon should be aware of the dependent position of the diaphragm or pelvis. If there is a large quantity of irrigation fluid that has not been adequately aspirated, there is potential risk for loculation of the fluid and abscess formation. After laparoscopic appendectomy, in cases of ruptured appendicitis for which an abscess is drained and the abdomen irrigated, the patient is placed in reverse Trendelenburg position at the end of the procedure to allow the irrigation fluid to run into the pelvis where it can be meticulously aspirated. Similarly, in cases of upper abdominal procedures where irrigation is used, the patient is placed in the Trendelenburg position at the end of the procedure, and may even be rotated to the right or to the left in a semidecubitus position, so that the fluid becomes dependent and can be completely aspirated.

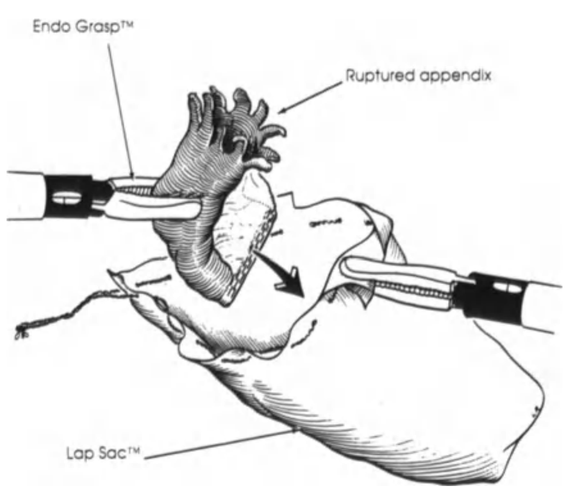

FIGURE 26.1.5. Extraction of the appendix using a sac. (By permission of TE Lobe, KP Schropp (eds), *Pediatric Laparoscopy and Thoracoscopy,* Philadelphia: W.B. Saunders, 1993; p. 118.)

The laparoscopic approach is advantageous in cases of abdominal pain when the diagnosis is unclear. Generally, we will perform an appendectomy and search for other causes of the symptoms. It is much easier to explore the abdomen with the laparoscope than through the conventional right lower quadrant incision. In little girls, the ovaries and tubes can be atraumatically manipulated and inspected. The bowel can be inspected in its entirety, looking for a Meckel's diverticulum or other pathology, and the upper abdomen evaluated for cholecystitis or abscess formation.

In cases of ruptured appendicitis with abscess, the laparoscopic procedure takes longer because it is necessary to dissect out the appendix and lyse the adhesion and loculations. Occasionally, in cases of retrocecal appendicitis, or where the tip of the appendix is markedly inflamed and involved in an inflammatory mass, retrograde removal of the appendix can be accomplished. Generally, this is achieved by either making an incision into the mesoappendix near the normal base and inserting the stapler at this juncture to divide the appendix, or simply dividing the appendix with the laser approximately 1 to 1.5 cm from its base. The ends are secured with Surgitie (US Surgical Corporation, Norwalk, CT) before grasping the resected end of the appendix and dissecting the appendix and its mesentery free.

After the procedure has been completed, the cannulae are removed and the wounds closed. Patients with ruptured appendicitis remain on antibiotics and nasogastric suction as in open appendectomy. Patients with acute simple appendicitis are allowed a regular diet and normal activity as tolerated, and are discharged either on the day of surgery or as soon thereafter as is feasible. Because there is no incision, patients may return to unrestricted activity immediately upon discharge.

Cholecystectomy

The laparoscopic cholecystectomy in children compares favorably with the procedure performed on adult patients.[10–14] A description of one method for cholecystectomy in the child follows. The surgeon positions himself to the patient's left. The scrub nurse stands next to the surgeon. The first assistant is across from the surgeon and the camera operator stands next to the first assistant (Figure 26.1.6). The patient is prepared for a laparoscopic procedure and the pneumoperitoneum is created in the standard fashion. A four-cannula technique is preferred (Figure 26.1.7). A 5-mm cannula is placed in the umbilicus for insertion of the laparoscope. Careful inspection of the liver and gallbladder allows for optimal insertion of the three operating cannulae. Different functions are performed through each of the cannulae, each of which determines cannula placement. The midclavicular cannula is placed initially. A grasper is inserted through this cannula and the fundus of the gallbladder is grasped. The fundus is pushed over the anterior edge of the liver. This exposes the triangle of Calot (Figure 26.1.8). This cannula site may be altered, depending on the position of the gallbladder. It may be lower on the abdomen in the smaller child.

The second 5-mm cannula is placed in the anterior axillary position. A grasper is positioned through this cannula and the gallbladder grasped at the junction of the body and neck. When this instrument is directed in a caudal and lateral direction, it exposes the structures in the hepatocystic triangle (Figure 26.1.9). As with the midclavicular port, it may be necessary to adjust the position of this cannula for smaller patients. It is sometimes desirable to reverse the roles of the graspers in the anterior axillary and midclavicular cannulae when retracting the gallbladder. It is helpful to use ratcheted instruments in these cannulae to make it easier for the assistant to hold retracted tissue securely.

The 10-mm cannula is placed in the subxyphoid position to the right of the falciform ligament in larger patients. The dissection and ligation of the cystic duct and artery will be performed through this cannula and the gallbladder is removed through this cannula. It is important that the instruments placed through this cannula in-

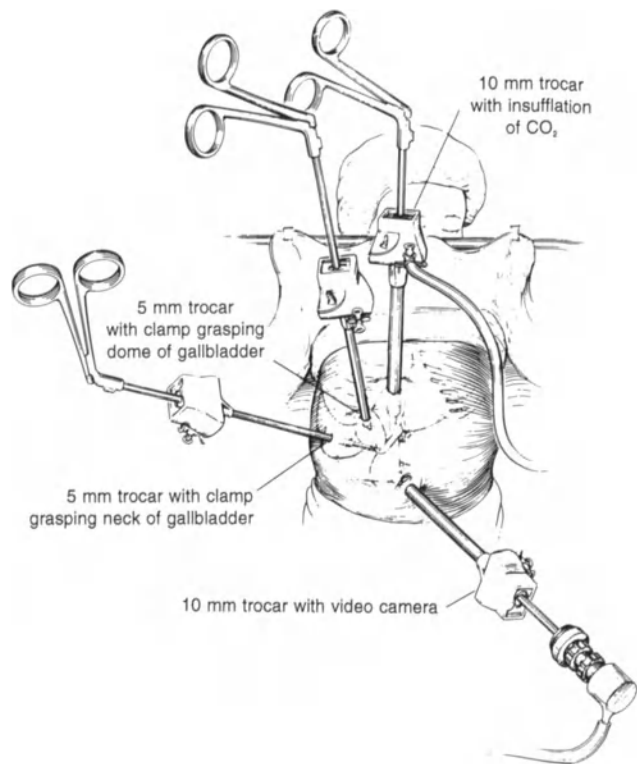

FIGURE 26.1.7. Port sites for laparoscopic cholecystectomy. (By permission of AM Davidoff et al., *Ann Surg,* 1992; 215:186.)

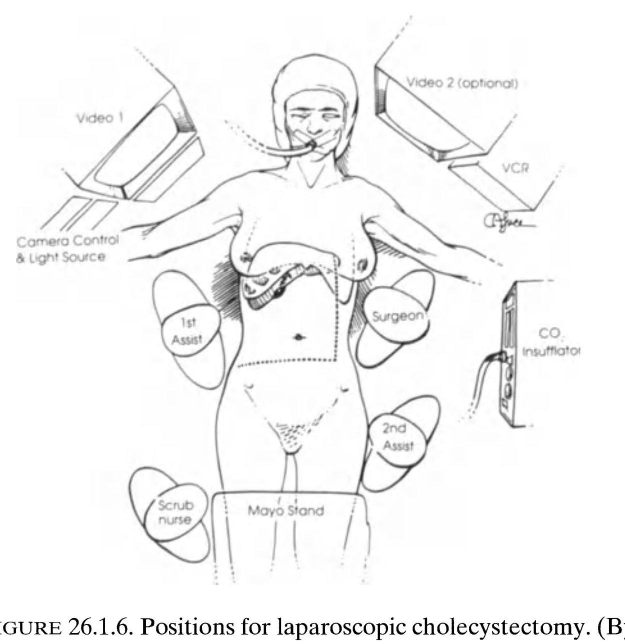

FIGURE 26.1.6. Positions for laparoscopic cholecystectomy. (By permission of BD Schirmer et al., *Ann Surg* 1991; 213:665.)

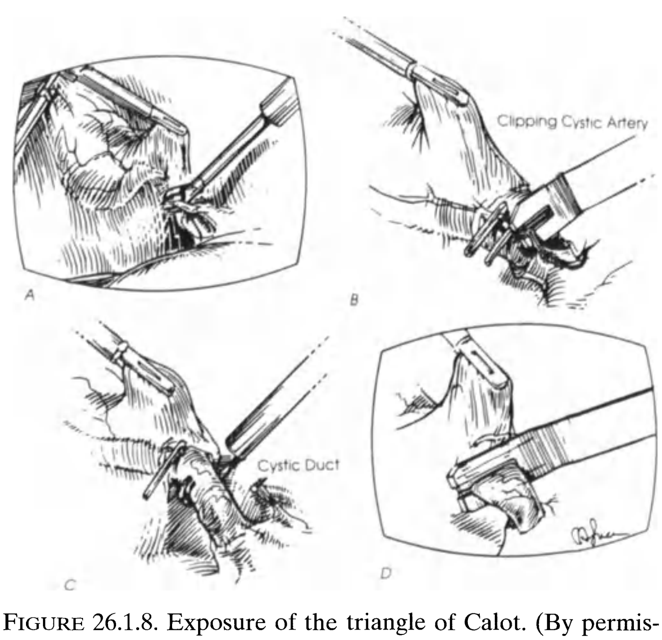

FIGURE 26.1.8. Exposure of the triangle of Calot. (By permission of BD Schirmer et al., *Ann Surg* 1991; 213:665.)

tersect the cystic duct at a 60 or 90° angle. To obtain this angle, it may be necessary to place this cannula to the left of the falciform ligament in smaller patients. The dissector can be passed below the ligament so the falciform ligament can be divided.

Adhesions to the gallbladder are dissected free. The cystic artery is separated from the cystic duct. The surgeon must ensure that the cystic artery, duct, and right hepatic artery are clearly identified before any structure is divided. The cystic artery is ligated with use of four clips, then divided with laparoscopic scissors between the two sets of two clips. The cystic duct is separated from the surrounding structures by blunt dissection. Two clips are then placed on the distal cystic duct in preparation for the cholangiogram.

Cholangiography may be performed by one of several methods. Commercial catheters have been produced that can be passed through one of the cannulae. Unfortunately, this results in a loss of exposure as one of the graspers must be removed. An 8- or 12-in. long, 16- to 18-gauge intravenous cannula, or the outer sheath of a Veress needle, can be placed directly through the abdominal wall, just below the edge of the liver, between the anterior axillary and midclavicular cannulae or needle. A cholangiogram catheter can be passed through this cannula (Figure 26.1.10). An incision is made in the exposed cystic duct and the catheter is advanced into its lumen. Clips are placed around the catheter to secure it in the duct. After the cholangiogram is obtained, the clips and catheter are removed. The clips are reapplied and the duct is divided. Cannulation should be accomplished well away from the junctions of the common bile duct and the cystic duct.

After the cystic duct is ligated, the divided end is grasped and retracted toward the patient's right shoulder. The gallbladder is then dissected free from the liver, using a combination of laser or electrosurgery and blunt dissection. When dissection reaches the point at which only the peritoneum attaches the gallbladder to the liver, the ligated cystic artery and duct are carefully inspected and the gallbladder bed is examined for bleeding (Figure 26.1.11). If this is not done before division of the peritoneal attachments, it is difficult to regain exposure of these areas. The intra-abdominal pressure should be lowered to < 8 torr because venous bleeding may be tamponaded at higher pressures. The last of the peritoneal attachments are divided and the gallbladder is removed through the 10-mm subxyphoid cannula site. This is achieved by grasping the gallbladder at the cystic duct and pulling the gallbladder through the cannula. If this is not possible, the cannula is removed while maintaining the grasp on the cystic duct. The gallbladder can then be pulled through the fascial defect. If large stones are present, the

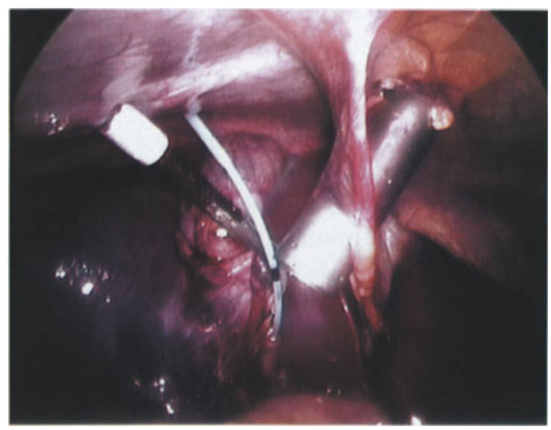

FIGURE 26.1.10. Cholangiogram catheter passed through percutaneously placed angiocath into bile duct.

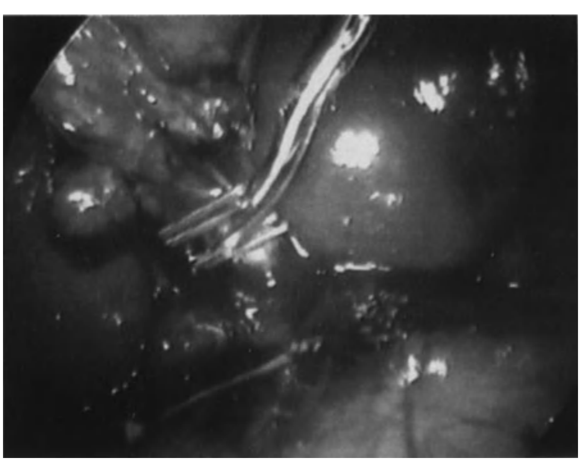

FIGURE 26.1.9. Exposure and division of the structures in the hepatocystic triangle of an inflamed gallbladder in a child with sickle cell disease.

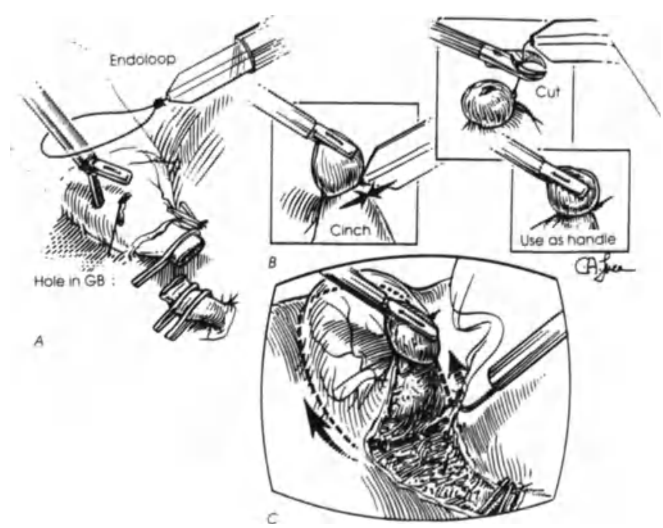

FIGURE 26.1.11. Examination of liver bed for control of hemorrhage. (By permission of BD Schirmer et al., *Ann Surg* 1991; 213:665.)

gallbladder may be opened, the stones crushed or removed with a large clamp, and then removed (Figure 26.1.12).

Undescended Testicles

Laparoscopy for cryptorchid testes is rapidly becoming the standard of care for this condition.[15–22] Patients with bilateral cryptorchidism or with a unilateral nonpalpable testis benefit from laparoscopy in several ways. In unilateral disease, the differential diagnoses include undescended testis versus testicular atrophy. At laparoscopy, the surgeon can visualize the testicle in the inguinal canal or abdomen. In cases of testicular atrophy, the testicular vessels and vas deferens ending blindly just at the internal inguinal ring can be noted. This observation, coupled with no palpable tissue in the inguinal canal or scrotum, indicates that testicular atrophy has occurred. Usually this is due to an intrauterine torsion. Laparotomy is not required in this case. With bilateral disease, the surgeon can determine whether or not the testes are present and whether or not they lie in proximity to the inguinal canal or are in a high intra-abdominal location.

A CO_2 pneumoperitoneum is established and a 5-mm umbilical cannula is placed for passage of the 4- or 5-mm laparoscope. Simple inspection of either or both internal inguinal rings provides the required information in most cases. For the high intra-abdominal testis, one option is to do a high ligation of the spermatic vessels and to displace the testis down to the internal inguinal ring, securing it there with a clip or sutures for orchidopexy six weeks later. The patient is maintained in Trendelenburg position and is rotated with the side opposite the cryptorchid testicle down. The testicle and its pedicle can be identified. A small incision is made over the proximal spermatic vessels, just enough to isolate them, and they are divided between surgical clips or suture ligated, depending on the preference of the surgeon (Figure 26.1.13). The peritoneum can then be incised toward the pelvis sufficiently to displace the testicle to the internal inguinal ring and secure it in position. This can either be accomplished by suture technique or the gonad can be clipped or stapled in place (Figure 26.1.14). Alternatively, a laser can be used to divide the testicular vessels without risking harm to adjacent structures.

After six weeks, sufficient vascular collateralization is likely to have occurred such that an inguinal orchidopexy can be performed. While it is too early to tell what the long-term results of this technique will be, there is minimal disruption of the collateral vascular supply, and therefore this approach is appealing. Unfortunately, the available experimental data suggest that while the testis is viable after spermatic vessel ligation, its endocrine and reproductive capacity may be impaired. After simple inspection or relocation of the testis, the cannulae are removed and the wounds closed as described above.

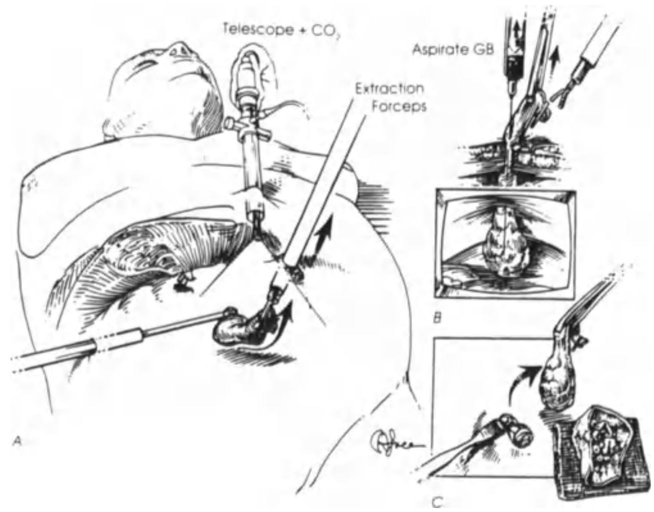

FIGURE 26.1.12. Technique for removing gallstones from bladder. (By permission of BD Schirmer, et al., *Ann Surg* 1991; 213:665.)

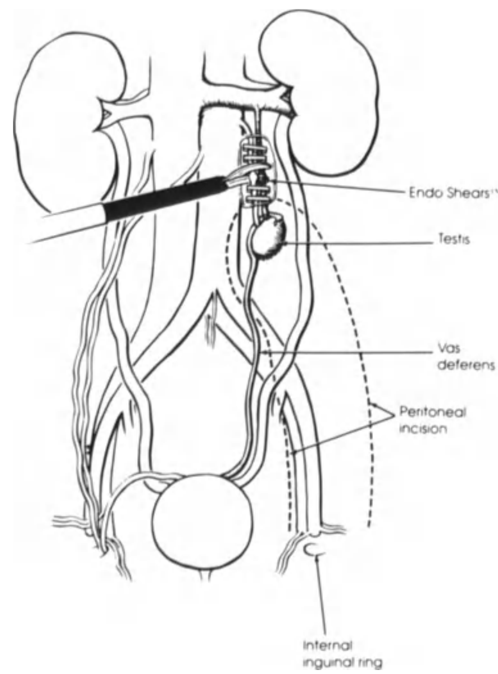

FIGURE 26.1.13. Endoscopic clip applied to testicular vessels below renal hilum. (By permission of TE Lobe, KP Schropp (eds), *Pediatric Laparoscopy and Thoracoscopy,* Philadelphia: W.B. Saunders, 1993; p. 137.)

Varicocele

Pediatric surgeons often see varicoceles in older children and adolescents presenting with pain or concern over a bulging mass in the scrotum. The diagnosis is frequently obvious. Alternatives to management include operative ligation of the spermatic vein and the pampiniform plexus, venous immobilization using imaging techniques, and direct ligation via laparoscopy. Laparoscopic division of the veins is a simple procedure and can be performed as an outpatient with minimal morbidity.[23] The technique follows.

A CO_2 pneumoperitoneum is established. The patient is maintained in the Trendelenburg position, and the initial 5-mm cannula is placed through the umbilicus. Two additional cannulae are required: one 5-mm cannula in the lower abdomen in the quadrant on the side of the lesion and the other either in the midline or the opposite lower quadrant. This is usually a 10-mm cannula for passage of the clip applier (Figure 26.1.15). After establishing a pneumoperitoneum, the testicular vessels are identified as they enter the internal ring. The peritoneum over these vessels is gently incised and retracted out of the way, exposing the vas deferens and vessels. By using a fine-tipped dissector and positioning the end of the laparoscope close to the vessels, the artery and vein are dissected free from each other. Once the vein is identified and is separated from the artery, it can be ligated with clips or sutured and divided as deemed necessary. Personal preference is for simple ligation with clips (Figure 26.1.16). Reperitonealization is not necessary. The surgeon must make certain that there is no perioperative hemorrhage, withdraw the cannulae, and close the abdominal wounds.

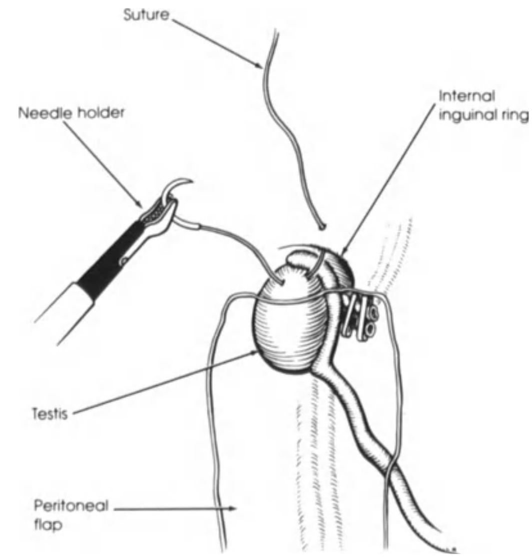

FIGURE 26.1.14. Gonad secured to internal inguinal ring. (By permission of TE Lobe, KP Schropp (eds), *Pediatric Laparoscopy and Thoracoscopy,* Philadelphia: W.B. Saunders, 1993; p. 138.)

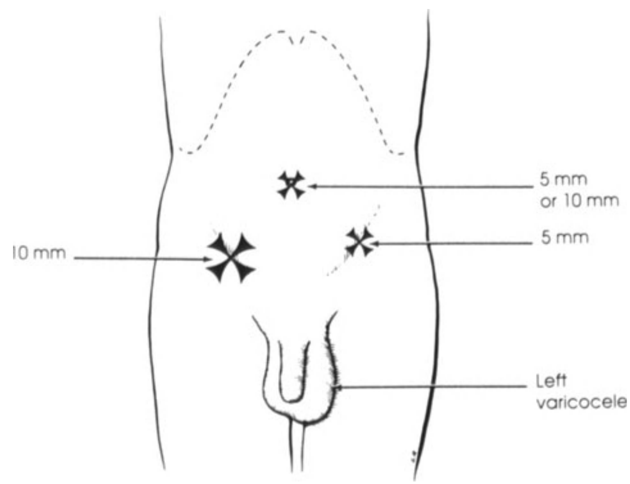

FIGURE 26.1.15. Port sites for left varicocele ligation. (By permission of TE Lobe, KP Schropp (eds), *Pediatric Laparoscopy and Thoracoscopy,* Philadelphia: W.B. Saunders, 1993; p. 140.)

Nissen Fundoplication

The laparoscopic approach to Nissen fundoplication is not new. Dallemagne first performed a laparoscopic Nissen fundoplication at the Clinique Saint Joseph in Liege, Belgium in January 1991.[24] Later that year, Geagea performed a similar procedure in Nova Scotia.[25] Cuschieri and colleagues began performing laparoscopic antireflux surgery in 1989. This group of surgeons has described their technique in eight elderly patients, ranging in age from 60 to 79 years, with a mean follow-up of 11 months.[26] Dallemagne has performed numerous procedures in patients ranging from 29 to 69 years of age. His mean operative time is 1.5 to 2 hours. Most patients eat and drink on the first postoperative day and are discharged on the second postoperative day. His results to date are similar to those achieved by laparotomy. While some adult patients have early, transient dysphagia, their postoperative course is described as benign and uneventful.

The indications for performing a laparoscopic antireflux procedure for gastroesophageal reflux in children are the same as those for the open approach. The theoretical advantages of the laparoscopic approach are related to the absence of an abdominal incision. In obese patients, an incision is more likely to develop a wound complication and it may impair postoperative pulmonary function. In the debilitated child, particularly those with severe mental retardation or those who cannot follow instructions, the incision may impair pulmonary function and predispose the patient to atelectasis or pneumonia.

One accepted technique involves placing five cannulae into the abdomen: one for viewing with the telescope, one for retracting the liver, two for tissue manipulation, and one for suturing. The operation is identical to that performed via laparotomy: the liver is retracted away from the esophageal hiatus, the esophagus is mobilized, the diaphragmatic crura are approximated with sutures, the

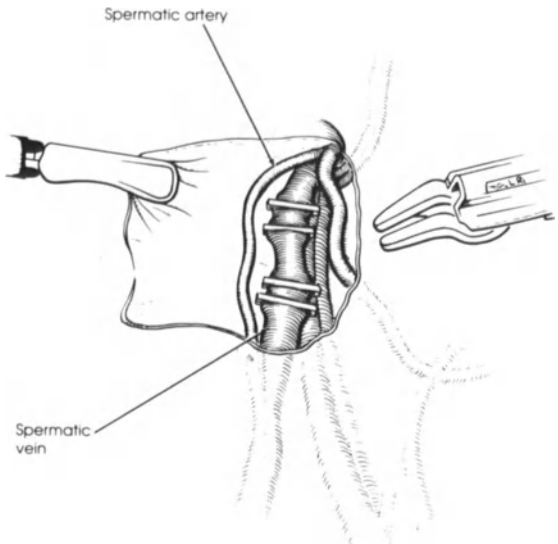

FIGURE 26.1.16. Clips on abnormal veins for varicocele ligation. (By permission of TE Lobe, KP Schropp (eds), *Pediatric Laparoscopy and Thoracoscopy,* Philadelphia: W.B. Saunders, 1993; p. 140.)

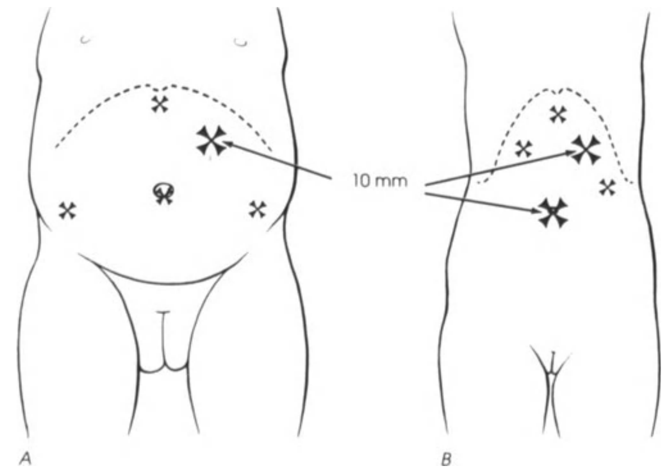

FIGURE 26.1.17. Port sites for Nissen fundoplication. (By permission of TE Lobe, KP Schropp (eds), *Pediatric Laparoscopy and Thoracoscopy,* Philadelphia: W.B. Saunders, 1993; p. 169.)

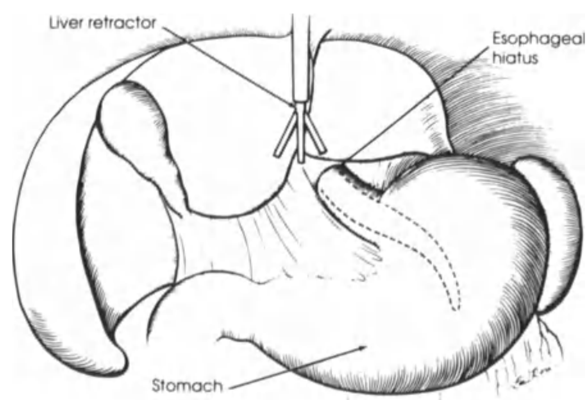

FIGURE 26.1.18. Exposure of esophageal hiatus for Nissen fundoplication. (By permission of TE Lobe, KP Schropp, K Lundsford. *J Pediatr Surg* 1993; 28:358.)

short gastric vessels are divided as necessary, a 360° fundoplication wrap is sutured into position, and a gastrostomy is placed as necessary.

Patients are best prepared for the operation by emptying their colon of gas and feces before the operation. Otherwise, the gas-distended colon is in the way and makes the procedure difficult, if not impossible. Under general endotracheal anesthesia, the bladder is catheterized or emptied via a Crede maneuver, and a nasogastric tube is passed Some surgeons prefer to place the patient in lithotomy position so that the camera operator can stand between the legs and out of the way. This position is better suited to older or obese children or teenagers. Using sterile technique, a CO_2 pneumoperitoneum is established and maintained, and a 5- or 10-mm 0° laparoscope is passed via an umbilical cannula. A 5-mm cannulae is placed below the right costal margin in the midclavicular line, and another placed in the epigastrium. A 10-mm cannula is placed in the left midclavicular line below the costal margin, and a 5-mm cannula is located in the left anterior axillary line below the costal margin (Figure 26.1.17). The liver is retracted via the epigastric cannula to expose the esophageal hiatus (Figure 26.1.18). In larger patients, a retractor may be necessary, while in smaller patients, the cannula itself is sufficient to hold the liver out of the way. The short gastric vessels are divided between surgical clips as necessary (Figure 26.1.19). We apply two medium-length clips on either side of the proposed line of division. The reticulating Endodissect (US Surgical Corporation, Norwalk, CT) is ideal for isolating these vessels. The esophagus, with as large a bougie in place as it will accommodate, is mobilized and retracted using dissecting instruments passed via the right and left lateral cannula. A short segment of umbilical tape is then passed behind the esophagus as illustrated (Figure 26.1.20). The exposed diaphragmatic crura are approximated to close the hiatus using interrupted 2–0 silk sutures that have been lubricated with mineral oil. We believe that extracorporeal knots are the easiest for securely tying under tension. Intracorporeal knot tying is an option if one is sufficiently skilled in this technique. The stomach is passed behind the esophagus from the patient's left to right. With the stomach held in position using an instrument passed from the right midclavicular line cannula, a back-handed suture is used to "snag" the stomach and to complete the first (distal-most) suture of the wrap. This maneuver saves having to put in another cannula. The 3- to 5-cm wrap is then secured into place using interrupted 2–0 silk sutures as for an open procedure (Figure 26.1.21). The esophageal bougie and the cannulae are then removed.

Of our first 12 laparoscopic Nissen fundoplications, ages ranged from 3 months to 11 years, and the children weighed from 2.5 to 53 kg (2 were female and 10 male). Our first three attempted procedures were converted to an open procedure because the proper instruments were not available (one case), a patient was discovered to have portal hypertension, and the procedure was aborted (one case), and an opening was made in the posterior esophagus that we preferred to repair using open techniques (one case). Since these initial cases, none have required conversion to laparotomy.[27]

Gastrostomies were placed in all but one patient. Initially, we used a percutaneous endoscopic technique while observing the stomach with the laparoscope (Figure 26.1.22). The laparoscope was used to determine the optimal position of the gastrostomy, grasping the correct spot on the anterior gastric wall (Figure 26.1.23), and externalizing the stomach through the subcostal midclavicular line trocar site (Figure 26.1.24). The gastrostomy is

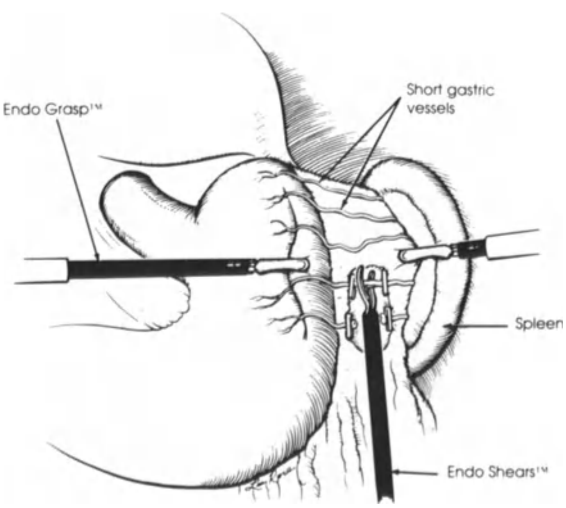

FIGURE 26.1.19. Division of short gastric vessels for Nissen fundoplication. (By permission of TE Lobe, KP Schropp, K Lundsford. *J Pediatr Surg* 1993; 28:358.)

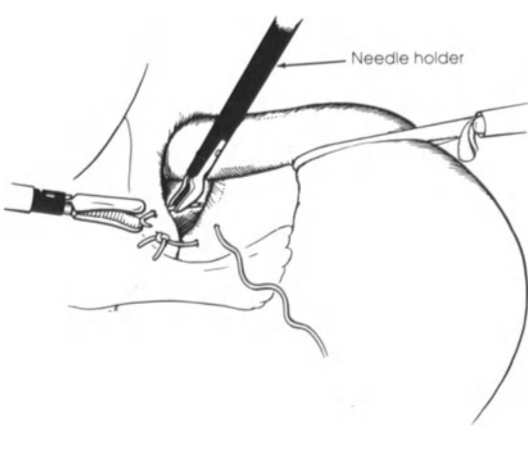

FIGURE 26.1.20. Umbilical tape around the esophagus for control and mobilization of the esophagus for Nissen fundoplication, in order to place sutures closing hiatus. (By permission of TE Lobe, KP Schropp, K Lundsford. *J Pediatr Surg* 1993; 28:358.)

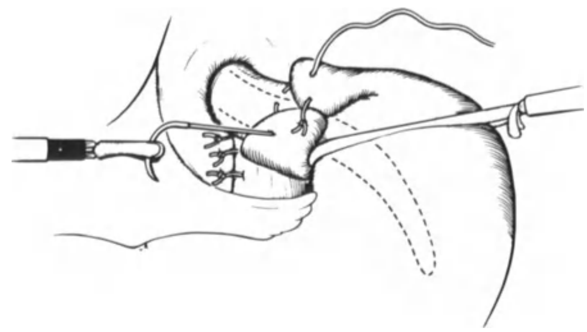

FIGURE 26.1.21. Sutures placed in stomach to secure 360° wrap. (By permission of TE Lobe, KP Schropp, K Lundsford. *J Pediatr Surg* 1993; 28:358.)

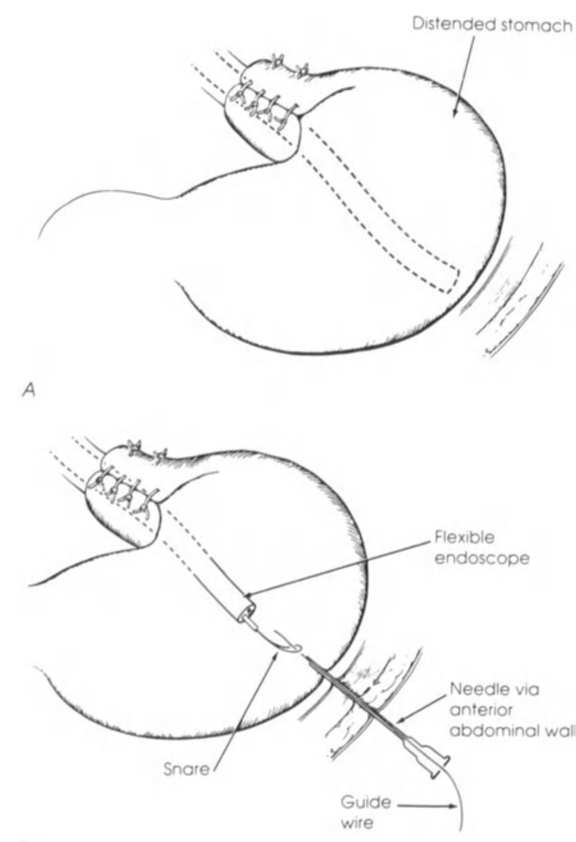

FIGURE 26.1.22. Percutaneous endoscopic gastrostomy under laparoscopic control. (By permission of TE Lobe, KP Schropp (eds), *Pediatric Laparoscopy and Thoracoscopy,* Philadelphia: W.B. Saunders, 1993; p. 175.)

FIGURE 26.1.23. Identification of G-tube site viewed endoscopically.

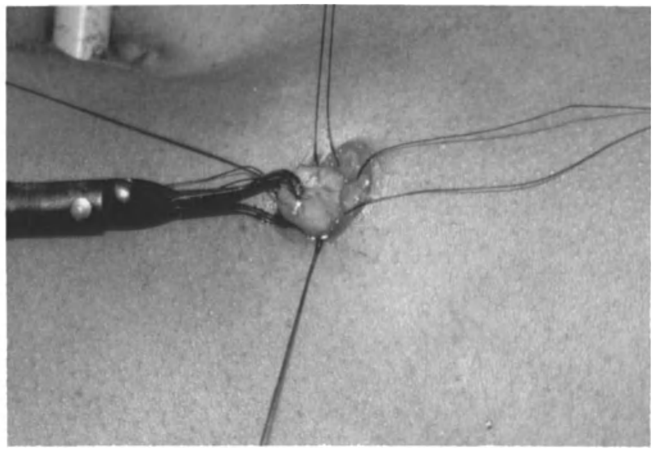

FIGURE 26.1.24. Stomach externalized through 10-mm port site to suture a Stamm gastrostomy.

then sutured into place after the fundoplication is completed (Figure 26.1.25). Because of a lack of suitable small instruments, the procedure is more difficult in infants weighing < 3 kg, and we prefer the conventional approach for these patients.

Postoperatively, patients are fed liquids on the evening of their surgery and a full diet (by tube or by mouth) postop day 1. They are generally discharged between 32 and 48 hours after surgery at which time they can return to unrestricted activities. No complications were noted in the series. Follow-up to 18 months shows the patients all to be asymptomatic for gastroesophageal reflux, and all of the fundoplications remain intact.

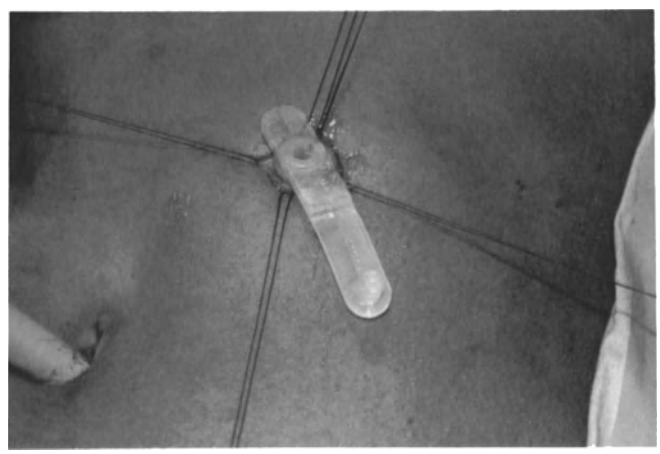

FIGURE 26.1.25. Gastrostomy being sutured in place after Nissen fundoplication.

Inguinal Herniorrhaphy

Many general surgeons believe that the laparoscopic repair of inguinal hernias in adults is an acceptable procedure. While many of these procedures are being performed today, the technique has not withstood the test of time and may not be as durable as an open inguinal repair. The adult repair consists of incising the peritoneum anterior to the hernia defect, excising the sac, inserting a roll of polypropylene mesh into the inguinal defect, tacking a piece of polypropylene mesh over the defect using a hernia stapler, and reperitonealizing the repair.

Routine laparoscopy usually proves useful in the management of inguinal hernias in children when trying to determine whether or not a hernia is present on the asymptomatic contralateral side.[28] A 3-mm cannula is inserted through an umbilical stab wound after insufflating the infant's abdomen to 8 to 10 torr with CO_2. A 2-mm 0° telescope (the same scope used by pediatric surgeons for cystoscopy or bronchoscopy) can be used to inspect the lower abdomen (Figure 26.1.26). Hernias are obvious

FIGURE 26.1.26. A 2-mm 0° telescope used for hernia exploration. (By permission of TE Lobe, KP Schropp (eds) *Pediatric Laparoscopy and Thoracoscopy,* WB Saunders, 1993; p. 157.)

when they are identified (Figure 26.1.27). A patent processus vaginalis or the neck of a small hernia sac can also be identified when present (Figure 26.1.28). Inguinal hernias have been repaired laparoscopically and appear to be a reasonable approach in older children. Essentially the same principles as other repairs of indirect inguinal hernias in children apply. The hernia sac is divided and the neck of the sac obliterated.

Repair is carried out with the patient in Trendelenburg position and three cannulae placed. An umbilical cannula is used for the laparoscope. Two other cannulae are inserted lateral to the rectus muscle, at or slightly above the level of the umbilicus—one on either side of the abdomen. The peritoneum is incised as in the adult repair. The hernia sac is then divided, taking care not to injure the cord structures which are easily identified. The distal sac can either be removed or left *in situ.* The hernia defect is sutured using interrupted, nonabsorbable sutures. The peritoneum is then sutured closed. Patients are discharged on the day of surgery and instructed to return to unrestricted activities. Our series now includes over 100 cases; we have not missed the diagnosis of an inguinal hernia, nor have we had any recurrent hernias.

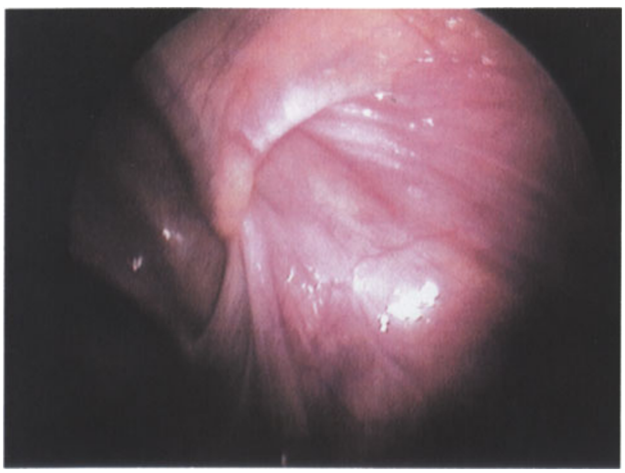

FIGURE 26.1.27. Right inguinal hernia.

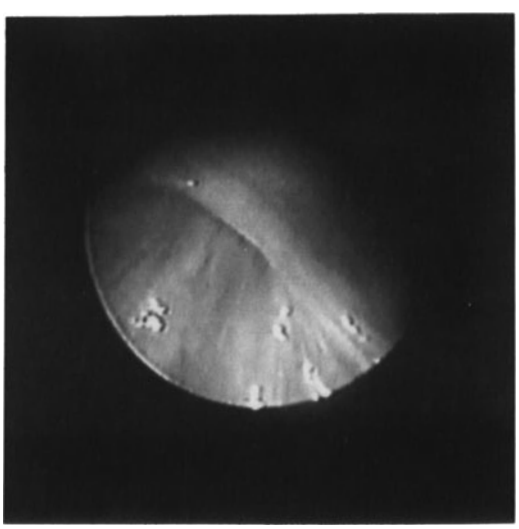

FIGURE 26.1.28. Patent processus vaginalis. (By permission of TE Lobe, KP Schropp (eds) *Pediatric Laparoscopy and Thoracoscopy,* WB Saunders, 1993; p. 158.)

Mesenteric Cysts

Many mesenteric cysts can be diagnosed preoperatively with use of diagnostic imaging. When a cyst is identified and it appears relatively free from other structures, it is easily amenable to laparoscopic intervention (Figure 26.1.29). Diagnostic laparoscopy is begun through an umbilical cannula. If the cyst is large enough to obstruct the view, and it is unlikely to be malignant, a needle can be inserted through the abdominal wall directly into the cyst to allow decompression. If the cyst is on a pedicle, it can usually be excised using laser, electrosurgical techniques, endoscopic sutures or loops, or mechanical devices such as clips or staplers.

Cysts buried in the mesentery or omentum can be dissected free and similarly excised. Decompression of the cyst may help with its removal via the laparoscopic cannula. Rarely, a cyst can be so intimately involved with an adjacent loop of bowel that a bowel resection may be necessary to remove the cyst. This, too, can be accomplished laparoscopically using the new linear staplers, if the laparoscopist is appropriately experienced.

Chronic Pelvic Pain

The diagnosis of pelvic pain in the adolescent is frequently clinically challenging and oftentimes a dilemma. Chronic pelvic pain (CPP), by definition, requires six or more months of persistent lower abdominal pain. The usual scenario is a distraught patient and parents making multiple visits to the physician's office in an effort to learn the underlying etiology of the pelvic pain. CPP should be subclassified into *primary* in which there is no clear underlying etiology versus *secondary* which is associated with an obvious cause.

The initial evaluation requires a thorough history and physical examination. The history should include information regarding any gastrointestinal problems such as spastic colon, chronic constipation, regional enteritis, etc. When evaluating the genitourinary system, the physician should look for evidence of recurring cystitis or gynecologic disorder such as persistent vaginal discharge, which may lead to upper and lower reproductive tract infection. The patient should be asked about dysmenorrhea. Pubertal milestones are also important, especially in an effort to determine any outflow tract obstruction that may be associated with hematocolpos, hematometra, hematosalpinx, and endometriosis, the latter a reflection of retrograde menstruation. Childhood diseases rarely cause pelvic pain. However, entities such as mumps oophoritis should be considered. A general physical exam is mandatory, complemented by a pelvic exam to include any evidence of pelvic mass, tenderness, uterine anomaly, or cul-de-sac abnormality.

Diagnostic laparoscopy is an integral part of the assessment of pelvic pain in the adolescent. Goldstein and coworkers evaluated 109 adolescent patients with CPP and noted endometriosis to be present in 49 (45%), with the youngest child being 10.5 years of age.[29] Other findings include postoperative adhesions in 17 (16%) and congenital anomalies of the uterus in 10 (9%). Pelvic inflammatory disease and associated adnexal adhesions were found in (10) 9% and a chronic hemoperitoneum in (6) 5%. Other sources of CPP are associated with functional ovarian cysts (5%); 11 (10%) were noted to have no pelvic abnormalities. "Miscellaneous" findings accounted for the remainder of the patients. The clinician should understand the importance of a logical-systematic approach to evaluation and management of CPP in this age group. An attempt should be made to correct any abnormal pelvic findings noted at the time of laparoscopy. A number of studies have been published with respect to the finding of endometriosis in the adolescent patient, and these are addressed in Table 26.1.2. Work has been published regarding the finding of endometriosis in association with an outflow tract obstruction, and creation of a patent tract has been associated with virtually 100% reversal of the endometriosis.[30]

Lysis of Adhesions

Pelvic or abdominal pain may be associated with complete intestinal obstruction in which the abdomen is maximally distended; laparoscopy may be difficult or impossible. When the obstructed loops of bowel are partially decompressed, however, and it is possible to establish an adequate pneumoperitoneum, laparoscopy can be used to divide the adhesions that caused the obstruction (Figure 26.1.30).

We prefer to use the open, or Hasson, technique to establish access to the peritoneal cavity.[31] After the initial inspection, it may be obvious where the source of obstruction is located. When this is not the case, insert one or two additional trocars to run the bowel. This maneuver facilitates evaluation and correction is best begun at either the ligament of Treitz or the ileocecal valve, whichever is easier to identify. Using two atraumatic graspers, the bowel is run until the point of obstruction is identified. When the adhesion is identified, it can be divided

FIGURE 26.1.29. Endoscopic view of large mesenteric cyst.

using electrosurgical techniques, or it can be divided between clips or with a stapler. If a compromised loop of bowel is noted that requires resection, the surgeon can perform this laparoscopically.

Patients diagnosed with a Meckel's diverticulum can be managed laparoscopically. These patients fall into two categories, those that present with obstruction or inflammation, and those that present with hemorrhage. Either group is usually diagnosed inadvertently at exploration, and can be resected. Those who present with hemorrhage are usually diagnosed preoperatively by imaging studies that demonstrate either acute hemorrhage or ectopic gastric mucosa.

When a Meckel's diverticulum is found, it can be resected in one of two ways. If it is broad based and its aberrant gastric mucosa is in its tip as opposed to its junction with the small bowel, it can be resected easily by transection across its base, using the linear stapler (Figure 26.1.31). In these cases, it is imperative that the surgeon inspect the removed specimen to ensure that the offending aberrant tissue is removed in its entirety. When the diverticulum is short, broad based, or aberrant tissue is suspected at its junction with the small bowel, a bowel resection will be required. This can be accomplished either by exteriorizing the diverticulum and performing the resection in a standard fashion, or laparoscopic techniques using the linear stapler can be used.

Hepatic and Splenic Cysts

Occasionally, cystic lesions of the liver will be observed and require intervention. Like other cystic lesions, they can either be excised or fenestrated using the techniques previously described. A laser can be used to unroof the cyst and then obliterate its lining. When infection is a

TABLE 26.1.2. Laparoscopic findings in adolescents with CPP.

Study	No visible pathology No.	No visible pathology %	Endometriosis No.	Endometriosis %	Adhesions No.	Adhesions %	Chronic PID No.	Chronic PID %	Ovarian cysts No.	Ovarian cysts %	Pelvic varicosities No.	Pelvic varicosities %	Myomas No.	Myomas %	Other No.	Other %	Total no.
Goldstein et al., 1980[34]	19	14	66	47	18	13	10	7	5	4	0	0	0	0	22	15	140
Chatman & Ward, 1982[35]	5	12	28	65	1	2	10	22	0	0	0	0	0	0	0	0	43
Vercellini et al., 1989[13]	19	40	18	38	2	4	1	2	1	2	0	0	0	0	6	13	47

Reprinted from Howard, Fred M. The role of laparoscopy in chronic pelvic pain: promise and pitfalls. *Obstet Gynecol Survey,* 1993; 48(6):357–87.

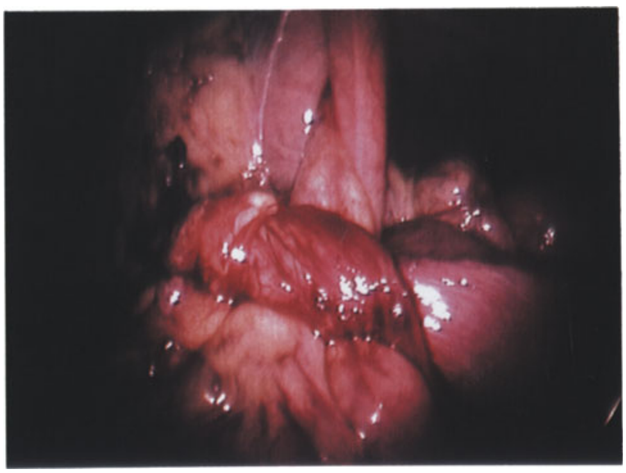

FIGURE 26.1.30. Adhesions causing a small obstruction in a 2-year-old-child. (By permission of TE Lobe, *Laparoscopic Surg,* 1993; 1:3.)

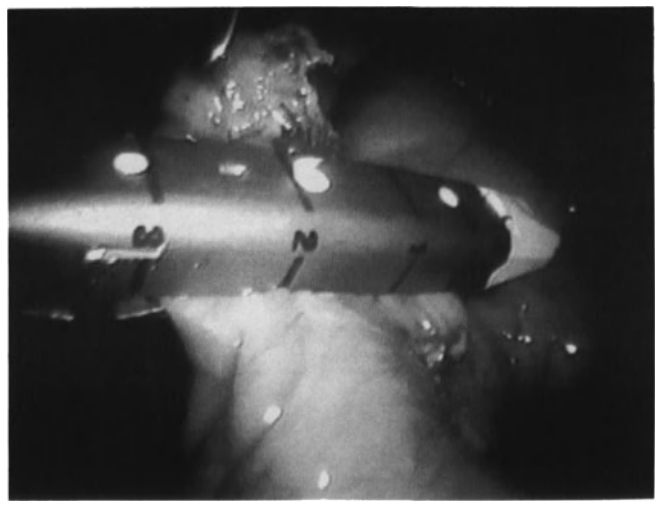

FIGURE 26.1.31. Resection of a Meckel's diverticulum with an Endo GIA stapler (US Surgical Corporation, Norwalk, CT).

consideration, cultures can be obtained with use of a drainage tube placed directly, using the laparoscope as a guide.

While splenic cysts are uncommon, simple epidermoid cysts are ideal for laparoscopic correction. We have treated one such cyst in a teenage girl using four cannulae to complete the procedure. A 10-mm umbilical cannula was used to visualize the cyst. Two 5-mm cannulae were placed in the lower abdominal crease on either side of the rectus muscle to manipulate the tissues. To complete the procedure, an additional cannula was required. This was placed in the right midclavicular line, midway between the umbilicus and the costal margin. Initially, the cyst was inspected. By all criteria (Figure 26.1.32) it appeared to be a simple cyst without evidence of infection. The Veress needle was placed through a separate stab wound immediately over the presenting portion of the cyst to puncture the wall and aspirate its contents. Serous fluid was removed, thus supporting the diagnosis of a simple cyst without infection. The cyst wall was then excised using bipolar cautery to remove the lining at its junction with the spleen. The entire presenting wall of the cyst was removed. One segment of the posterior wall appeared to be thicker than the rest. This was transected using the Endo GIA stapler. The lining of the cyst had some shallow trabeculations and appeared to overlie the splenic

FIGURE 26.1.32. Demonstration of a splenic cyst as viewed endoscopically.

hilus. It was not worthwhile to attempt to strip the lining from the cyst for fear of inducing hemorrhage, necessitating a splenectomy.

Splenectomy

Laparoscopic splenectomy is a procedure that shows promise for adolescent patients. Generally, these are performed on patients with hematological disorders. The indications are determined by their primary disease. Patients are prepared for the fundoplication, and they are vaccinated preoperatively with the appropriate polyvalent vaccines against pneumococcus and *Haemophilus influenzae.* Depending upon the size of the patient, a 5- or 10-mm laparoscope is placed through an umbilical cannula. Steep Trendelenburg is required. The patient is slightly rotated with the left side elevated. Cannula placement is essentially a mirror image of that required for laparoscopic nephrectomy (see following) (Figure 26.1.33). Two cannulae are placed: one 10-mm in the midclavicular line, and one 5-mm in the midclavicular line at or below the level of the umbilicus. The child is placed in a left lateral decubitus position and two 5-mm cannulae are placed in the anterior axillary line, one below the costal margin, and one between the umbilicus and the iliac crest.

Initially, the greater curvature of the stomach is grasped gently with an atraumatic grasper or Babcock clamp and the gastrosplenic ligament retracted to expose the short gastric vessels. The short gastric vessels are then divided between surgical clips, with the clip applicator passed through the 10-mm midclavicular cannula (Figure 26.1.34).

As the dissection progresses, it is helpful to rotate the patient to a more anterior position to allow the intestines to fall out of the way. Using instruments passed through the lateral cannulae, the spleen is elevated, and the splenic artery and vein at the hilum, just beyond the tail of the pancreas, identified using gentle dissection with a curved or right-angle dissector. The splenic hilum is then isolated and the vasculature controlled with an Endo GIA stapler that is used to divide both vessels simultaneously (Figure 26.1.35). This device provides excellent hemostasis and diminishes operative time significantly.

After the major splenic vessels have been divided,

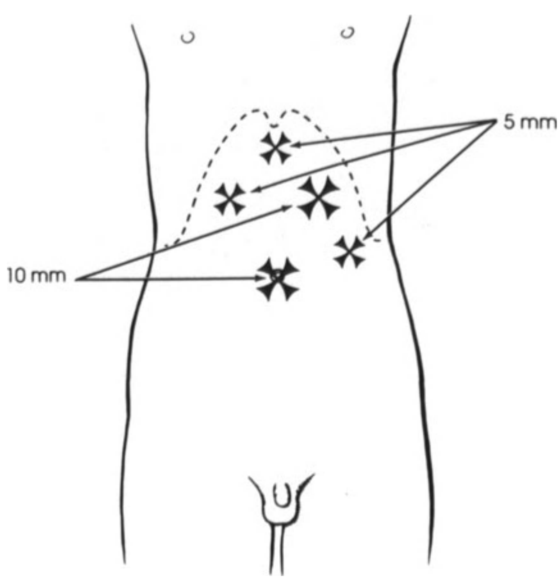

FIGURE 26.1.33. Port site placement for laparoscopic splenectomy. (By permission of TE Lobe, KP Schropp (eds), *Pediatric Laparoscopy and Thoracoscopy,* Philadelphia: W.B. Saunders, 1993; p. 191.)

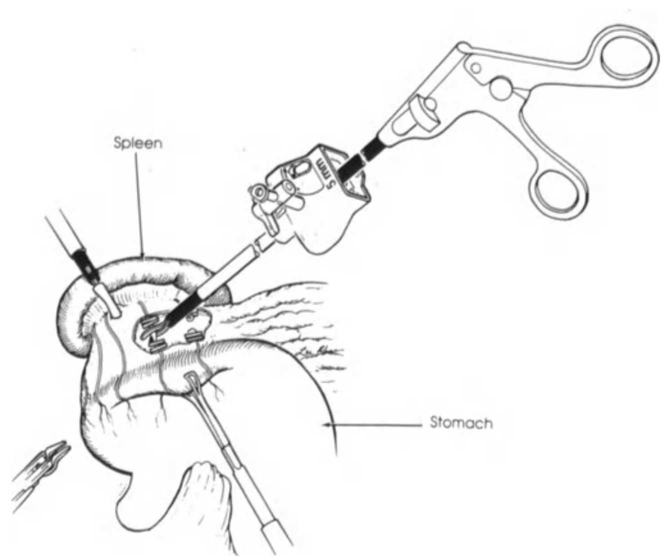

FIGURE 26.1.34. Division of short gastric vessels for laparoscopic splenectomy. (By permission of TE Lobe, KP Schropp (eds), *Pediatric Laparoscopy and Thoracoscopy,* Philadelphia: W.B. Saunders, 1993; p. 191.)

FIGURE 26.1.35. Exposure of the splenic hilum for a laparoscopic splenectomy.

there are often some ligamentous attachments that should be carefully divided using Metzenbaum-type scissors. At this point the spleen is completely mobilized and free in the peritoneal cavity. A Lap Sac (Cook Urological, Spencer, IN) is inserted through the 10-mm cannula. The sac is unfurled and the three tabs at the mouth of the sac are held open while the spleen is placed in the sac (Figure 26.1.36). The neck of the sac is drawn up into a 10-mm cannula. When the entire neck is in the cannula, it should be withdrawn until the neck of the sac is exteriorized, onto the anterior abdominal wall. The neck of the sac is opened and the tissue morcellator placed within the pouch. The organ can then be morcellated until it is sufficiently small, such that the entire pouch with any residual tissue can be withdrawn through the trocar site. The trocar and cannula are then reinserted and pneumoperitoneum re-established.

Depending upon the indication for a splenectomy, a search should be made for an accessory spleen and if identified, it, too, is removed. Once it is established that there are no accessory spleens and that there is excellent hemostasis, the cannulae are removed and the incisions closed. Thus far, we have performed five splenectomies on children (girls) ages 18 months to 8 years. One child had hereditary spherocytosis and underwent a concomitant cholecystectomy. The other children had idiopathic thrombocytopenic purpura. All the children were offered liquids on the night of surgery and returned to unrestricted activity by 48 hours after their operation was completed. There were no complications.

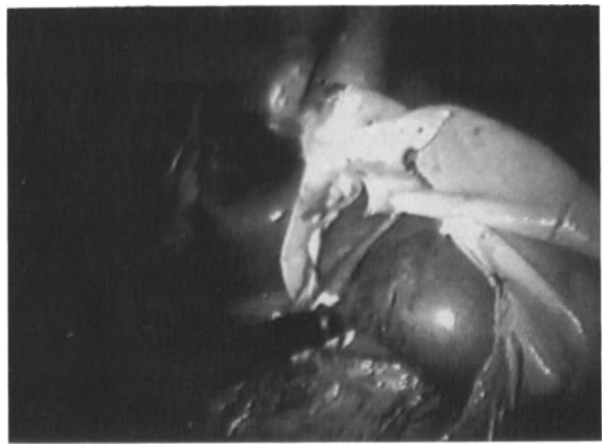

FIGURE 26.1.36. Placing the spleen in a Lap Sac (Cook Urological, Spencer, IN) for completion of laparoscopic splenectomy.

Ovarian Cysts

Ovarian cysts are often diagnosed preoperatively by a variety of imaging modalities. Occasionally, a child with abdominal pain is discovered to have an ovarian cyst at laparoscopy. Large cysts can be decompressed with a needle if necessary. When malignancy is of low probability, such cysts can be excised completely or they can be fenestrated so as not to cause further problems. Oophorectomy is rarely indicated, except in cases of malignancy. When it is required, it can be performed laparoscopically, along with omentectomy and other necessary procedures.

Adnexal Torsion

Increasing evidence attests to the role of detorsion from a laparoscopic approach. The surgeon should give consideration to a conservative "untwisting" approach with operative laparoscopy. Evaluation of the opposite adnexa is also recommended. An oophoropexy should be considered, especially if the adnexa is associated with a long mesosalpinx-mesovarium, all in an effort to prevent subsequent torsion. Of interest, torsion is more frequent on the right side. There appears to be minimal, if any, evidence of thromboembolism associated with "untwisting" of the involved adnexa.

Pyloric Stenosis

Several pediatric surgeons around the world now perform laparoscopic pyloromyotomy for idiopathic hypertrophic pyloric stenosis.[32] The technique used is a simple one. Umbilical access is achieved after CO_2 insufflation in the standard fashion. Another cannula is inserted laterally from the left of the patient's midline. With the stomach decompressed it is easy to see the pyloric tumor. An electrosurgical instrument of pylorotomy is used to incise the pyloric muscle down to the mucosa, along the length of the pylorus. Another instrument is then used to spread the muscle and separate its two halves. Surgeons adept at the technique state that it takes between 20 and 45 minutes to perform. In our opinion, the surgeon appears to have relatively little control of the pylorus during the procedure. The high risk of perforation (nearly 10%) makes the procedure still investigative.

Nephrectomy

Nephrectomy for congenital abnormality or selected tumors can be performed laparoscopically. This technique appears to be most useful in the older child in whom a laparotomy would result in a longer and more morbid postoperative recovery. The technique requires a tissue morcellator to break up the solid mass into sufficiently small pieces so that it can be removed via a laparoscopic cannula.[33]

The procedure is initiated with the patient supine. Cannulae are inserted into the umbilicus (for the laparoscope), into the midclavicular line on the side of the kidney to be removed, and into the anterior axillary line on that side. The patient is then turned into a lateral position to carry out the procedure. First, the colon is dissected to expose Gerota's fascia (Figure 26.1.37). This fascia is incised to expose the kidney. Using the lateral-most two ports, grasping instruments are used to elevate the kidney so the renal vessels can be dissected free and then divided. These vessels can be divided using clips or the linear stapler. The ureter is then dissected as distally as necessary and then divided. The kidney is freed from the renal fossa (Figure 26.1.38). The patient is then returned to a supine position. An endoscopic sac is inserted into the abdomen and opened. The kidney is placed into the sac, the neck of which is withdrawn from the abdomen through a 10- or 12-mm trocar site. The tissue morcellator is then inserted into the sac and the tissue extracted. After careful inspection of the abdomen for hemostasis, all instruments are removed. Patients can usually be returned to full diet and unrestricted activity within 48 hours.

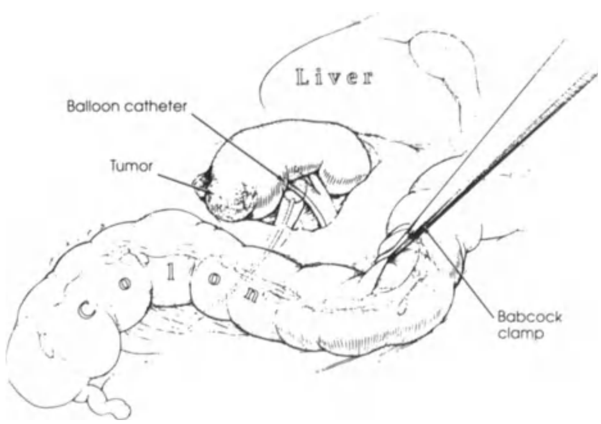

FIGURE 26.1.37. Mobilization of right colon to expose Gerota's fascia for a right nephrectomy. (By permission of TE Lobe, KP Schropp (eds), *Pediatric Laparoscopy and Thoracoscopy,* Philadelphia: W.B. Saunders, 1993; p. 187.)

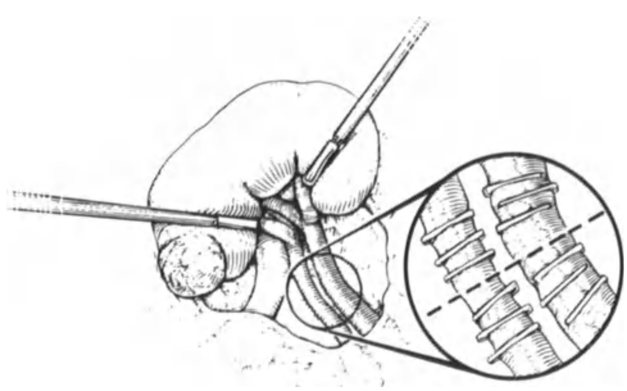

FIGURE 26.1.38. Mobilized kidney for a laparoscopic nephrectomy. (By permission of TE Lobe, KP Schropp (eds), *Pediatric Laparoscopy and Thoracoscopy,* Philadelphia: W.B. Saunders, 1993; p. 187.)

Pull-Through for Hirschsprung's Disease

A pull-through for Hirschsprung's disease can also be safely performed laparoscopically. While Swenson, Suave, and Duhamel procedures have all been performed, we prefer the Duhamel operation. Patients are prepared for surgery as for a standard Duhamel pull-through. In most instances, a leveling colostomy already exists. The stomach is emptied by a nasogastric tube and a bladder catheter inserted. Because of the pre-existing colostomy, the surgeon may prefer to use the open (Hasson) approach for placement of the initial cannula in the umbilicus. A CO_2 pneumoperitoneum is established and the laparoscope inserted through the umbilical cannula.

After initial inspection with the patient in Trendelenburg position, additional cannulae are inserted (Figure 26.1.39). A 12-mm cannula is inserted into the right side of the abdomen for application of the linear stapler. This stapler is used across the colostomy site, just at the level of abdominal fascia, to take down the bowel from its attachment to the anterior abdominal wall. Two left-sided cannulae are then placed in the upper and lower quad-

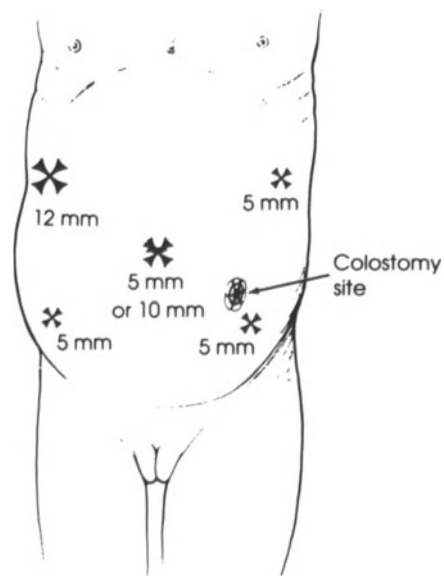

FIGURE 26.1.39. Cannula placement for a Duhamel pull-through. (By permission of TE Lobe, KP Schropp (eds), *Pediatric Laparoscopy and Thoracoscopy,* Philadelphia: W.B. Saunders, 1993; p. 208.)

rants at the anterior axillary line lateral to the rectus muscle, and one additional right-sided cannula is placed. These can usually be 5-mm cannulae. Using the two left-sided cannulae, the bowel is elevated exposing the mesentery. The peritoneum over the mesentery is incised and, if necessary, the vessels can be divided between the surgical clips at this point (Figure 26.1.40). With the bowel intact, the colon is elevated and a closed Endo GIA or an Endoscopic Kitner (OR Concepts, Inc., Roanoke, TX) used for the retrorectal dissection distally 1 cm from the mucocutaneous junction. The Endo GIA stapler device is ideally suited because its size approximates the size of the proximal bowel to be pulled through (Figure 26.1.41). The patient's bowel has been previously prepped and the perineum is exposed on the surgical field, allowing access to the perineum for anorectal dissection and anastomosis. Once the retrorectal dissection has been completed, the bowel can be transected using one Endo GIA stapler device at the peritoneal reflection and another proximal to the colostomy (Figure 26.1.42).

Sutures are placed in the proximal staple line to pull the bowel through the retrorectal space. A transverse incision is made in the posterior rectum just 1 cm proximal to the mucocutaneous junction as in a standard pull-through, and a curved clamp is inserted into the retrorectal space. The sutures are grasped and the bowel is pulled through (Figure 26.1.43). A single layer of interrupted 4–0 absorbable sutures is used to complete the anastomosis in the standard fashion. An Endo GIA stapler device is then inserted transrectally, its anterior limb is in the anterior aganglionic pouch and its posterior limb is in the posterior ganglionic bowel. The stapler is applied

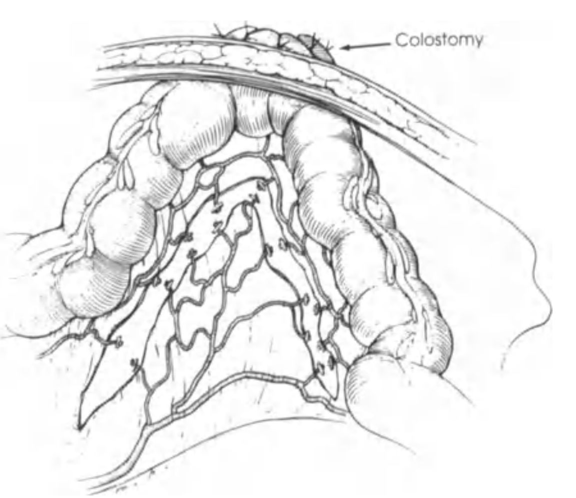

FIGURE 26.1.40. Division of mesentery vessels for a Duhamel pull-through.

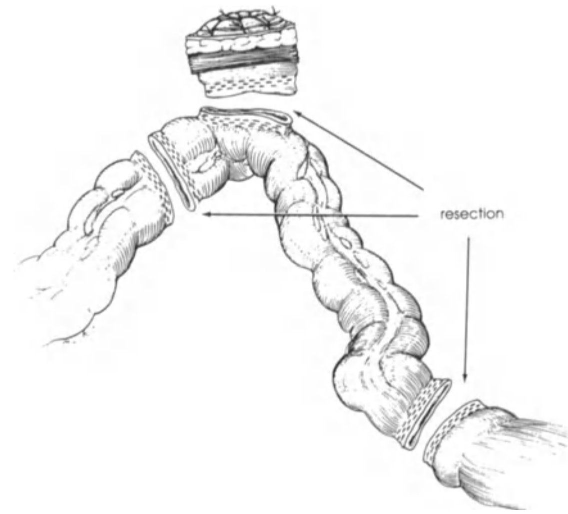

FIGURE 26.1.42. Endo GIA transection of bowel for a laparoscopic Duhamel pull-through. (By permission of TE Lobe, KP Schropp (eds), *Pediatric Laparoscopy and Thoracoscopy,* Philadelphia: W.B. Saunders, 1993; p. 209.)

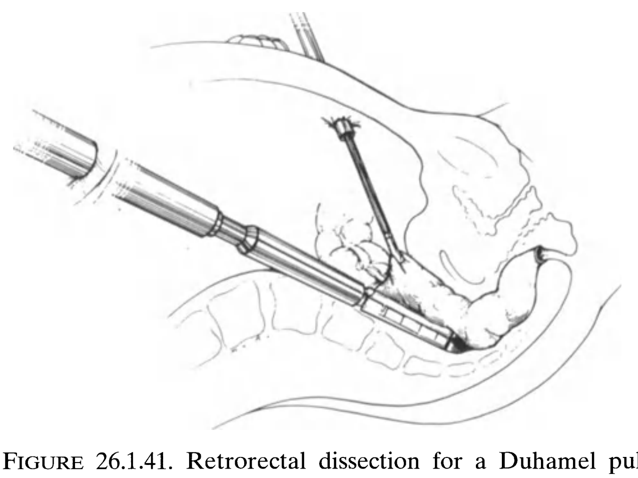

FIGURE 26.1.41. Retrorectal dissection for a Duhamel pull-through. (By permission of TE Lobe, KP Schropp (eds), *Pediatric Laparoscopy and Thoracoscopy,* Philadelphia: W.B. Saunders, 1993; p. 209.)

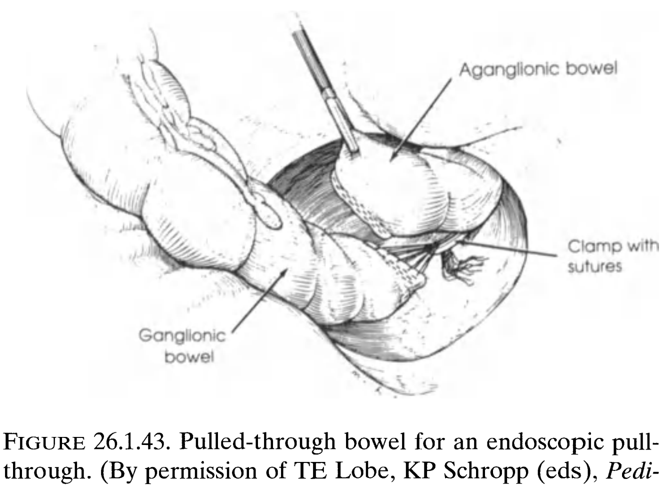

FIGURE 26.1.43. Pulled-through bowel for an endoscopic pull-through. (By permission of TE Lobe, KP Schropp (eds), *Pediatric Laparoscopy and Thoracoscopy,* Philadelphia: W.B. Saunders, 1993; p. 210.)

to create the anastomosis between the two lumen (Figure 26.1.44). Because the pneumoperitoneum will have been lost, it is now re-established and additional applications of the Endo GIA stapler can be applied to ensure that the suture line is as close to the end of the anterior pouch as possible. Sutures can be placed to approximate the corners of the anterior pouch to the posterior intestine. If desired, an Endo GIA stapler can then be applied to create a single transverse suture line to include the anterior wall of the anterior pouch and the anterior wall of the posterior pouch in a single suture line, thus eliminating any anterior spur, so that stool will not accumulate (Figure 26.1.45). The mesentery can be closed as desired and all creases should be inspected for hemostasis. The excised remnant of colon can be removed in one of two ways: it can either be brought out through the transrectal incision before the pull-through is accomplished; or it can be removed at the end of the procedure at the time of excision of the residual colostomy. At the end of the procedure, the colostomy (if present) is excised down to the fascia, the bowel segment removed through this fascial opening, if it has not already been removed, and the anterior abdominal wall can be closed in the standard fashion.

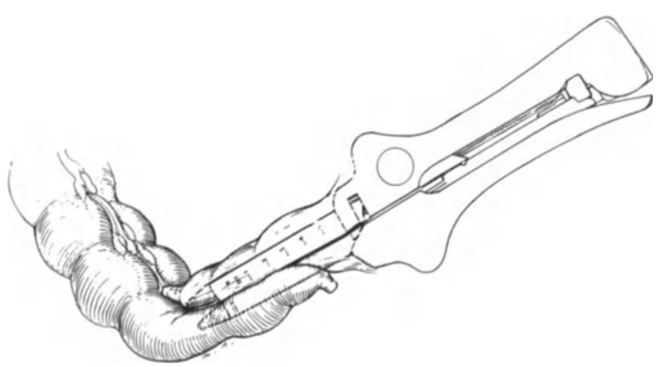

FIGURE 26.1.44. Endo GIA application to complete rectal anastomosis for a laparoscopic Duhamel procedure. (By permission of TE Lobe, KP Schropp (eds), *Pediatric Laparoscopy and Thoracoscopy,* Philadelphia: W.B. Saunders, 1993; p. 210.)

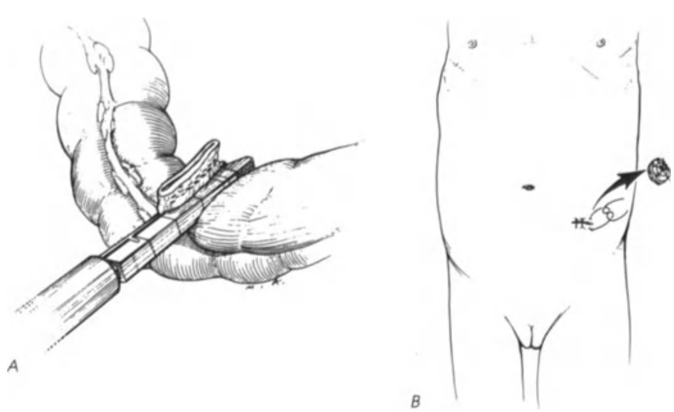

FIGURE 26.1.45. Endo GIA stapler applied to eliminate the anterior spur for a Duhamel pull-through procedure. (By permission of TE Lobe, KP Schropp (eds), *Pediatric Laparoscopy and Thoracoscopy,* Philadelphia: W.B. Saunders, 1993; p. 211.)

Acute Pelvic Inflammatory Disease

While the exact incidence of acute pelvic inflammatory disease (PID) in adolescents is difficult to discern, there has been a report that a 15-year-old girl who is sexually active has a 1 in 8 chance of acquiring acute PID. This is 10 times greater than for a woman 24 years of age.[34] About one million patients are treated for acute PID annually, of which 45,000 adolescents between the ages of 15 and 19 are hospitalized for acute PID.[35] *Chlamydia trachomatis* and *Neisseria gonorrheae* are the most common organisms associated with acute PID in the adolescent and adult populations.[36]

Westrom has reported that 11.7% of hospitalized patients with acute PID become infertile if they have one episode of PID; 23.1% become infertile after two episodes, and 54.3% after three or more episodes. Infertility is associated with tubal obstruction.[37] In addition, Grimes has estimated that 0.29 deaths per 100,000 women aged 15 to 44 are directly related to acute PID.[38] It is estimated that 18 to 20 per 1000 women between the ages of 15 and 24 acquire acute PID annually.[37] The economic cost of PID is substantial. When one considers PID-associated diseases like ectopic pregnancy and infertility, an excess of $2.6 billion was spent in 1984.[39] In the 1990s, it is estimated that $3.50 billion will be spent annually for the cost of PID and its sequelae. The diagnosis of acute PID may be difficult to establish. In one series of 814 women, only 65% of the cases were confirmed at laparoscopy.[40] In 12% of this series, laparoscopy revealed conditions other than acute PID. These include acute appendicitis, endometriosis, hemorrhagic corpus luteum, ectopic pregnancy, ovarian neoplasm, and chronic salpingitis.[40]

Why a laparoscopic approach appears efficacious in evaluation and treatment of acute PID has been addressed by Reich.[41] Fibrin trapping and sequestration of the bacterial inoculum by the omentum, as well as intestinal distention and tubo-ovarian complex, localize the infection, resulting in abscess formation. Thick fibrin deposits appear to be a barrier to *in situ* destruction by neutrophils so abscesses form.[41] Once an abscess is formed, it becomes difficult for adequate penetration of antibiotics to correct the abnormality. By aggressively removing fibrin, exudate, and associated purulent material, the prognosis is improved. Henry-Suchet and coworkers evaluated 50 patients with tubo-ovarian abscess treated laparoscopically. These were all complemented by preoperative and postoperative intravenous antibiotic therapy. These researchers re-emphasized the efficacy of early aggressive laparoscopic management of acute PID.[42]

One other report with respect to laparoscopic treatment of acute adnexitis by Cobal and coworkers[43] noted that of 28 patients with acute PID who underwent laparoscopy supplemented by antibiotic therapy, 8 of the 28 showed rapid, subjective improvement. Absence of early PID complications, shorter hospital treatment, and the absence of recurrence within the first six months proved to be major advantages of the "supplementary laparoscopic treatment" of acute PID.

Mecke, Semm, and coworkers reported on 66 patients with pelvic abscesses; 25 required laparotomy, and 41 underwent operative laparoscopic treatment. The authors proceeded with follow-up examination one to two years after the initial surgical intervention. Twenty-seven of the patients treated with operative laparoscopy complained of chronic abdominal pain, compared with 37% who were treated via laparotomy. These authors recommended that especially in young patients, operative laparoscopic treatment of pelvic abscess is a valuable alternative to laparotomy.[44]

Operative Technique with Acute PID

The laparoscopic approach should include an attempt to lyse adhesions, remove purulent material, fibrin, and exudate. Copious amounts of irrigation should be used to accomplish this goal, ideally including Ringer's lactate solution. Gentle grasping of reproductive tissues is strongly recommended. Cultures should be obtained and appropriate therapy administered, both pre- and postoperatively. The patient is placed in reverse Trendelenburg position, suctioning the fluid to remove as much of the purulent material as possible. An "underwater" examination is recommended in order to observe the completely separated tubes and ovaries and document hemostasis.[41]

Intraovarian abscesses have been treated via laparoscopic aspiration and povidone-iodine lavage. In a case report by Stubblefield,[45] a patient was reported with prolonged morbidity associated with intraovarian abscess following acute PID, which was secondary to an intrauterine contraceptive device. Laparoscopically guided needle aspiration of the abscess with iodine lavage was quite effective in correcting the abscess process.

Fitz-Hugh-Curtis syndrome has been treated laparoscopically in adolescents, as well as adults. In a case report of a patient presenting with chronic right upper quadrant abdominal pain and in whom extensive adhesions were noted, the use of a laser (KTP/532) was not only effective in eliminating the adhesions but completely resolved the pelvic pain. There was no further recurrence of pain after six months of follow-up.[46]

Second-look laparoscopy after treatment of acute salpingitis with doxycycline/benzylpenicillin procaine or trimethoprim-sulfamethoxazole has been reported in a series of 64 patients.[47] The study group was randomized into one of two treatment arms. Each patient underwent second-look laparoscopy three to six months posttreatment. At that time, adhesions and tubal patency were evaluated. Two patients were noted to have bilateral tubal occlusion. Thirty-one had adhesions, but tubal patency on at least one side, while 31 patients had normal-appearing pelvic organs. Each antibiotic therapy proved equally effective with respect to treatment of acute PID. It is increasingly clear that early aggressive operative laparoscopic intervention may well change the course of acute PID sequelae. Removal of fibrinous exudate and purulent material, complemented by appropriate antibiotic therapy has been effective with respect to less pelvic organ damage, infertility, and subsequent pelvic pain.

Lymphadenectomy and Urological Procedures

Lymphadenectomy has been reported, especially in association with Hodgkin's disease, and other entities including neoplasms of the stomach, gallbladder, liver, and pancreas, as well as intestinal pathologic states requiring biopsy of lymph nodes or lymphadenectomy.[48] In addition, laparoscopic percutaneous transperitoneal lithotripsy on pelvic kidneys has been reported in 1985.[48,49] A laparoscopic approach facilitated observation and displacement of loops of bowel during percutaneous access to the pelvic kidneys via retrograde nephrostomy. In a series of 16 patients aged 18 months to 38 years in which nonpalpable testes were noted, 6 were bilateral cryptorchid patients, and 10 presented with a unilateral gonad.[49] Furthermore, laparoscopic observation of the vas deferens and gonadal vessels in association with anorchia appears to be feasible in the pediatric and adolescent patient. Laparoscopic ureterolysis has been reported in a 15-year-old female with a two-month history of right flank pain.[50]

Summary

The surgeon must be cognizant of the extensive applications of laparoscopic surgery in the pediatric and adolescent patient. The ability to provide surgical care on an outpatient basis or short-stay appears to be cost-effective and appropriate state-of-the-art medical care. As the array of surgical instruments continues to evolve, new and innovative laparoscopic procedures will continue to become increasingly available.

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26.2 Principles of Nonacute Pediatric Laparoscopy

J.S. Valla and J.L. Alain

Introduction

Laparoscopic surgery in children is a new surgical method that is still being evaluated. Gans[29,30] demonstrated the safety of laparoscopy in children as early as 1971, but this technique was only a simple procedure used for diagnostic purposes. Indications included diseases of the internal genital organs,[81] chronic abdominal pain,[44] pathologic neonatal jaundice,[13,67,75] and especially intra-abdominal undescended testis.[36,44,49,51,68,70,80,81]

During the last decade, indications for diagnostic laparoscopy decreased steadily because of increasing skills in biologic and modern radiologic diagnostic procedures, ultrasonography in particular.[66] The extraordinary development of operative laparoscopy since 1989, and in particular the diffusion of laparoscopic appendectomy, has permitted pediatric surgeons to become familiar with these new mini-invasive techniques. The diagnostic and therapeutic indications of laparoscopy are expanding rapidly. The main advantage of laparoscopic surgery is that surgeons can now do diagnostic and therapeutic procedures together in the same operative time.[57,63] Pediatric surgeons as a whole are more cautious compared to their colleagues who perform surgery on adults.[5] Many reasons could explain this attitude. First of all, pediatric surgeons work with patients who are still growing up; they judge results of different treatments only when the growth period has finished. It has been shown that many operations have undesirable effects by the end of growth period, so they have been abandoned.

The anesthetists also are often reticent, particularly in neonatal period, when CO_2 pneumoperitoneum could very rapidly modify the newborn physiology. To do laparoscopic surgery in neonates, the surgeon must get over a psychological threshold that exists in these situations.[77] Laparoscopic surgery can be done safely as early as the first day of life, and even in premature babies, providing that it is performed by a well-trained surgical team with adapted materials, who actively applies all usual precautions. The youngest infant operated on by Waldschmidt weighed 1,400 g.[77] Estes and Harrison have already passed on to the next step in their experimental work; they propose to operate on a fetus (in utero endoscopic surgery).[25,26] Specific pediatric laparoscopic instruments (of less size, diameter, and length) for newborns and infants are now available, but their design has not kept pace with adult laparoscopic instruments.

Laparoscopic surgery is a mini-invasive procedure. However, classically it is necessary to insert blindly an intra-abdominal needle and trocar, with the risk of visceral and vascular injuries. This risk is greater in children because of the short distance between the aorto-iliac axis and abdominal wall. For laparoscopic surgery in children, learning and technical difficulties have only been resolved for procedures already practiced in adults. However, for pediatric indications, many technical aspects have to be reconsidered.

In adult patients, advantages of laparoscopic surgery include fewer parietal complications, reduction of hospitalization, and a more rapid return to full activity after the operation. In children, however, parietal complications are fewer, hospitalization is already very short, and stopping preoperative activities has no consequences for social costs of the disease. The other advantages of laparoscopic surgery (reduction of postoperative pain and prevention of psychological trauma by preserving corporeal image integrity) are important and are argument enough to let children benefit from these new techniques.

In France, an association has been created[5] (GECI) for pediatric surgeons to study and discuss laparoscopic surgery in children, and to inform each other about observed complications.[6] There is no age limit for applying these new surgical techniques. Experience and the capability of the surgical team are the only limiting factors. Our experience is based on a series of 1640 (1215 from Nice plus 425 from Limoges) pediatric cases (acute and nonacute).

Laparoscopic Abdominal Surgery

Anatomic Considerations and Their Applications in Laparoscopic Surgery

In children between zero and six years old, the anatomy of the abdominal wall and abdominal cavity has some differences that could modify laparoscopic techniques. Umbilical vessels in a newborn are proportionally of large diameter; they may even be permeable. Until the child is three years old, the bladder with the extension of urachus is still an abdominal organ. It projects on the abdominal wall higher than the pubis in all instances, whatever its repletion. It is very important to evacuate the bladder either by manual maneuvers or by urethral catheter. In neonates, umbilical, infraumbilical, and right supraumbilical areas should be avoided when inserting the insufflating needle and trocars. Insertion could be done in other abdominal regions such as left epigastrium and left and right hypochondrium with less risk. Obliteration of processus vaginalis in both boys and girls may not have been completed. It could be reopened because of pneumoperitoneum. The surgeon should verify inguinal regions by the end of operation to avoid intestinal incarceration in a still incompletely closed processus vaginalis. Rectus abdominis muscles are proportionally wider and more displayed in children than in adults. This is important to know in order to avoid injury to epigastric vessels when inserting lateral trocars. The abdominal cavity in children is normally free of parietal adhesions. Visceral adhesions are also rare. Omentum is usually underdeveloped and mesenteric fat is not so abundant. This facilitates laparoscopic exposition of viscera, dissection, and hemostasis. After the age of six to eight years old, abdominal anatomy in children is no different from that of adults.

Besides these anatomical considerations, pediatric laparoscopic surgeons should keep in mind the results of size reduction in three scopes: reduction of abdominal cavity volume; reduction of internal abdominal wall surface; and reduction in abdominal wall thickness. Indeed, all dimensions of the abdominal cavity are diminished. The aorto-iliac axis is very near to the anterior abdominal wall so that it is very threatened, especially since the abdominal wall is thin and easily punctured. All acts of blind puncture when inserting the insufflating needle or first trocar should be done very softly, progressively, and well-controlled by counter maneuvers. However, these blind maneuvers should probably be abandoned and replaced by open laparoscopy techniques described by Hasson[37] and applied to children by Rosser.[63]

The small abdominal cavity in children has two other consequences. First, insufflation (but also exsufflation in case of leaks) is rapid (a few seconds in neonates), and intra-abdominal pressure should be well controlled. It should never exceed 8 cm H_2O. Second, the working distance between optics and viscera is short and optics used in neonates are of small diameter (4 to 5 mm). Surgeons must work in a diminished visual field with a weak light on fragile viscera (in premature babies in particular). Gentle, scrupulous, and precise maneuvers are of utmost importance.

The anterior abdominal wall surface is also reduced in children. Trocars' penetration points are far closer to each other than in adults. From a biomechanical point of view, mobility of laparoscopic surgical instruments is limited by these fixed trocars' points of penetration. Their movements delineate conic projections in space. These conic projections are remote from each other in adults, but they are superimposed in children. This results in additional difficulties in manipulating different instruments (Figure 26.2.1). Thus, it is difficult to tie intracorporeal knots.

Slight thickness of the abdominal wall has some advantages: easy insertion of trocars and the possibility of operating without pneumoperitoneum, using abdominal wall lift techniques. These techniques could be realized by simple transcutaneous tractor threads held by assistants or by a self-blocking system. Laparoscopic surgery using abdominal wall suspension techniques should be performed more often in young children. However, because of a thin abdominal wall, trocars slide out of the abdomen very easily. Screw trocars have not resolved this problem completely, even after doing a tight bursa around them. Caution should be taken not to release instrument or optic handles, leaving the other extremity

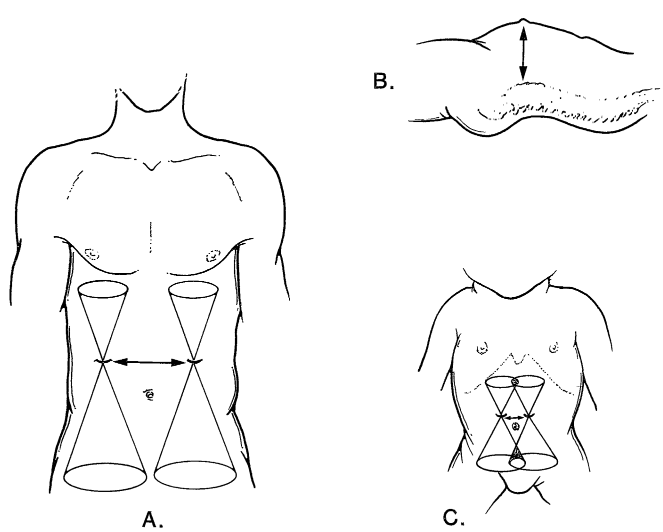

FIGURE 26.2.1. Differences in surgical anatomy between adults and children in laparoscopy.

in the abdominal cavity. Iatrogenic injuries could be avoided by bringing all laparoscopic instruments out of the abdominal cavity before any visual withdrawal from the operative field.

Pre- and Perioperative Precautions: Contraindications

Anesthesia

Anesthetic precautions and requirements should be emphasized because of the risk of nocuous respiratory and hemodynamic effects of laparoscopic surgery. For the respiratory system, pneumoperitoneum is accompanied by operative risk of hypercapnia. This results from the shunt effects in relation to ventilation/perfusion problems, rather than resorption of CO_2 from the abdominal cavity. With respect to hemodynamic effects, there is usually increased systemic vascular resistance, which results in decreased venous return and cardiac output. These changes are proportional to the increase in intra-abdominal pressure.

Anesthetic precautions are very important, especially with neonates in whom closure of the arteriovenous bypass is not yet complete. A rise in pulmonary arterial resistance from hypoxia, hypercapnia, acidosis, or hypovolemia could cause a return to fetal circulation. Preoperative consultation followed by coagulation tests and thoracic x-rays should be done routinely.

Contraindications such as congenital cardiac diseases, bronchopulmonary dysplasia, unstable hemodynamic states, prematurity, and congenital diaphragmatic hernias that could be asymptomatic, and only diagnosed by a thoracic x-ray should receive special consideration because of the need for abdominal insufflation during laparoscopy.

Surgery

Abdominal wall obstacles like peritoneal adhesions were considered to be contraindications to laparoscopic surgery. But now it is possible to do adhesiolysis by laparoscopy. However, laparoscopic surgery is hazardous when there is a history of significant abdominal wall malformation such as gastroschisis or omphalocele. All explications and informed consent of parents are obligatory.

Specific Materials

Anesthesia

Laparoscopic surgery is performed under general anesthesia with endotracheal intubation and curarisation. Surveillance during the operation should include: hemodynamic monitoring (continuous electrocardiogram and arterial blood pressure); respiratory functions (oxygen saturation, ventilation pressures, and rapid reactive capnographer which is, however, not very reliable for small pressure ventilations); and body temperature due to intra-abdominal cooling by insufflated gas.

Surgery

All VCR equipment is the same for children and adults as are materials used to create pneumoperitoneum; CO_2 is the gas of choice. Insufflators should have an automatic regulator. Intra-abdominal pressure should not be higher than 8 cm H_2O in infants and 12 cm H_2O in children. One of the major problems of laparoscopic surgery in neonates is intraoperative decrease in body temperature. CO_2 is usually conserved in a fluid state in special cylinders; it is transformed to a gas just before intra-abdominal insufflation. This gas is cold. We do not have any way to warm it up before intra-abdominal insufflation. In neonates, continuous monitoring of body temperature is very important because continuous insufflation cools a small body quickly. This disadvantage is an argument in favor of the abdominal wall lift method of laparoscopic surgery, which does not involve peritoneal insufflation in neonates. This method is very easy to do with simple transparietal tractor threads.

In children more than 10 years old, standard laparoscopic adult materials could be utilized without any problem. For children between 2 and 10 years old, trocars of 4 to 5 mm are very well adapted. However, in neonates and infants a laparoscope of 4 mm and trocars of 3 mm should be utilized. These instruments are of reduced length so as to permit introduction of instruments that are of 25- to 30-cm length. Complementary materials include bipolar coagulators, laser,[76] and ultrasonic desiccators. In summary, classical laparoscopic surgical techniques that are used in adults could be used in children who weigh more than 10 to 15 kg. Open laparoscopy and abdominal wall lift techniques are preferred in children who weigh less than that, especially neonates.

Postoperative Management

Postoperative surveillance should continue in a surgical department for at least six hours. In the first 24 hours, scapular pain may be observed, especially when pneumoperitoneum has not been completely evacuated before removing all trocars. Intestinal movements appear to be far less than after laparotomy. Absence of intraoperative traction on parietal tissues results in normal return to full activity within a few days. Infectious parietal complications are almost nonexistent. After a short hospitalization it is important, however, to continue to monitor the patient closely.

Nonspecific Indications for Laparoscopic Abdominal Surgery

Hiatal Hernia and Gastroesophageal Reflux Disease

Gastroesophageal reflux in children could be treated by a Nissen Rossetti operation under laparoscopic control. This technique is now well established for gastroesophageal reflux in adults, and can be performed in children with some modifications.

Operative Technique

The child is positioned on the operating table on his back with the legs spread apart. Nothing is put under his shoulders. A special retractor is fixed at the epigastrium level about 40 cm above the xiphoid. The lace that is used for the suspension will be attached to this device. The operator stands between the legs of the child. Two assistants will be needed and the operation will be followed on two TV monitors. The placement of the different trocars is shown in Figure 26.2.2. The first phase of the operation includes division of the hepatic branches of the left gastric artery and the hepatic ramification of the left vagus nerve to be able to retract the left hepatic lobe. If there is a left hepatic artery, the lesser omentum will have to be divided above the level of the artery. A right diaphragmatic crux is dissected from top to bottom so that the right margin of the esophagus is displayed. The right vagus nerve should always be preserved. In children, the dissection of the right diaphragmatic crux is more difficult because of the proximity of the inferior vena cava and the big volume of the caudate lobe. The operation continues by opening the phrenoesophageal membrane and dissecting the superior aspect of the left diaphragmatic crus and the gastrosplenic ligament. A 0° scope will not always allow for a left diaphragmatic crus. In order to create the window for the gastric valve, it is important to continue the dissection of the left crus from under the esophagus. This valve will need to be passed between the left diaphragmatic crus and the posterior aspect of the esophagus. This is a very important step in the operation. It is extremely important to do this maneuver to avoid going into the mediastinum and the preaortic region. This is a permanent danger in young children because they are thinner than adults. When the retroesophageal dissection is completed, the surgeon can proceed to other steps of the operation: closing the cruras behind the esophagus with two stitches of nonabsorbable-2 0 threads, with extracorporeal rotors knots, which will be pushed in with a special knot pusher. The fundoplication is performed by traction of the posterior aspect of the gastric fundus that wraps easily around the inferior aspect of the esophagus. The fixation of the fundoplication is performed by one or two

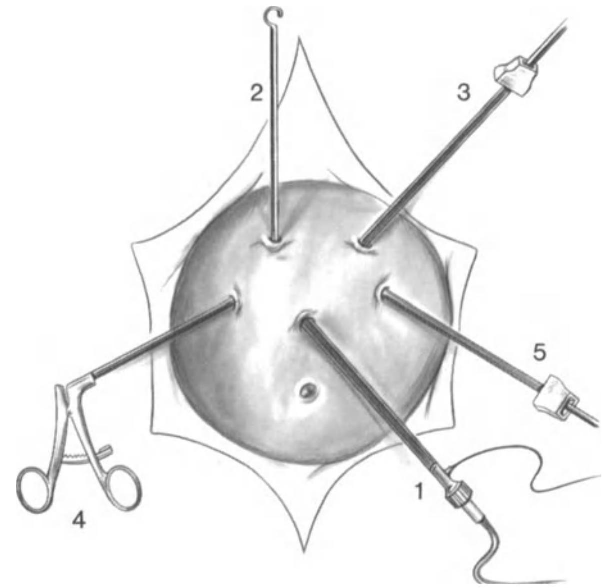

FIGURE 26.2.2. (1) 8-mm port: 0 optic lens; (2) 3-mm port: wall suspension device; (3) 5-mm port: retractable palpation probe; (4) 5-mm port: atraumatic grasper; (5) 5-mm port: instruments; (0) umbilicus.

sutures at the level of the inferior margin of the esophageal hiatus. Then a continuous suture is performed from top to bottom for a length of at least 4 cm. It is accomplished by using intracorporeal knotting techniques. No other additional procedures such as gastrectomies or pyloric myotomies are needed. Postoperative management includes an nasogastric tube for at least 18 hours. The size of the laparoscopic instrument has to be adapted to the child's age and size. A rigid laparoscope with direct vision should have a diameter or 7 to 8 mm. It is possible to do the operation with an angle view laparoscope of 30 to 50°, according to the surgeon's preference. The abdominal wall lifting method is always preferred. The hepatic retractor is a retractable, diamond-shaped one. A 60°, 5-mm articulated grasper is very useful in performing the fundoplication; other materials include a 5-mm clip applier, a needle holder, and an electrical hook.

Results

Thirty-four children were operated on since 1993. There has not been enough time to judge the quality of the obtained results. There have been no complications in this series, except two cases of transient dysphagia, and the first clinical and radiological results of the first 20 children, which have been seen in consult three and six months after the operation, were excellent. The first published series of small children operated on by the same technique is also very satisfying. Laparoscopic surgery has unquestionable advantages.[32,47] Postoperative course is far more comfortable, more rapid, and less painful.

More importantly, these children will not have unsightly abdominal scars, as all incisions are less than 5 mm. Even very small cutaneous marks persist in children as they grow. Serious evaluation of the advantages and risks of the antireflux procedure should continue in order to prove its safety and efficacy. Only then can this method become the treatment of choice for gastroesophageal reflux in children.

Chronic Intestinal Obstruction

Intestinal obstruction by adhesive bands is now a classical indication for laparoscopic surgery in adults. This technique, however, is possible and should be developed in children. It is worth noting that the principle cause of intestinal obstruction in children merits an appendectomy using the MacBurney incision.

Cholecystectomy

Laparoscopic cholecystectomy should be performed in children who suffer from gallstone disease. This disease, however, is very uncommon in children. Predisposing factors include hemolytic jaundice and other hematologic diseases, short bowel syndrome, parental nutrition, chronic hepatic diseases, and biliostasis point. In some hematological diseases, cholecystectomy could be performed along with splenectomy in the same operative time. In our 18 consecutive cholecystectomies, conversion has not been needed.

Operative Technique

Careful preoperative assessment, a complete radiological study, an ultrasound, and an angiography should always be done in children. The etiology of gallstone diseases can be very difficult to discover. Operative technique for laparoscopic cholecystectomy in children is similar to that practiced in adults. In spite of the narrow cystic duct, it is very important to do intraoperative cholangiograms because of the well-known anatomical variations. Laparoscopic cholecystectomy and acute cholecystitis is sometimes difficult to perform in children as it is in adults. Intraoperative conversion to a standard open cholecystectomy is sometimes necessary.

Results

Many studies have already been published to justify laparoscopic cholecystectomy in children.[64,69,78] Each study includes about 10 cases of children who had no special complications. Parents have been made aware of the common practice of laparoscopic cholecystectomy and are enthusiastic about applying this technique to their children. They appreciate the short operative course, aesthetic results, and the lack of abdominal scars.

Splenectomies

Because of its important role in the immune response, pediatric surgeons usually have a very conservative attitude regarding the splenic parenchyma. However, splenectomies are still indicated in some children (children more than three years old who have already had their vaccinations with antibio profilaxia). These indications include hemolysis with splenic sequestration, and idiopathic thrombopenia purpura (IMP) that could not be treated medically. Coagulation parameters should be carefully measured before the operation. Splenectomy is possible by laparoscopic surgery. The child is positioned on his back. Trocar placement is shown in Figure 26.2.3. The operative technique is identical to that of adults,[12,22] but using an Endo GIA is often not necessary. The hemostasis of the hilar vessels is maintained simply by clips, even in the case of a big spleen (hemolysis). Special maneuvers and manipulation of the spleen in order to be able to put it in a special retrieval bag where it can be fragmented or aspirated is one of the crucial phases of this operation. Dissemination of parenchymal fragments inside the peritoneum should be avoided, as this could lead to the iatrogenic postoperative splenosis. In case of a very big spleen, a traction can be done by special suprapubic incision in cosmetic regions. We have done two splenectomies by laparoscopic surgery without complications. Splenectomy could be done at the same time as a cholecystectomy, as was done in one case.

Specific Indications for Laparoscopic Abdominal Surgery in Children

Hypertrophic Pyloric Stenosis

Extramucosal pylorotomy in infants is now considered one of the possible applications of laparoscopic surgery in children. Initially described by Conrad and Ramsted in 1907, pyloromyotomy has not undergone any important modification. However, juxtaumbilical incisions have recently been proposed.

The laparoscope is inserted through the umbilicus, after a small incision. The umbilicus should always be cleaned thoroughly. Two operative trocars with videoscopic controls are then inserted. The first is a 3.5-mm trocar, which is incorporated through the left of the midline where a raspier instrument is introduced. The second trocar is inserted directly over the olive (Figure 26.2.4). The duodenum is clamped away from the pyloric olive in such a way that will permit holding the duodeno-pyloric block firmly during the following maneuvers. The pyloromyotomy is then begun. The incision of the seromuscular layer is performed using a 3-mm retractable scalpel. The incision should be very carefully started at the area

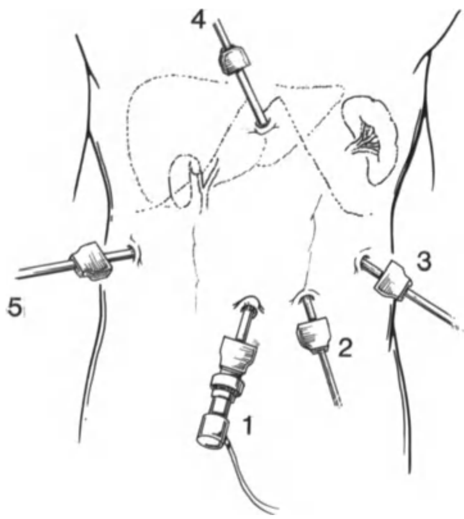

FIGURE 26.2.3. Splenectomy and cholecystectomy. (1) 10-mm laparoscope; (2) 10-mm clip applier; (3) 5-mm scissors, retractor; (4) 5-mm irrigation suction; (5) 5-mm atraumatic forceps.

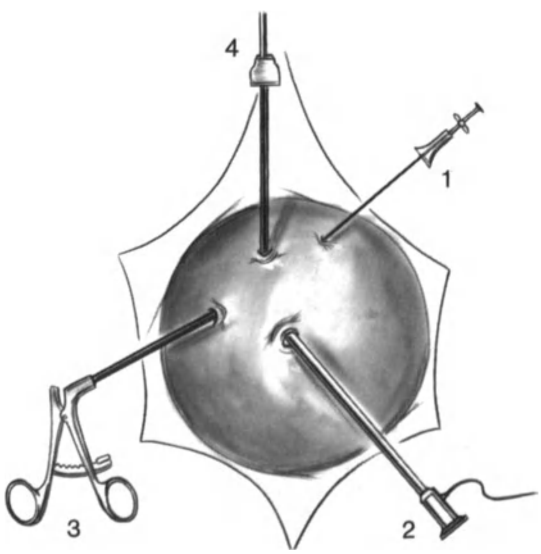

FIGURE 26.2.4. Extramucosal pyloromyotomy. (1) Veress needle; (2) 4-mm laparoscope 0; (3) 3.5-mm palpation probe; (4) 3.5-mm knife and special grasper.

that is the thickest, the middle of the olive and laterally to the two borders of the olive. At this stage of the operation, the gastric mucosa could be cut because of the deep penetration of the blade. This should be avoided, and the incision should always remain very superficial. The two margins of the muscle layer are separated, using an endoscopic spatula first, and then using dissecting graspers. Separation of the seromuscle layer is performed progressively to permit herniation of the mucosa through the incision.

It is important to verify the mucosa to look for any possible mucosal opening. This is done by injecting air through a nasogastric tube to see whether there are any bubbles between the two margins of the pyloromyotomy. Gastroduodenal fiberoscopy has even been proposed. Laparotomy should be performed if there is any doubt about the existence of mucosal injury. The pyloromyotomy can usually be performed without any bleeding if it is done well on the avascular line of the gastric antrum. At the end of the operation, a complete exsufflation of the pneumoperitoneum is very important. The small, continuous incisions are closed with interrupted stitches. No abdominal scar will remain. Minimum painkillers are given during the first four postoperative hours. The children are usually fed about 6 to 10 hours after the operation. Special instrumentation for laparoscopic pyloromyotomy, and specially adapted laparoscope and trocars are necessary. The diameter of these instruments is usually < 4 mm. Other instruments include the fine scalpel, the retractable blade scalpel, and a special dissecting grasper such as the grasper of Benson.

Since May 1990, we have operated on 65 infants. The minimum weight was 3,050 g. The operation time is now about 25 minutes. Two mucosal perforations have been observed in the first cases. These two complications were not recognized during laparoscopy. The 2 infants were operated on the next day due to clinical signs of peritonitis. Laparotomy was performed and the perforation was treated successfully without further problems. Mucosal pyloric pyloromyotomy is possible and safe. It could become a good standard in pediatric surgery.

Meckel's Diverticle

The diagnosis of Meckel's diverticle is always suspected in nonspecific abdominal pain and recurrent rectal bleeding, especially in children. Diagnosis of the Meckel's diverticle is very easily performed using the laparoscope.

Hirschsprung's Disease

Laparoscopic rectosigmoidectomy for Hirschsprung's disease according to Duhamel is feasible even in very young patients (before six months). Whole bowel irrigation is carried out the day before. As in classical surgery, the patient is placed in a Trendelenburg position with skin preparation including abdomen, legs, and perireal area. The TV monitor is positioned at the bottom end of the table, the surgeon on the patient's right side, and the assistant on the left side. Four or five trocars are needed: a 12-mm trocar through the umbilicus for 0° laparoscope and Endo GIA, a 10-mm trocar in the right iliac fossa, and two or three 5-mm trocars paramedian at the level of the umbilicus. Extension of aganglionosis is defined by multiple extra mucosal biopsies. After dissection and division of the inferior mesenteric vessels (which are ligated or clipped) a reclosigmoidectomy is carried out keeping the dissection very close to the bowel. Using Endo GIA, the rectum is divided in the pelvis as deep as possible in order to avoid any blind rectal pouch. Via anal approach, posterior semicircular incision allows to grasp normal ganglionic bowel, which is pulled through the rectum hole. Colorectal anastomosis is made as usual and completed with Endo GIA via transanal approach. Our experience is really at the beginning: two cases and one case had to be converted (lack of Endo GIA); no postoperative complication. In conclusion, rectosigmoidectomy can be done laparoscopically but this procedure remains to be evaluated.

Anomalies of Mesenteric Disposition

Many trials of laparoscopic transection of ladd bands have been done; no successful studies have been reported.

Intra-Abdominal Cystic Masses

Laparoscopic surgery is indicated in order to diagnose certain intra-abdominal fluid masses, such as omental mesenteric cysts, lymphangiomas, and intestinal duplication. Laparoscopic surgical techniques include the evacuation of the fluid in order to facilitate the dissection and the resection of the cyst.

Neonatal Jaundice

Because of the correlation between the results of a Kasai operation and early operation, biliary atresia is almost a surgical emergency. Laparoscopy is a very good diagnostic method if diagnosis is still uncertain on the basis of clinical signs, biological indications, and ultrasound examination.[13,75] Laparoscopy can explore the extra hepatic biliary ducts directly, permit radiological control, and liver biopsies. Laparoscopy can also allow irrigation of the gallbladder, which can result in removing obstruction from the biliary ducts.[67] Choledochal cysts are easily diagnosed by ultrasound. Surgical excision of the cyst and bilio enteric anastomosis is a treatment choice. This has already been realized using laparoscopic techniques, but it is still an important challenge.[28]

Ectopic Spleen and Splenic Cysts

Diagnosis of ectopic spleen could have been made before the acute portion of the pedicular cures. This is an unusual congenital anomaly of peritoneal fixation and lengthening of the splenic ligaments. Surgical intervention is indicated to repair the fixation by using interrupted stitches, biological glue, or perisplenic net. These different surgical techniques could be done with laparoscopic surgery. Benign congenital cysts are an excellent indication for laparoscopic surgery. Evacuating a puncture with partial excision or marsupialization are the easiest techniques. This could be complemented by filling in the cavity with part of the greater omentum. The placement of the trocar depends on the position of the cyst in relation to the spleen (superior and inferior poles external margins).

Inguinal Hernias and Hydrocele

Laparoscopic surgical repair of different types of inguinal hernias in adults is still under evaluation. In children, congenital inguinal hernia results from the failure of the processus vaginalis to close. The peritoneal sac should always be excised during hernial repair by stitches or glue. Theoretically, this is an excellent indication for laparoscopic surgery. However, total excision of the peritoneal sac is dangerous to the different elements of the spermatic cord. In addition, pneumoperitoneum and general anesthesia could appear out of proportion, considering the simplicity of the classical inguinal hernia repair with spinal or local anesthesia. It is worth noting that in the introduction of the 5-mm 45° laparoscope inside the hernial sac, hernioscopy, during classical surgery, is helpful in two circumstances: (1) if there is any doubt about the contralateral open processus vaginalis that will need surgical repair[46]; (2) to verify the integrity of the intra-abdominal visceras (small intestine or ovaries) if an incarcerated hernia has been reduced. Hernioscopy is a very simple, harmless examination that we recommend in such cases (30 cases in our experience).

Intraperitoneal Catheter

Intraperitoneal catheters, like those of peritoneal dialysis or ventriculoperitoneal shunts for hydrocephaly are easily inserted under laparoscopic guidance. Laparoscopy is also used for the exploration of the abdominal cavity, for moving or shifting these catheters in case of dysfunction due to peritoneal adhesions.[21–43]

Laparoscopic Urologic Surgery

Laparoscopic exploration for intra-abdominal testes was one of the first indications for laparoscopy in children. It has been used for more than 20 years.[29]

Treatment by laparoscopic surgical techniques is expanding very quickly. Operations on urinary systems could be done by a laparoscopic approach either with an intraperitoneal or a retroperitoneal approach. The intraperitoneal approach is more common and easier, but it predisposes children to the risk of intestinal aggression and subsequent intestinal obstruction, although this is less common after laparoscopy than after open laparotomy. Some authors prefer the retroperitoneal laparoscopy to avoid this inconvenience.[17,31] The retroperitoneal approach allows operations on kidneys, ureters, spermatic pedicles, and iliac lymph nodes. This retroperitoneal approach is considered more urologic and a more logical method, but it is more difficult to master and to perform because of the narrow operating field.

Nonspecific Indications for Urologic Laparoscopic Surgery in Children

Laparoscopic Nephrectomy

Laparoscopic nephrectomy is indicated only for benign diseases: small kidneys due to pyelonephritis, kidney dysplasia, polycystic disease, and destruction by obstructive uropathy. These are the most common indications for total nephrectomy in children.[1] Operative technique in classic open surgery includes two abdominal incisions in 50 percent of cases: a superior incision for nephrectomy and another inferior incision for ureterectomy. Laparoscopic surgery allows a surgeon to do a total nephrectomy with uretectomy in the same operative time. The techniques of the laparoscopic operation are the same for adults, via intraperitoneal or retroperitoneal approach. We prefer the retroperitoneal approach, which is illustrated in Figure 26.2.5. We have operated on five patients (two by transperitoneal approach and three by retroperitoneal approach); no conversion and no complication. Hence the necessity to choose indications carefully. Two indications must be rejected: the Wilm's for oncological needs and trauma for hemastatic difficulties.[16] Partial nephrectomies are still a big risk by laparoscopy.

Surgical interventions on the **ureter**, such as uretectomy, could be done by laparoscopy. In a retroperitoneal fibrosis case, removal of adhesions around the ureter has been published.[42] This operation is, however, rarely indicated in children.

Varicocele is mostly seen in teenagers. This is now considered an indication for surgery, especially if there is an associated diminished testicular growth and volume.[18] Many surgical techniques can be considered for treatment of varicocele under a general anesthesia: open surgery with different techniques of vascular ligation[41] (Ivanissevitch, Palomo inguinal approach) or microsurgical anastomosis in the iliac venous system. Vascular embolization is a simple technique that can be performed with local anesthesia. But selective embolization of the spermatic vein is not always possible.[82] There is a risk of remote embolization and recurrence that is probably identical to other surgical techniques. Laparoscopic surgery is a good method;[24,35,52] it allows high ligation of the spermatic veins, allows good visualization of dilated veins, spermatic, cremasteric, or small accessory veins. If laparoscopy is associated with the Doppler examination,[48] the spermatic artery can easily be seen as well. However, in our experience, the localization of the spermatic artery is not always possible. Another advantage of laparoscopy is that it permits the treatment of bilateral varicocele in the same operative time. The usual technique of laparoscopic intra-abdominal approach in the treatment of varicocele needs the insertion of three trocars. One trocar, inserted through the umbilicus for the 8-mm laparoscope, another 5-mm trocar just above the left iliac spine, and a third 10-mm trocar in the right iliac fossa or just above the pubic bone (Figure 26.2.6). The patient is put laterally

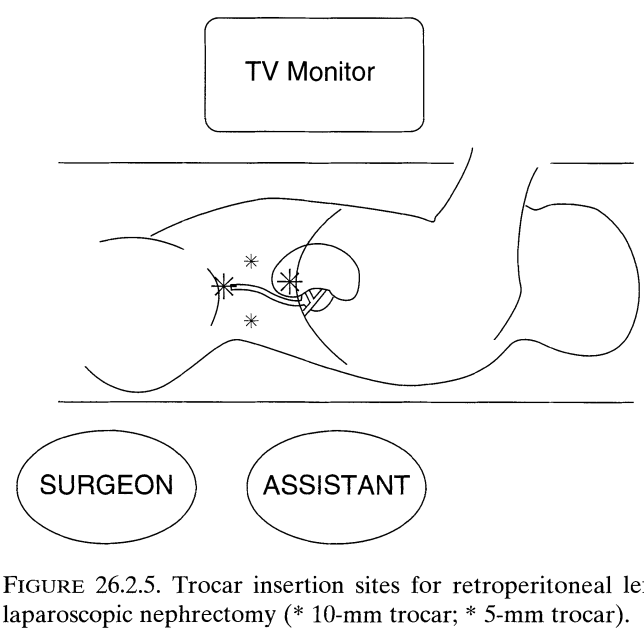

FIGURE 26.2.5. Trocar insertion sites for retroperitoneal left laparoscopic nephrectomy (* 10-mm trocar; * 5-mm trocar).

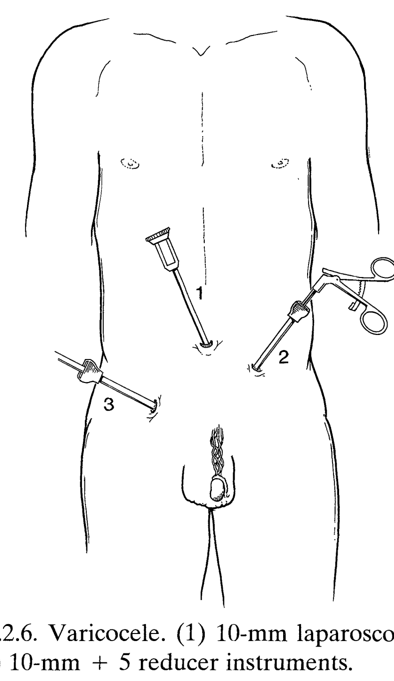

FIGURE 26.2.6. Varicocele. (1) 10-mm laparoscope; (2) 5-mm grasper; (3) 10-mm + 5 reducer instruments.

on the table in Trendelenburg position. The operator is placed on the right and the assistant is opposite him. The posterior peritoneum is opened by scissors at the level of the internal inguinal ring. The vascular pedicle is dissected and the spermatic veins (two or more) are ligated by clips and divided. The spermatic artery is preserved if it is visible, otherwise, the vascular pedicle is ligated, then divided. Other dilated veins, especially the cremasteric veins, are also dissected and divided. The peritoneum is closed with the purse string stitch at the end of the operation.

The instruments necessary to perform this technique include: curved scissors, dissectors, and atraumatic graspers, 5- and 8-mm clip appliers, needle holders, and thread. We have operated on 40 children between 11 and 16 years. We have always been able to finish the operation without the need to convert to open. There were no technical difficulties nor any postoperative complications. We were unable to see the spermatic artery on three occasions. Patients were able to leave the hospital the day after the operation and they were able to resume their activities on the fourth day post-op. There have been no recurrences, but the follow-up is still too short. It is probable that this technique will have the same recurrence rate (10 to 20%) as conventional surgery. We think that an extraperitoneal approach is also logical. This approach has already been used for groin hernia repair in adults.

As with adults, **uterine and ovarian diseases** in young girls are easily diagnosed and treated laparoscopically. These indications are detailed in other chapters.

Specific Indication for Urologic Laparoscopic Surgery in Children

Nonpalpable Testes

Nonpalpable testes (Figure 26.2.7) are an indication for laparoscopy. It is for this pathology that laparoscopy was first used in children.[29] Laparoscopic exploration for nonpalpable testes is considered to be the only reliable method. Many published studies show the popularity of this indication among pediatric surgeons.[7,10,14,19,23,38,58,60,61,68] P. Vaysse from our group has been conducting a prospective study since 1991.[74] He has collected 150 observations and concluded that laparoscopic surgical procedures can be added to diagnostic laparoscopy. Laparoscopic surgery allows the surgeon to do the first stage of the Fowler Stephens operation,[9,76] or to realize the removal of the testes in the cases of congenital dysplasia.[8,15,71] Figure 26.2.7 shows the place of laparoscopy in undescended testes. In our series, the average age is four years, but laparoscopic surgery could be performed as early as one year of age. Children should be carefully

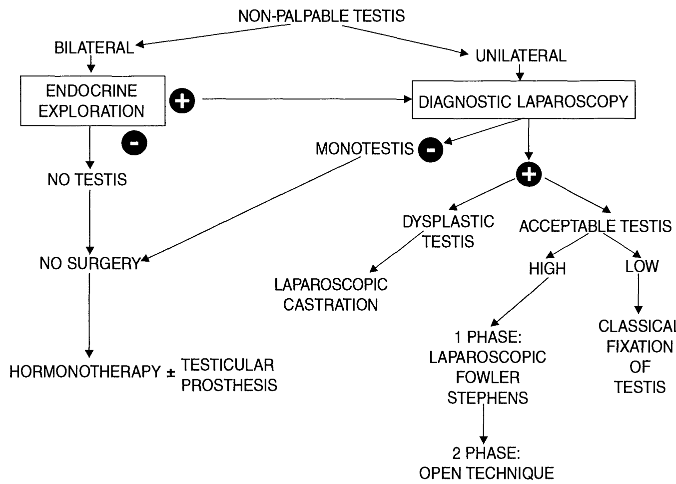

FIGURE 26.2.7. Nonpalpable testis.

examined under general anesthesia and laparoscopy performed only if the testes are unpalpable with anesthesia. If the gonads are in the form of a small scrotal nodule, a limited inguinal incision is performed to confirm the diagnosis of atrophic testes to remove the testes. If doubt persists, laparoscopic exploration through the processus vaginalis is performed in the same way as hernioscopy. The usual operative technique, especially in the bilateral palpable testes, include the utilization of a 5- to 10-mm umbilical trocar, and a palpation probe through a 3-mm trocar in the iliac fossa, on the same side of the lesion. Other trocars could be inserted as needed. The Trendelenburg position is very useful, especially if adhesions on the colon are to be removed. The exploration begins with the identification of the spermatic pedicle and the vas deferens. Another important aspect is to check whether the processus vaginalis is obliterated or not.

The important findings are that in 50% of the cases, spermatic vessels and the vas deferens are found in the deep internal ring. In these cases, it is essential to bring the testes back into the abdomen with the help of a deep inguinal palpation. In one-third of these cases, the testis is found in the inguinal canal. It was unpalpable because of the facia or obesity. The processus vaginalis is usually not obliterated. In the other two-thirds of the cases, only a small testicular remnant is found. The processus vaginalis is usually obliterated and the spermatic vessels are underdeveloped. These testicular remnants have unknown risk of degeneration. Routine inguinal exploration is probably not necessary in the cases of an underdeveloped spermatic cord with an obliterated processus vaginalis and a negative concomitant palpation.

In 35% of the cases, the testes are found in the abdomen, and the processus vaginalis is still not obliterated. The microscopic aspect of the testes is very important, as well as its high or low position and its mobility. The quality of the testes is an important consideration. Dysplastic testes could be removed by laparoscopic surgery. The hemostasis of its pedicle is done by clip or electrocoagulation. The testes could be brought down for placement in the scrotum so that they are located near the inguinal ring. If they have an easily tractable vascular pedicle, it will be placed classically in the scrotum during the same operation. On the other hand, if the testes are located high and have a rather short pedicle, the Fowler Stephens operation is performed. The ligation of the spermatic pedicle, which is the first phase of the operation, can be done by laparoscopic surgery. Ligation by clip seems to be the most reliable technique. It is important to avoid injury to the digestive organs, such as the cecum on the right, and the sigmoid colon on the left. An injury to the digestive tract could result from the diffusion of electrocoagulation (one personal case). The second surgical phase could be performed a month later, using an inguinal incision to place the testicle in the scrotum. In a nonpublished data of GECI[5] (about 35 cases), the conclusions are in favor of this technique with a reduced risk of testicular atrophy (7%) in comparison with one phase of the Fowler Stephens operation initially described.

In 15% of the cases, exploration showed that the spermatic vessels and the vas deferens end in a cul-de-sac at the level of the iliac vessels. There is no visible intra-abdominal testicular fragment. The processus vaginalis is usually obliterated. Further exploration is not necessary. Congenital total agenesia and crossed ectopic testis are very rare conditions. We have not seen these conditions during our practice.

The diagnostic value of laparoscopy in the undescended testes has been proven for some time. There is a very strong correlation between laparoscopic and open surgical results. Advantages of therapeutic laparoscopic include the possibility of avoiding unnecessary surgical intervention, realizing laparoscopic castration, performing the first phase of the Fowler Stephens operation, and determining the mobility and quality of the testes in order to choose the best surgical approach.

Ambiguous Genitalia (Intersex Syndromes)

In intersex syndromes, the anatomy of internal genital organs is not well-described by ultrasonography. In rare circumstances, especially in certain cases of true hermaphroditism, the anatomy must be well evaluated. In these cases, laparoscopy is the best method for precisely determining anatomical structures (wolfian duct structures or müllerian systems) and for doing gonadal biopsy. In one case of an impalpable testis, laparoscopic exploration has allowed us to diagnose a clinical form of a male with a uterus that developed from a lack of müllerian inhibiting substance. Another good indication for laparoscopic surgery is removal at the age of puberty of a dysgenetic gonad in the male with pseudohermaphroditism or Turner's syndrome, if chromosomal studies have shown the presence of a fragment of Y chromosome.

Thoracoscopic Surgery

Thoracoscopic surgery in adults is just beginning.[55] Possibilities of thoracoscopic surgery in children is not mentioned in a recent textbook published by Fallis in 1991.[27] As usual, pediatric surgeons are very cautious and they use only well-documented and proven techniques. We have just begun to follow 15 cases. Indications for thoracoscopic surgery will be more common in the near future. Just like laparoscopy, thoracoscopy also allows excellent visibility and it reduces morbidity and scars.

Von Jacobeus first described thoracoscopy in 1910. He performed thoracoscopy with a cystoscope. Some authors have been performing diagnostic thoracoscopy in children for a long time.[65] Electrocoagulation and irrigation aspiration following biopsies were also used. Thoracic surgeons have profited from improvements in the instruments used by gynecologists and digestive surgeons. Thoracotomy in children is now considered to be a well-tolerated procedure. Flexibility and adaptability of the chest wall in this age group allow easier surgery and a simpler postoperative course. Thoracoscopy is better, however, because it significantly reduces postoperative pain and scarring.[62]

Thoracoscopic Technique

Thoracoscopy is done under general anesthesia. It requires an exsufflated lung and endotracheal intubation of the opposite side. In big children, a Carlens catheter could be used. In small children, only one simple catheter is used. Selective intubation of the right bronchus is usually easier than that of the left bronchus. A guiding wire or a flexible bronchoscope may be helpful. Thoracoscopy could also be performed even if selective endotracheal intubation is impossible. Anesthetic monitoring is the same as in laparoscopic surgery. Additional trocars are necessary to keep away pulmonary parenchyma during surgery.

The patient is in a lateral decubitus position (Figure 26.2.8). Installation for operation is the same as for a thoracotomy and the surgical instruments for a thoracotomy should always be on hand. The operating table position is modified during the operation according to surgical needs, and to facilitate the localization of intrathoracic lesions. The operation begins with the creation of a pneumothorax. There are two techniques for pneumothorax, a blind and an open one. Blind technique includes insertion of a Veress needle high on the middle axillary line at the level of second or third intercostal space. Pulmonary atelectasis due to selective endotracheal intubation

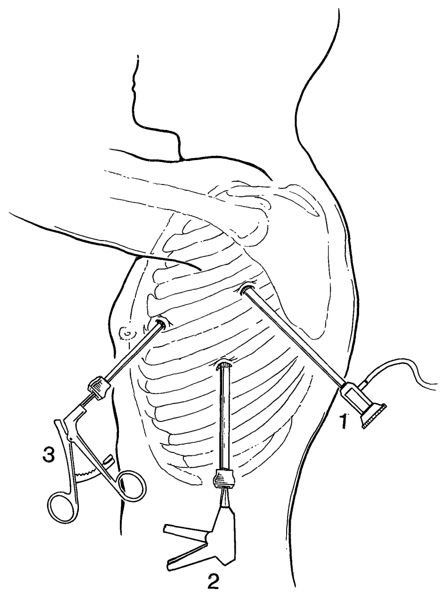

FIGURE 26.2.8. Thoracoscopy. (1) 10-m optic; (2) 12-mm GIA; (3) 5-mm grasper.

results in drawing up the diaphragmatic dome. We prefer the open technique, which includes an incision of 5 to 10 mm at the level of fifth intercostal space, with progressive dissection until the opening of the visceral pleura. A classical trocar for laparoscopy is inserted afterwards. A disposable thoracoscopic trocar can also be used. Next is a pleural cavity exploration with the thoracoscope. We use a rigid thoracoscope (Storz 5 10-mm 0°). An oblique optic is also very useful. New semirigid optics with swiveling extremities are now available; they allow access to every recess and thoracic cavity cul-de-sac. Quality of image is not as good as that of rigid optics. When a lesion is located and the type of operation is determined, other trocars are inserted according to surgical needs. The following instruments are needed: scissors, dessicators, pince à préhension, and Endo GIA stapler (12 mm). Instruments should be inserted the greatest distance possible from the lesion in order to facilitate intrathoracic manipulation. This is very important in children because of the small size of the thorax. Changing the location of the thoracoscope is sometimes necessary and should be done as needed. Specific instrumentation for thoracic surgery includes a short trocar, which is easier to use than laparoscopic trocars. Air leakage is not a problem in thoracic surgery. Curved instruments are very important in order to have enough access to concave areas of the thoracic cavity. They are two methods available. Either the introduction of a curved instrument through a soft trocar, or utilization of a special instrument with a swivelling extremity. We think that the first option is simpler because it allows utilization of more solid and more reliable instruments. Hemostasis is also a concern. Surgeons should keep in mind that monopolar electrocoagulation had the risks of producing cardiac arrythmias if used near the pericardium. This is an important reason to favor using the laser or ultrasonic knife. Contraindications of thoracoscopy are limited. Complete pleural symphysis is the only contraindication.

Indications

Nonspecific Indications in Children

Spontaneous pneumothorax often seen in teenagers can be successfully resolved by thoracoscopic surgery. Wedge resection is particularly visible by thoracoscopy,[54] especially when the lesion is peripheral and can be easily located. If the lesion is central, the usual kind of exploration is not helpful. Palpation of the pulmonary lobe with two instruments is not reliable enough and intraoperative ultrasonography on an exsufflative lung is still under evaluation. The best method for localizing the lesion is still digital palpation, done with a small 1-cm thoracotomy. Thoracotomy will allow extraction of the lesion after resection has been completed.

Labectomy is rarely indicated in children but it is possible by thorascopic approach. Four trocars are needed; arteries and veins are dissected free and then ligated with suture or clip. An Endo GIA stapler device is applied on the bronchus. The piece of lung is removed through the trocar's hole which must be enlarged to a small thoracotomy without retracting the ribs.

Specific Indications for Thoracoscopy in Children

Some congenital pulmonary malformations are seen very early in children. They sometimes need excision by thoracotomy. Congenital cysts, lung sequestration, and adenomatoid malformations could be resected by thoracoscopy. Their vessels, the principal operative risk, can be located before the operation by Doppler, ultrasonography, and arteriography. In the same way, localized pulmonary lesions including segmental or lobar bronchiectasis can also be treated by limited resection with thoracoscopy. As in adults, complications of pulmonary resections such as bronchic fistula after pneumonectomy can also be treated successfully by thoracoscopy.

Neoplastic pleural diseases are very rare. Acute infectious diseases are usually treated by drainage and antibiotics. Chronic infectious diseases could be treated by thoracoscopy but this is very controversial. Decortication by thoracoscopy is always very difficult and hemorrhagic. These technical difficulties result in bad endoscopic visualization.

Tumors of the mediastinum are benign in about 50% of cases. These lesions could be primarily treated by thoracoscopy. Thoracoscopy allows confirmation of diagnosis and preliminary eliminary dissection. Thoracotomy is indicated in difficult cases.[45]

Isolated H tracheoesophageal fistula could theoretically be treated by thoracoscopy. In practice, however, these fistula are often situated at the cervicothoracic junction. The endoscopic approach to these fistula is progresssing. This technique is less invasive than thoracoscopic surgery in children who often suffer from chronic pulmonary infections.

Irreversible, corrosive injuries and stenosis need esophageal resection and supplantation by a gastric or colic tube. Esophageal dissection and resection are done by blunt technique. Advantages of this technique are avoiding thoracotomy and a simplified operating procedure. Many operative complications can occur during blind esophagectomy, including vascular lesions and tracheobronchic injury. Thoracoscopy allows visual control of blunt dissection when the surgeon feels a region of tight adhesions during the operation.[33]

As with adults, megaesophagus is an ideal indication for thoracoscopy. Intervention consists of performing a longitudinal myotomy. This disease is very rare in children.

Diaphragmatic plication is a well-adapted thorascopic procedure. The patient is placed in lateral position and in Trendelburg position to allow the deflated lung to fall to the apex of the chest. Three trocars are needed; the diaphragm is plicated with five to ten nonreusable sutures which are knotted extracorporeally.

Surgery of the great vessels in children consists of few operations that are not technically very difficult, with the exception of operations for coarctation of the aorta. Persistent arterial canal could be treated successfully by thoracoscopy. Ligation is done with a clip. Often this operation is necessary in a premature baby. Endoscopic material is not very available. The very small circulating blood volume in a premature baby makes bleeding complications dangerous. In an older child, thoracoscopic surgical techniques are now in competition with interventional radiological percutaneous techniques, which include obliterating the canal by a special umbrella device. Aberrant aortic arch could also be sectioned by thoracoscopy. Anterior fixation of the aorta is sometimes indicated in some cases of tracheomalacia when there are respiratory problems. This simple operation could be easily done with thoracoscopy.

Results

Our experience is very limited. We have operated on 15 children aged three months to 15 years. Indications were five pneumothorax, four pulmonary biopsies, two mediastinal noted biopsy, one pyopneumothorax, and two bronchogenic cyst. Thoracoscopy was successful in doing exploration and resection in all cases. In this short series no conversion to thoracotomy was necessary. The most difficult operation was that for pyopneumothorax. There was a purulent effusion, with many pleural collections and pockets. In spite of irrigation and aspiration, intraoperative visibility was rather bad. Removal of fibrinous deposits and parietal decortication was feasible. Postoperative courses were uneventful and reduced to 24 hours, with the exception of the pyopneumothorax patient who needed a pleural drainage for 15 days. We prefer to leave a pleural drainage in for 24 hours. Rogers[62] recommends not leaving a pleural drainage in after thoracoscopic lung biopsies because of the good quality of hemostasis and aerostasis obtained by mechanical staples. Many operations could be done on children using thoracoscopy if surgical teams are well trained. These operations include: treatment of spontaneous pneumothorax, lung biopsies, resections of long metastasis, esophageal dissection, and resection of benign mediastinal tumors. Further studies should demonstrate the advantages of thoracoscopic surgery over open thoracotomy. Other indications of thoracoscopy are still theoretical. As this technology evolves, it will be used in a growing number of situations.

Oncology

Possibilities for laparoscopy and thoracoscopy in pediatric oncology are just being explored.[65] For diagnostic purposes, these methods allow good abdominal or thoracic exploration for tumors when diagnosis is still not very clear using other methods. Precise diagnosis could be made from macroscopic examination of the tumor and also from wide visually guided biopsies. In our experience, laparoscopy has allowed us to confirm a diagnosis of abdominal lymphoma in one case and to eliminate it in another case. Sometimes small lesions not already seen by echography or by scanner could easily be explored by laparoscopy or thoracoscopy. These methods define tumor staging. For therapeutic purposes, laparoscopy is not recommended for radical surgery for nephroblastoma or neuroblastoma. However, aortic or iliac lymphadenomectomy could be a good indication. On one occasion, we did an iliac lymphadenectomy on a teenage patient suffering from rhasdomyosarcoma of the foot who had been treated by radical resection of primitive tumor with chemotherapy. Technical details of this lymphadenomectomy are the same as those described in adults. When pelvic radiotherapy is indicated in young girls, in order to reduce gonadal irradiation, transposition of the ovaries is sometimes necessary. This intervention could be simply done by laparoscopic surgery. We have operated on two girls for ovarian transposition very easily using the laparoscope.

In Utero Endoscopic Surgery

Fetal surgery has not met all the expectations attached to it in the early 1980s. There are some indications for this surgery, in spite of the risks resulting from opening a gravid uterus. Indeed, real fetal surgery (which is wrongly called *in utero* surgery by the media) includes opening the uterus and partial extraction of the fetus. This surgery is associated with a large incidence of premature delivery. Recent development of laparoscopic surgical materials allows the application of laparoscopic techniques to antenatal surgery. This could greatly reduce surgical insult to the uterus. Ideally, the fetus should be operated on in its natural environment, the amniotic fluid. Unfortunately, amniotic fluid is too opalescent to allow adequate vision; some of the fluid should be replaced by CO_2. In experimental studies, laparoscopic surgical treatment of a cleft palate[25] or deviation of an obstructing urologic disorder[26] has already been realized. The safety of this technique for the fetus is still to be proven.

Conclusion

Laparoscopic surgery will be more widely developed in children in the near future. It will be used for exploration and treatment of abdominal, thoracic, and urogenital diseases. Advantages of these mini-invasive techniques are now well known. Prospective controlled studies should be done to confirm feasibility and results for each indication. In every country, laparoscopic surgical groups should be encouraged to study these new techniques. In pediatric surgery, some laparoscopic operations could be considered as evaluated and accepted. They include appendectomy, fundoplication, pylaromyotomy, cholecystectomy, exploration of neonatal jaundice, impalpable testis in young boys, and ovarian and uterine diseases in young girls. Efforts should continue to improve these surgical techniques and procure essential instrumentation. Adapted instrumentation for laparoscopic surgery is still very expensive and fragile. This will hamper developing countries from using these new techniques.

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27
Laparoscopic Ultrasound: Principles and Techniques

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Introduction

Since its introduction, ultrasound has developed into an important diagnostic and therapeutic tool for physicians and surgeons. It is safe, relatively inexpensive, and versatile. Its main disadvantage is that few surgeons are experienced in its use. Intracorporeal ultrasound has become feasible with the recent development of smaller high-quality high-resolution B-mode transducers. We are no longer limited to the percutaneous route. Many groups are now investigating the use of ultrasound in endoscopic, intravascular, and laparoscopic procedures.

Prior to its use in laparoscopy, intraoperative ultrasound was demonstrated to be comparable and often superior to other preoperative imaging techniques [conventional radiology, percutaneous ultrasound, computed tomography (CT), and magnetic resonance imaging], to laboratory tests, and to intraoperative palpation.

Although laparoscopic ultrasonography was first used more than 25 years ago, it was quickly abandoned because of the poor image quality. Now, the rapid progress of laparoscopic surgery and the improvement in ultrasound technology have renewed interest in laparoscopic ultrasound. Potential uses include: diagnosing biliary stones; staging malignancies; characterizing hepatic and pancreatic tumors; assessing resectability; and so on. With increasing experience new uses will most likely be found. In this chapter, we review the literature on intraoperative ultrasound (IU). We add our preliminary experience in the use of laparoscopic ultrasound (LU) and review that of others.

Intraoperative Ultrasound in Open Surgery

Intraoperative ultrasound has been demonstrated to be useful in many surgical situations including: biliary tract surgery; cancer staging (mainly colon cancer); assessment of primary and secondary tumors of the liver; and pancreatic surgery.

The use of IU for biliary lithiasis was described more than 25 years ago.[1,2] It has been used with good results to identify common bile duct stones and anatomic variations of the biliary tree. The diagnostic accuracy of intraoperative ultrasonography in detecting common duct stones is similar to that of operative cholangiography (Table 27.1). The false-negative rate for intraoperative ultrasound is between 2 and 4%. The predictive value of positive findings has been estimated to be between 91 and 93% for ultrasound and between 72 and 79% for cholangiography.[8]

IU has the advantage of not using ionizing radiation, and it is economic, relatively easy to master, and can be performed quickly. Less time may be required to perform ultrasound than to perform cholangiography.[3,6] Additionally, it can be useful in assessing the biliary tract during pregnancy.[9] The use of intraoperative ultrasound can prevent unnecessary biliary tract explorations and potential biliary injuries. In 1963 Knight and Newell concluded that "the advantages of the method are that the machine is entirely portable, the results are immediate, and the sur-

TABLE 27.1. Performance of cholangiography and intraoperative ultrasound in detecting common duct stones during open cholecystectomy compared.

	Intraoperative ultrasound			Operative cholangiography		
	Sens.	Spec.	Acc.	Sens.	Spec.	Acc.
Lane and Coupland[3]	96.0	93.0		96.0	96.0	
Sigel et al.[4]	89.0	97.0	95.0	91.0	93.0	92.0
Sigel et al.[5]	93.8	90.9	98.0	90.9	95.4	98.7
Jakimovicz et al.[6]	93.7	98.8	97.5	86.1	95.6	94.4
Gonzalez et al.[7]	84.2	100.0	94.0	75.0	96.8	94.3

Sens.—Sensitivity.
Spec.—Specificity.
Acc.—Accuracy.

geon is the interpreter."[1] In Mosnier's series of 131 patients, sonography allowed the total number of stones to be counted with more precision than in intraoperative cholangiography, and it was useful when intraoperative cholangiography was difficult or impossible.[8] One limitation of intraoperative sonography is that biliary tract air can make visualization of the biliary tract difficult.[3] This, however, is also a problem in the interpretation of intraoperative cholangiography.

Gonzalez and colleagues concluded that intraoperative ultrasound has an advantage over cholangiography when biliary lithiasis is found in the intrahepatic biliary tree and the very distal common bile duct. In these cases the differentiation from neoplasia is easier.[7] Intraoperative ultrasound can also clarify the diagnosis in cases of obstructive jaundice. In Gonzalez's series, IU led to the diagnosis of liver metastases in a patient with a hydatid cyst and in another, the detection of biliary stones following endoscopic retrograde cholangiopancreatography (ERCP) which suggested an ampullary tumor. The differentiation of biliary stones from pancreatic cancers was also possible. Gonzalez elsewhere reports that intraoperative ultrasound provided information about tumor extent and the level of obstruction and made it easier for the surgeon to obtain cytological samples from a pancreatic mass.[10]

Staging of Colon Cancer

Intraoperative ultrasound provides complementary or more accurate information for staging during surgery than other imaging techniques, information that might lead the surgeon to change or abort the original surgical plan. Accurate staging is essential in determining the appropriate therapy for carcinoma of the gastrointestinal tract, as well as to predict survival, tumor-free interval, and the potential for recurrence. There is abundant evidence of the usefulness of ultrasound in detecting liver metastasis. Many studies have shown that intraoperative ultrasound can detect lesions missed by intraoperative palpation as well as by preoperative studies.

Intraoperative ultrasound is a more sensitive technique of assessing liver metastasis than preoperative ultrasound, angiography, and computed tomography (CT)—including contrast-enhanced CT.[11-17] In some studies the specificity of intraoperative ultrasound in assessing liver metastases from colorectal carcinoma has been reported to be between 94 and 94.9%, compared to 95.5 to 96.7% for preoperative ultrasound, 92.5 to 94.1% for preoperative CT, and 85.1 to 89.5% for operative exploration.[14-16] The accuracy of these tests is shown in Table 27.2. Superficial lesions are the most difficult to diagnose by intraoperative ultrasound,[17,18] but they can be detected by palpation and inspection. Intraoperative ultrasound is particularly useful in detecting small tumors. These tiny tumors are seated deep in the liver parenchyma, and percutaneous ultrasound does not always identify them, particularly when they are located in the right hepatic lobe. Also, lesions just below the diaphragm are obscured by the ribs and lung, which interfere with sound transmission. Palpation and inspection can fail to detect these small tumors as well.[13,14,16,19]

TABLE 27.2. Accuracy of intraoperative ultrasonography in diagnosing liver metastasis from colorectal cancer.

	Preop. US	Preop. CT	Op. expl.	Op. US
Sigel et al. (1987)[15]	72.2	72.9	75.2	95.5
Machi et al. (1987)[16]	73.5	74.3	74.3	95.6
Machi et al. (1991)[14]	74.2	75.0	80.1	94.1

Preop. US—Preoperative ultrasound.
Preop. CT—Preoperative CT.
Op. expl.—Operative exploration.
Op. US—Operative ultrasound.

Many have found intraoperative ultrasound far more accurate than preoperative imaging and intraoperative palpation. Olsen studied 213 patients with colorectal carcinoma and found that intraoperative ultrasound was a more sensitive means of detecting liver metastasis (98.3%) than the combination of preoperative ultrasound and intraoperative inspection and palpation (66.1%).[19] Russo reported a sensitivity of 92.8% for intraoperative ultrasound, compared with 42.8% for preoperative ultrasound, CT, and intraoperative inspection and palpation combined.[20] The specificity was 96.6% in both groups. The diagnostic accuracy was 96.6 and 86.3%, respectively. None of the lesions diagnosed by intraoperative ultrasound was palpable, and they were all extremely small (ranging from 4 × 6 mm to 12 × 16 mm). Similar findings were reported by Stadler and Adolf of Germany. The identification of occult lesions ranging in diameter from 5 to 20 mm led to a change in operative procedure in 15.3% of cases and abortion of the procedure in four patients.[13] Machi and colleagues found that the sensitivity of intraoperative ultrasound for liver metastasis was 93.3% ($p < 0.0001$), higher than that of preoperative ultrasound (41.3%), CT (47.1%), and surgical exploration (66.3%). Long-term follow-up of these patients for new liver metastasis indicated that the sensitivity of intraoperative ultrasound decreased to 82.3%, but this was still significantly ($p < 0.0005$) better than for the sensitivity of other methods.[14]

Staging of Gastric Cancer

In gastric cancer, ultrasound assessment is useful for evaluating the depth of tumor invasion of the gastric wall, para-aortic lymph node metastasis, and hepatic metastasis. In one study, the accuracy of operative ultrasonography in defining the depth of tumor invasion was 81%.

Its accuracy in diagnosing para-aortic lymph node metastasis was 93%. Intraoperative ultrasound was more sensitive for lymph node metastasis than preoperative studies.[21] Intraoperative ultrasound can identify the five layers of the stomach wall and their tumoral involvement. It can also localize and demarcate the lateral tumor extent more precisely than other imaging techniques.[22] Moreover, 10% additional hepatic metastases were identified with intraoperative ultrasound that were unrecognized preoperatively or were not palpable intraoperatively.[21]

Liver Surgery

In liver resection for primary or secondary tumors, intraoperative ultrasound is very useful for localizing and characterizing tumors, including metastasis, daughter nodules, and tumoral thrombus. The accurate information obtained is helpful in making intraoperative decisions.

The sensitivity of intraoperative ultrasound to main lesions in 279 cases was 99.3%, compared with 87.9% for percutaneous ultrasound, 83.9% for angiography, and 89.2% for CT.[23] Some authors suggest using contrast media SHU 454 (galactose microparticles) or CO_2 with ultrasound to detect very small tumors. The contrast media is intraoperatively injected via the portal vein or the biliary tract, and the CO_2 (20 cc) is injected into the hepatic artery with a 23-gauge needle. However, this makes the procedure invasive, thus increasing its risk.[24,25]

Intraoperative ultrasound is also useful for detecting daughter nodules as well as intraparenchymal and portal-vein tumor thrombi.[23,26–29] These findings are important because hepatocellular carcinoma spreads by these means. In 207 patients with small hepatocellular carcinomas, the sensitivities of intraoperative ultrasound, preoperative ultrasound, angiography, and CT for daughter nodules or intrahepatic metastasis were 52.5, 13.1, 16.1, and 23.8%, respectively.[23] In 318 patient evaluations, the sensitivities of intraoperative ultrasound, preoperative ultrasound, and angiography for detecting tumor thrombus were 69, 24, and 21%, respectively.[23] Also, Tachimori and colleagues reported the diagnosis of tumoral venous thrombosis of the omentum in a patient with hepatocellular carcinoma.[30]

Because it enhances characterization of tumors, intraoperative ultrasound is useful for determining resectability and the extent of resection required, and in establishing contraindications to resection.[12,31–38] Between 10 and 30% of operative plans are changed because of ultrasound findings.[32,37,39–41] For major liver resections intraoperative ultrasound provides a more rational basis for deciding which procedure to follow.[42] According to some authors, it is an indispensable tool for resecting small hepatocellular carcinomas.[31] These lesions are usually nonpalpable and often invisible at the time of surgery. Ultrasound allows performing a limited resection, thus preserving liver parenchyma, and determining adequate margins of resection.[12,31–33] In cirrhotic patients and patients who have had previous liver surgery, intraoperative ultrasound is particularly useful for these reasons.[26,35,36,43] Moreover, it is an essential guide for resection of cirrhotic livers because of the difficulty of identifying and delineating the margins of the hepatomas.[38] Bismuth and colleagues add that it "enables the surgeon to undertake more precise and limited resections than were previously possible."[41] For example, it is possible to perform lobectomies, segmental, subsegmental, or wedge resections depending on the nature of the tumor and the patient's condition. Intraoperative ultrasound can guide the division of liver parenchyma and allow anatomic resection of the portal unit of the liver.[28] Surgery can be performed with less blood loss[39] and reduced operative mortality.[33]

Intraoperative ultrasound has also been used to guide hepatic cryosurgery. It allows accurate placement of the cryoprobe into tumors and aids monitoring of the freezing margin.[44]

When the nature of the tumor is not discovered during the preoperative work-up or a suspicious lesion is found during surgery, ultrasound-guided biopsy can be performed with minimal risk,[35] thus identifying the tumor and avoiding blind resection. These advantages also apply to liver surgery for benign lesions. Unnecessary or potentially hazardous resections can be avoided.[34,35,41]

Pancreatic Surgery

Intraoperative ultrasound is useful in studying pancreatic pathology. It can be used to detect insulinomas and gastrinomas, differentiate solid lesions (tumors) from pseudocysts, assist surgery for the complications of pancreatitis, identify small cancers, evaluate the extent and resectability of masses, and guide biopsies. Ultrasound provides more complete information, detects lesions unsuspected preoperatively, reduces dissection time, and helps avoid portal vein and pancreatic duct injuries.[45]

In surgery for pancreatic adenocarcinomas, ultrasound can help confirm the diagnosis, detect tumor encasement of blood vessels, and identify anatomic relations before resection.[15] Ultrasound allows biopsy without risk of visceral or vascular injuries. Sonography helps differentiate blood vessels from other hypoechoic structures. Doppler imaging has been used for this purpose with good results.[46] Lane and Glazer used intraoperative ultrasound in five patients with pancreatic disease and found it useful in detecting portal vein infiltration by tumor.[47] Serio and colleagues used intraoperative ultrasound to identify small focal lesions less than 1 cm in diameter. They reported a sensitivity of 96%. Also, intraoperative ultrasound-guided fine-needle aspiration biopsy allowed biopsy tumors nonpalpable either because of their small size or because of the superimposition of pancreatitis. For staging, ultrasound is useful in detecting vascular involvement, liver metastases, and enlarged nodes.[48]

Norton and colleagues demonstrated that palpation and intraoperative ultrasound are complementary in detecting islet-cell tumors of the pancreas. In 11% of patients surgical management was affected by information provided by intraoperative ultrasound and not provided by palpation. The sensitivity for detecting pancreatic islet-cell tumors was 93%. Also, ultrasound helped differentiate malignant islet-cell tumors from benign tumors.[49] In Gorman's series, intraoperative ultrasound had the highest sensitivity for insulinomas. Additionally, it was valuable in determining the relation of the insulinoma to the pancreatic and bile ducts, thereby facilitating safe enucleation. This precise localization lessens the incidence of postoperative pancreatic fistulas. The combination of palpation and ultrasound optimizes sensitivity. In patients with previous pancreatic explorations ultrasound can be particularly helpful, helping to determine which procedure to follow.[50] In a series by Grant and colleagues of 36 operations for insulinoma, the sensitivity of tumor localization was 53% for arteriography, 36% for CT, 59% for preoperative ultrasound, and 90% for intraoperative ultrasound. For 62% of the patients who underwent intraoperative ultrasound, the information obtained influenced the surgical plan.[51] Cromack and colleagues used intraoperative ultrasound in 10 patients with Zollinger-Ellison syndrome. They found that palpation had better sensitivity and specificity than ultrasound in localizing a gastrinoma. However, the combination of ultrasound and palpation raised the specificity and positive predictive value to 100%.[52]

In surgery for complications of pancreatitis, ultrasound findings are helpful in confirming the diagnosis and can disclose previously unknown problems due to pancreatitis, allowing them to be managed during the same procedure.[15] Intraoperative ultrasonography has been useful in the management of pseudocysts and chronic pancreatitis and has allowed unsuspected pseudocysts to be detected.[53] In operations for pancreatic pseudocysts, this method helps identify and characterize the pseudocyst, measure the wall thickness, determine the best site for internal drainage of the pseudocyst, and avoid injury to vascular and other adjacent structures. Also, nonpalpable peripancreatic fluid collections and abscesses can be identified.[54] In two pancreatic cases, Kurohiji and colleagues detected multiple pancreatic pseudocysts that were unrecognized preoperatively. Doppler evaluation allowed the delineation of small blood vessels around the pseudocysts.[55] In surgery for chronic pancreatitis, sonography revealed the size and location of pancreatic ducts, thereby helping to determine the surgical plan.[56] In pancreatic surgery in general, intraoperative ultrasound reduces the amount of vascular and tissue dissection done as well as surgical time.[48,53,55]

Other Applications

Ultrasound-guided fine- or thick-needle biopsy allows precise control of tissue obtained. Additionally, ultrasound-guided ethanol injection for ablation of hepatocellular carcinomas ensures accurate and adequate diffusion of the injected material in the tumor, thus optimizing necrosis.[57] Excellent results have been reported. Intraoperative ultrasound has other miscellaneous applications. For example, splenic venous thrombosis was diagnosed in a patient with massive gastric hemorrhage. This finding determined that the appropriate therapy was splenectomy.[58]

Laparoscopic Ultrasound

Characteristics of Laparoscopic Ultrasound Probes

As advanced laparoscopic surgery develops, the number and variety of procedures increases daily. Because surgeons lose tactile sensation during laparoscopic surgery, we lose the ability to perceive what is inside solid and hollow organs and the retroperitoneum. The technological capability of placing high-frequency high-resolution transducers on the tip of probes that can be inserted through laparoscopic trocars, promises not only to replace the lost sense of touch but to surpass it in accuracy. Currently the applications and techniques of laparoscopic ultrasound are being investigated in Japan, Europe, and the United States.[59–75] Different transducer configurations are being evaluated. These include rigid probes with the transducer on the tip, flexible tips, and flexible fiberoptic scopes incorporating an ultrasound transducer that are modifications of endoscopic ultrasound systems. Other systems have small probes that can be passed through a cystoscope. A flexible tip promises to enhance access to difficult areas such as the dome of the liver, as well as to allow the surgeon to optimize contact between the probe and the organ. Probe diameters vary between 7 and 12 mm, but there is also a miniature ultrasound-transducer-containing catheter measuring 3 mm in diameter. When the transducer is an independent instrument, another port must be used for the laparoscope that guides the sonography. Transducers that operate at frequencies of 3.5, 5, 7, 7.5, and 10 MHz provide different penetrations and resolution. The scanning modes are sector, linear, A and B mode, and real-time. Also probes designed for vascular purposes have been used in laparoscopic surgery.[61] The following section describes applications that allow the benefits of laparoscopic ultrasound to be compared with those of open-surgery ultrasound.[12]

Initial Experience with Laparoscopic Ultrasound

Although the echolaparoscope was first used more than two decades ago, the first reports were anecdotal accounts of the use of experimental probes on a limited number of patients and pathologies. The first report on laparoechography gave an accuracy rate of 88% in 24 cases, which was considerably higher than those of percutaneous ultrasound (47%) and laparoscopy (59%).[62] For some reason, however, interest in laparoscopic ultrasound dwindled, perhaps because advanced therapeutic procedures were not described and because sonography was not completely developed.

Fukuda and colleagues studied two types of echolaparoscopes that operated at 7.5 and 10 MHz and had a rotating mirror connected to the motor unit. They studied autopsy specimens with good results.[63] Later Fukuda used echolaparoscopy in 67 patients. He found laparoscopic ultrasound was able to demonstrate occult lesions in the liver, including cysts and tumors. Hemangioma and hepatocellular carcinoma could be differentiated without difficulty. Ultrasound was also used as a guide for liver biopsy of occult tumors and for decision making in cases where surgical resection of hepatic lesions was under consideration.[64] In cases of hepatic tumor it was useful in identifying daughter nodules adjacent to the tumor, tumor thrombi in the vascular lumen, and the degree of vascular invasion. Ota and colleagues used a combined scanner and laparoscope that had a wide field of view, a forward-oblique optical axis, and was equipped with 7.5-MHz mechanical radial scanner at the tip. They used it in patients with suspected tumor of the liver, pancreas, or gallbladder. They were able to detect a small liver tumor that could not be detected by a standard ultrasound scanner. Aramaki used a laparoscope with an ultracompact ultrasonic transducer operating at 7.5 MHz (a mechanical sector-scanning, B-mode scope). He used it in patients with chronic active hepatitis, liver cirrhosis, fatty liver, polycystic liver, hepatoma, and polycystic kidney. This laparoscope worked well for tumor assessment.[66] Furukawa used two different probes operating at 5 and 7.5 MHz with radial mechanical scanning. A second port was required for the laparoscope. They studied 126 patients with hepatobiliary tract and digestive tract disease. They diagnosed liver tumors, liver cysts, gallstones, and other tumors in the gastrointestinal tract.[67]

A flexible fiberscope system with a linear scanner has also been developed. Kodama used this device in patients with hepatocellular carcinoma, liver cirrhosis, pancreatic cancer, pancreatic cyst, metastatic liver cancer, subphrenic abscess, gastric cancer, and other disease processes. Laparoscopic ultrasound provided accurate information about the pancreas and permitted pancreatic biopsy under direct vision. Kodama recommended linear rather than sector scanning.[68,69] Fornari and colleagues in Italy used a 7.5-MHz rotating transducer fixed to the tip of the laparoscope with a sector-scan display of 180°. Although this was a suboptimal device they were able to visualize small liver lesions and appreciate clearly the patterns of cirrhosis, hepatic cysts, and hemangiomas. Intraoperative ultrasound was more sensitive in detecting small hepatic lesions than conventional ultrasound. They recommended the use of laparoscopic ultrasound to study patients with cirrhosis, screen for small metastases or hepatocellular carcinomas, assess tumors prior to liver surgery, guide biopsies, diagnose confusing hemangiomas, and examine the gallbladder wall.[70]

Frank and colleagues in Germany used a different type of probe. It had a tubular shaft with a channel for a 3-mm cystoscope. This prototype operated at 7 MHz and used linear scanning.[71,72] Goldberg and colleagues reported their preliminary experience with a miniature ultrasound transducer (12.5 MHz) housed in a 9F catheter. They evaluated 20 patients undergoing cholecystectomy, exploratory laparoscopy, gynecologic laparoscopy, and mediastinoscopy. They were able to characterize a liver mass seen on preoperative magnetic resonance as a complex cyst. They were able to obtain biopsies and aspiration samples using ultrasound guidance.[73] Another application of the laparoscopic ultrasound is the ability to obtain, with low risk, tissue from intraorganic lesions for histologic work-up using sonographic-guided thick or true-cut needles.[74,75] Ascher evaluated a probe designed for vascular ultrasound that allowed visualization of the extrahepatic biliary tract in 20 patients. Moreover, he tested this probe in four pigs in whose common bile duct a single human calculus had been placed. In all instances the size and location of the calculus was accurately detected.[61]

Although the current experience with laparoscopic ultrasound is limited, ultrasound has been found useful in assessing the liver, biliary tract, pancreas, and retroperitoneum, and for obtaining safe and accurate biopsies. The future will determine its usefulness in the investigation of other organs, such as the stomach, duodenum, spleen, uterus, kidney, adrenals, vascular structures, and lymph node chains. We certainly agree with Frank that "laparoscopic sonography is going to add a new dimension to the diagnosis of abdominal disease."[71]

University of Göettingen—Preliminary Experience

Preliminary experience at the University of Göettingen included 20 patients (Table 27.3).[76] Two different probes were assessed. One was a linear 7.5-MHz scanner with

TABLE 27.3. University of Göettingen experience with laparoscopic ultrasound.

Diagnosis	Laparoscopic ultrasound	Confirmed
Gallstones	No evidence of common bile duct (CBD) stones	No stones on IOCG
Gallstones	Stones smaller than 3 mm in CBD	Small stones on IOCG
Gallstones	3.7-mm stone close to the papilla	CBD stone on IOCG
Gallstones	No evidence of CBD stones	NO stones on IOCG
Gallstones	3-mm stone close to the papilla	CBD stone on IOCG
Gallstones	No evidence of CBD stones	No stones on IOCG
Gallstones	Multiple small stones close to papilla	CBD stones on IOCG
Gallstones	No evidence of CBD stones	No stones on IOCG
Gallstones	Common hepatic duct (CHD) stone	CHD stone on IOCG
Gallstones	No evidence of CBD stones	No stones on IOCG
Staging laparoscopy non-Hodgkin's lymphoma	Enlarged para-aortic lymph node	Confirmed histologically
Staging laparoscopy non-Hodgkin's lymphoma	Normal LU	No histopathologic findings
Liver metastases	LU-guided biopsy	Metastases confirmed histologically
Rectosigmoid cancer	Tumor localization by LU, no liver or lymph node metastases	Correct localization of the tumor, no lymph node metastases
Rectal tumor (6 cm)	Tumor could not be localized, no metastases	Histologically no metastases
Rectosigmoid cancer	Tumor localization by LU, no liver or lymph nodes metastases	Correct localization of the tumor, no lymph node metastases
Rectosigmoid cancer	Tumor localization by LU, peritumoral lymph nodes metastases	Correct localization, lymph node metastases confirmed histologically
Pancreatic cancer	Multiple preoperatively unsuspected liver metastases, splenic vein thrombi	Nonoperable, liver metastases confirmed histologically
Pancreatic cancer	No liver metastases, no vessel compromise	Operable
Cystic gastric tumor	Submucosal tumor, no metastases	Ectopic pancreatic tissue

color duplex sonography, flexible shaft movable in all directions and 13-mm external diameter. The other was a rotating sector scanner, with a field of view of 360°, operating at 5.5 MHz, and a rigid shaft with 7-mm external diameter. The probes were assessed during several laparoscopic procedures, which included cholecystectomies, staging laparoscopy for non-Hodgkin's lymphoma, laparoscopy for liver metastasis, pancreatic tumor staging, colon cancer surgeries, and one surgery for a cystic gastric tumor. Intraoperative ultrasound identified common duct stones in five patients, finding corroborated with cholangiography. Additionally, intraoperative ultrasound helped provide more accurate tumor staging, guided liver biopsy, and showed splenic vein thrombosis in a patient with pancreatic cancer.

St. Vincent Hospital—Preliminary Experience

With the rapid progress of laparoscopic surgery, many advanced procedures are now possible. The immediate applications of intraoperative ultrasound will most likely be in the biliary tract, liver, and pancreas. With experience, the indications will increase. In this preliminary study we have assessed the uses, function, design, and limitations of two prototype laparoscopic transducers.

Material and Methods

Between September 1992 and March 1993, laparoscopic ultrasound was performed during 68 surgeries at St. Vincent Hospital and Health Care Center. Patients evaluated had a variety of indications for laparoscopic surgery. Twenty-three (33.8%) were males and 45 (66.2%) were females. The age range was 17 to 88 years, with a mean of 51.1.

The prototype transducers were designed by Acoustic Imaging Corporation for use with the AI 5200 B ultrasound unit (Acoustic Imaging Inc., Phoenix, AZ) The devices were rigid probes consisting of a 7- or a 10-MHz linear transducer on a 36-cm tubular shaft with a flat surface 3 cm long on one side of the shaft tip (Figures 27.1 and 27.2). At the other end was a fatter handle, which was connected to the cable linked to the ultrasound unit.

The 7-MHz transducer was used 51 times, and the 10-MHz transducer was used 21 times. In four patients both probes were used. Fifty patients underwent cholecystectomy with intraoperative cholangiogram (IOCG) using a state-of-the-art digital-fluoroscopy unit with digital subtraction capability (Unit 9400, OEC-Diasonics, Inc., Salt Lake City, UT). In all cases IOCG was performed following laparoscopic ultrasound. Eighteen additional patients underwent different procedures (Table 27.9).

The probe was introduced through the 11-mm umbilical port. Through an accessory port a 5-mm laparoscope was introduced to guide the ultrasound probe. In order to diminish interference from air, we often infuse about 50 to 500 cc of normal saline.

FIGURE 27.1. Prototype Acoustic Imaging laparoscopic ultrasound probe.

FIGURE 27.2. Intraoperative laparoscopic ultrasound with the Acoustic Imaging 5200B unit.

Results

In order to present our experience more clearly, we have separated the patients into two categories: group 1—evaluation of the common bile duct during laparoscopic cholecystectomy; and group 2—evaluation of liver and other organs.

Group 1—Evaluation of the Common Bile Duct During Laparoscopic Cholecystectomy

In this group there were 50 patients: 15 (30%) males and 35 (70%) females. The age range was 17 to 79 years. The 7-MHz probe was used 39 times, the 10-MHz probe 13 times, and both transducers were used 2 times. The diagnoses included: chronic cholecystitis with cholelithiasis in 35 patients; acute cholecystitis with cholelithiasis in 9; and chronic acalculous cholecystitis in 6. Additionally, nine patients had common bile ducts stones, two had gallstone pancreatitis, one had a cholecystoduodenal fistulae, and one had intractable gastroesophageal reflux. All patients subsequently underwent cholecystectomy with IOCG. Additionally there were 12 biliary tract explorations, 11 choledochoscopies, one electrohydraulic lithotripsy of a common bile duct stone, one repair of a cholecystoduodenal fistula, and one Nissen fundoplication (Figures 27.3–27.8).

In eight patients, common bile duct stones were suspected preoperatively (Table 27.4), although bile duct stones were not seen on preoperative ultrasound. One of these patients underwent preoperative ERCP with removal of multiple common bile duct stones. In five of these eight patients common duct stones were found during surgery. Stones were also found in another four patients with unsuspected choledocholithiasis (Table 27.5).

In all, stones were found in nine patients. Intraoperative cholangiography had one false negative and three

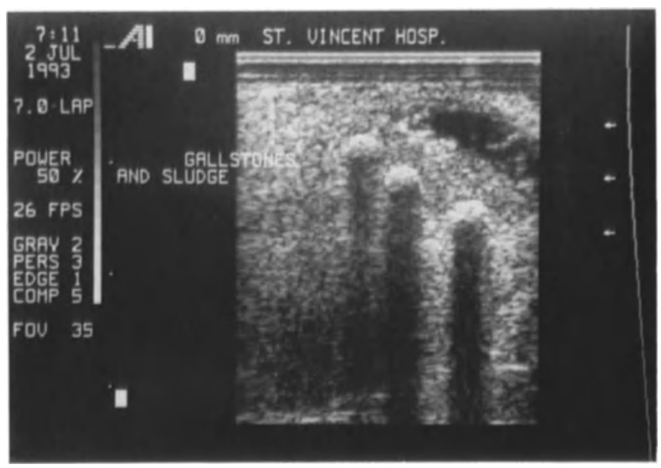

FIGURE 27.3. Gallbladder filed with sludge and stones. Note the posterior shadowing of the dense stones.

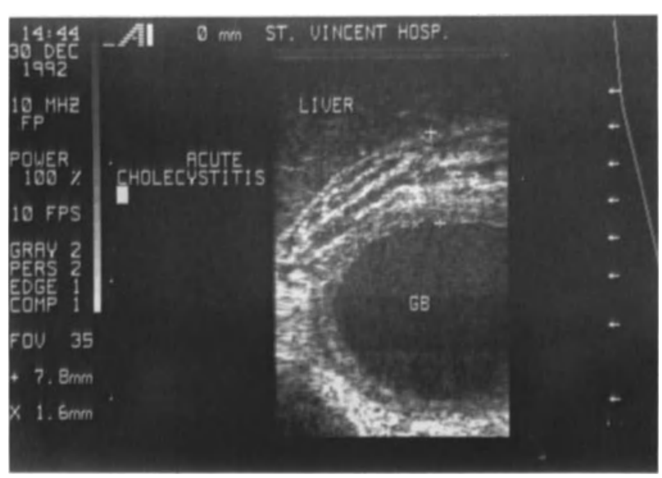

FIGURE 27.4. Thickened gallbladder wall (7.8 mm) in a patient with acute cholecystitis.

FIGURE 27.5. Transhepatic view of the liver, common bile duct, hepatic artery, and portal vein.

FIGURE 27.6. Dilated common bile duct with dense stone. Note the posterior shadowing.

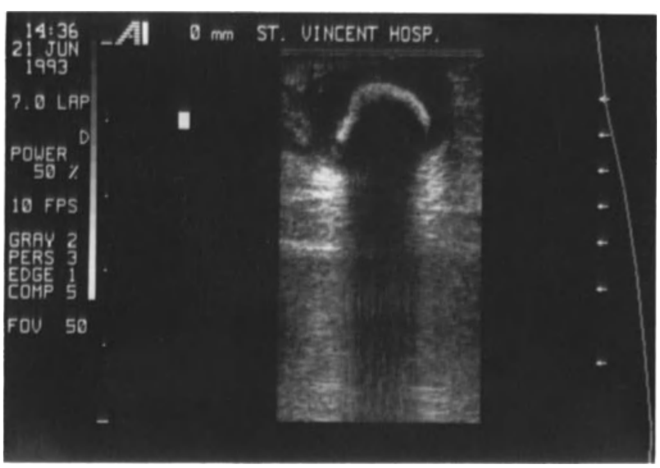

FIGURE 27.7. View of the head of the pancreas showing a dilated common bile duct and a pancreatic duct containing some debris. The vena cava underlying is somewhat compressed.

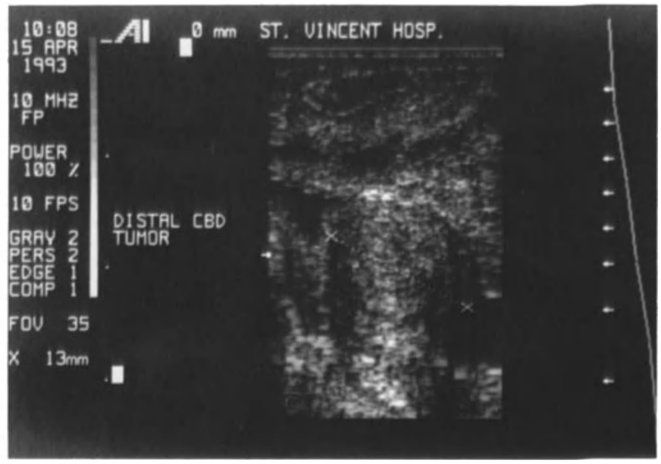

FIGURE 27.8. Ultrasound view of a patient with a tubovillous adenoma in the distal common bile duct. Note that the adenoma is solid with internal echoes and no posterior shadowing. The tumor measures 13 mm. This patient had high-grade dysplasia with no evidence of invasive adenocarcinoma.

TABLE 27.4. Patients with preoperatively suspected common bile duct (CBD) stones.

				Presence of CBD stones or filling defect		
Patient	Jaundice	Elevated alk. phos.	Preop. US	LU	IOCG	Choledochoscopy
1*	+	+	Dilated CBD	+	+	+
2	−		Dilated CBD	+	+	+
3	+		Dilated CBD	+	+	+
4	+	+	CBD not seen	−	−	**
5	+	+	Normal CBD	−	−	**
6	+	+	Normal CBD	−	+	−
7	+	+	Normal CBD	+	+	+
8	+	+	Normal CBD	−	+	+

*This patient underwent preoperative ERCP with incomplete stone extraction.
**Biliary tract exploration was not performed.

TABLE 27.5. Patients with preoperatively unsuspected common bile duct (CBD) stones.

				Presence of CBD stones or filling defect		
Patient	Jaundice	Elevated alk. phos.	Preop. US	LU	IOCG	Choledochoscopy
9	−	−	Normal CBD	+	+	+
10	−	−	Normal CBD	+	+	*
11	−	−	Normal CBD	+	+	+
12	−	+	Normal CBD	+	−	+

*In this patient it was impossible to advance the choledochoscope through the cystic duct. She underwent biliary tract exploration with a basket.

false positives. In the patient with a false negative the stone was identified by laparoscopic ultrasound. Ultrasound identified common bile duct stones in eight of the nine cases. Ultrasound had one false negative. This was a stone impacted in the ampulla that was detected with intraoperative cholangiography. In seven patients biliary tract stones were clearly seen by laparoscopic ultrasound. In the patient who underwent preoperative ERCP, a questionable filling defect was seen on intraoperative cholangiography. Intraoperative ultrasound of the common biliary duct was performed again. Though they were difficult to see, stones were then identified. There were no false positives for laparoscopic ultrasound. The sensitivity, specificity, and accuracy for these tests are shown in Table 27.6.

Twelve biliary tract explorations were performed. There were three negative explorations. In one patient with cholelithiasis and pancreatitis, intraoperative ultrasound showed that the common bile duct was dilated and tortuous. There was no obvious choledocholithiasis, but there appeared to be sludge in the distal duct. Cholangiography showed no filling defects, but the contrast did not empty into the duodenum. The sludge was not detected with intraoperative cholangiography. Biliary tract exploration confirmed the sludge and showed an occluded papilla. This patient subsequently underwent endoscopic papillotomy for this high-grade stenosis. In another patient with pancreatitis and cholelithiasis, laparoscopic ultrasound was normal, but intraoperative cholangiogram showed a distal filling defect and no contrast flowed into the duodenum. Ultrasound was repeated after intraoperative cholangiography but still no stones were seen. Choledochoscopy was negative, confirming the ultrasound diagnosis. In the third patient, laparoscopic ultrasound showed a dilated common duct but no stones. Intraoperative cholangiogram showed a questionable filling defect in distal common duct. Choledochoscopy was negative.

The liver, gallbladder, intra- and extrahepatic biliary tract, and pancreas were also examined with ultrasound. In some cases information was obtained with ultrasound that was not suspected preoperatively (Table 27.7). This information was useful because it clarified some diagnoses, changed surgical plans, and assisted in executing the operative procedure.

In one patient, ultrasound was useful in locating the choledochoscope tip during proximal exploration of the biliary tree. In a patient with air in the gallbladder on preoperative abdominal x-ray, a cholecystoduodenal fistula was suspected. This fistula was identified with both laparoscopic ultrasound and intraoperative fluorocholangiography. In two patients with acute cholecystitis and severe inflammation around the triangle of Calot, intraoperative ultrasound helped identify the cystic duct, thus making exploration safer.

Limitations. These prototype laparoscopic probes had many shortcomings. The configuration of the probes and the capabilities of the transducers caused problems, usually related to the body habitus of the patient. In patients with thin livers the intrahepatic biliary tree could be seen well. In fatty livers, penetration to the level of the bile duct was limited and suboptimal detail was obtained. Because the probe was rigid, the angle between the transducer and the tissue was often suboptimal. The common bile duct was often distorted.

The body and head of the pancreas were usually well visualized. Occasionally, the tail of the pancreas could not be seen due to interference by air or food in the stomach. In many patients, especially those with much fatty tissue in the portal area and duodenal bulb, the pancreatic parenchyma was not distinguishable from the surrounding fatty tissues. Transverse, rather than sagittal views of the pancreas might have allowed better visualization of the pancreatic duct. The orientation of the anatomy of the pancreas and surrounding structures would also have been more familiar.

The transducers often produced a "rainfall pattern" in the image, especially in the case of deeper penetrations. This artifact was more of a nuisance than a limitation, however. Transverse horizontal lines were often evident during imaging. These also were mostly an annoyance and did not prevent interpretation of the image.

Group 2—Other Procedures

In this group there were 18 patients: 8 (44%) males and 10 (55.6%) females The age range was 27 to 88 years. The 7-MHz probe was used 12 times, the 10-MHz probe

TABLE 27.6. Diagnosis of biliary tract stone: intraoperative cholangiography (IOCG) vs. laparoscopic ultrasound (LU).

	IOCG	LU
True positive	8	8
True negative	38	41
False positive	3	0
False negative	1	1
Sensitivity	89	89
Specificity	93	100
Accuracy	92	98

TABLE 27.7. Information obtained only by laparoscopic ultrasound.

CBD stone	1
CBD debris	2
CBD sludge	1
Edematous CBD	1
Hepatic artery anterior to CBD	3
Cystic artery anterior to CBD	1

was used 8 times, and both transducers were used 2 times. Laparoscopic ultrasound was accomplished in all cases. The liver, gallbladder, intra- and extrahepatic biliary tract, pancreas, kidneys, adrenals, spleen, lymph node chains, stomach, duodenum, and colon were selectively examined. The liver was evaluated most frequently, usually to characterize its anatomy, search for metastasis, or characterize tumors (Table 27.8). The preoperative diagnosis, postoperative diagnosis, and procedures performed are listed in Table 27.9.

Evaluating the Liver. The liver was evaluated in 17 cases for various reasons, most commonly, for staging colorectal carcinoma or evaluating metastatic lesions. During resection for colon carcinoma, ultrasonography was used to rule out metastatic lesions to the liver parenchyma. Three patients underwent colon resections for cancer. Laparoscopic ultrasound did not show liver metastases. This confirmed preoperative CT scan and ultrasound findings. One of the patients who underwent open resection had a palpable mass in the left lobe of the liver. The ultrasound probe was used to identify this as a simple cyst.

Two patients underwent laparoscopic ultrasound evaluation prior to planned partial hepatic resection for colorectal metastasis to the liver (Figures 27.9–27.11). One liver metastasis identified by ultrasound was not seen in the preoperative CT. Additionally, ultrasound showed hypolucency surrounding a mass in the posterior segment of the right lobe of the liver, suggesting diffuse infiltration. This patient underwent open exploration because laparoscopy and laparoscopic ultrasound did not allow a decision of nonresectability to be made. At open exploration a palpable portal lymph node was identified. The ultrasound probe was applied to the tumor to confirm that it could be seen with either the 7- or the 10-MHz transducer. It was determined that the transducers could identify an enlarged suspicious node (Figures 27.12 and 27.13). Hepatic resection was canceled because of the metastatic portal lymph node. In another patient, who was referred for resection of metastatic rectal cancer to the liver, laparoscopic ultrasound staging confirmed the number of metastases seen on preoperative CT evaluation. One of the tumors, however, was larger than it had appeared on preoperative studies. On this occasion the ultrasound probe was used to look for enlarged portal lymph nodes. An enlarged node was identified, and biopsy confirmed adenocarcinoma. Open surgery was not needed to determine nonresectability.

TABLE 27.8. Diagnosis of lesions in organs other than the biliary tract in which laparoscopic ultrasound was used.

Liver metastasis	4
From colon cancer (2)	
From pancreatic cancer (2)	
Colon cancer	3
Unspecified liver mass	2
Diverticulitis	2
Carcinomatosis	2
Exploratory laparotomy to rule out malignancy	1
Idiopathic thrombocytopenic purpura	1
Splenic rupture	1
Adrenal tumor	1
Lymphoma	1

Other lesions were also clarified or characterized with the laparoscopic ultrasound probe. In an HIV-positive patient with perforated appendicitis three hepatic masses were discovered preoperatively. These masses were hypolucent on CT and solid on preoperative ultrasound. The most-probable diagnosis was abscess, but it was impossible to rule out tumor. With laparoscopic ultrasound two of the three masses were clearly seen and characterized. The more clearly seen was 2.5 cm, complex, appearing solid, but with some small areas of clear microcysts suggesting an early liver abscess. Ultrasound-guided biopsy was attempted but was unsuccessful because of the lack of an ultrasound needle guide. Repeated postoperative ultrasounds and CT scans have shown persistence of the masses but no change. The exact nature of these lesions remains unknown. In one patient with known metastatic pancreatic cancer who developed acute cholecystitis with an adjacent liver abscess, it was possible to aspirate the gallbladder and abscess under ultrasound guidance. The abscess was in the liver parenchyma and not visible laparoscopically. In another patient with an unknown primary intra-abdominal adenocarcinoma with peritoneal implants, ultrasound evaluation revealed no evidence of metastatic liver implants.

Evaluating Other Organs. Laparoscopic ultrasound was used to evaluate still other organs. In a patient with known metastatic pancreatic carcinoma who was to undergo laparoscopic gastrojejunostomy, the preoperative CT scan poorly characterized the tumor, and preoperative ultrasound demonstrated the mass fairly well. Laparoscopic ultrasound could not clearly distinguish the large, diffusely infiltrating mass from the surrounding tissue. In this case intraoperative ultrasound was of no value.

One patient with a preoperative diagnosis, based on preoperative CT, of gastric-outlet syndrome secondary to pancreatic pseudocyst and liver hemangiomas was found to have pancreatic cancer with liver metastases and peritoneal implants on laparoscopic and ultrasonographic examination. Intraoperative ultrasound was more accurate in this case than preoperative CT or preoperative ultrasound.

One patient had a preoperative diagnosis of large-bowel obstruction thought to be secondary to colon carcinoma. During surgery, laparoscopic ultrasound evaluation showed a uniform thickening of the bowel wall with

TABLE 27.9. Laparoscopic procedures other than cholecystectomy in which laparoscopic ultrasound was used.

Preoperative diagnosis	Postoperative diagnosis	Procedure
1. Liver metastases from colon primary	Unresectable liver metastases Portal lymph node metastases	Exploratory laparoscopy and laparotomy Liver and lymph node biopsy
2. Liver metastases from colon primary	Unresectable liver metastases Portal lymph node metastases	Exploratory laparoscopy Lymph node biopsy
3. Sigmoid carcinoma and cecal villous adenoma	Sigmoid carcinoma and cecal villous adenoma	Laparoscopic low anterior resection Wedge resection of the cecum Intraoperative colonoscopy
4. Sigmoid-colon carcinoma	Sigmoid-colon carcinoma	Laparoscopic low anterior resection
5. Right-colon carcinoma	Right-colon carcinoma	Laparoscopically assisted right colectomy
6. Acute cholecystitis + liver abscess Panc. CA + carcinomatosis	Acute cholecystitis + liver abscess Panc. CA + carcinomatosis	Exp. laparoscopy. Debridement and drainage of liver abscess. Gallbladder aspiration. Cholecystostomy.
7. Perforated appendicitis Liver abscess	Perforated appendicitis Liver abscess/tumor?	Laparoscopic appendectomy Peritoneal lavage. Liver biopsy
8. Large-bowel obstruction due to colon carcinoma?	Large-bowel obstruction due to complicated diverticular disease	Open left hemicolectomy Transverse-sigmoid anastamosis
9. Perforated viscus	Perforated diverticulitis Retroperitoneal fatty mass	Laparoscopic sigmoidectomy Colostomy + Hartmann pouch
10. Gastric-outlet obstruction Pancreatic pseudocyst	Gastric-outlet obstruction Panc. CA + carcinomatosis Liver metastases	Laparoscopic gastrojejunostomy Liver biopsy
11. Gastric-outlet obstruction Panc. CA + carcinomatosis	Gastric-outlet obstruction Panc. CA + carcinomatosis	Laparoscopic gastrojejunostomy
12. Intractable ascites Intrabd. CA (unknown primary)	Intractable ascites Intrabd. CA (unknown primary)	Exp. laparoscopy. Placement of Tenckhoff catheter. Biopsy peritoneal implant.
13. Intrabd. CA (unknown primary)	Intrabd. CA (unknown primary)	Exploratory laparoscopy. Biopsy peritoneal implant.
14. Intra-abdominal tumor?	No evidence of intra-abdominal tumor	Exploratory laparoscopy
15. ITP	ITP	Laparoscopic splenectomy
16. Retroperitoneal lymphoma	Retroperitoneal lymphoma	Exp. laparoscopy. Biopsy of lymphoma. Liver biopsy.
17. Left adrenal tumor	Left adrenal tumor	Laparoscopic left adrenalectomy
18. Splenic rupture	Splenic rupture	Exploratory laparoscopy Peritoneal lavage

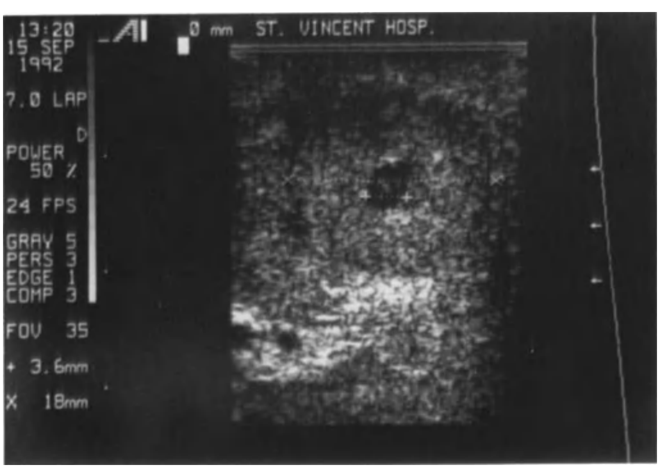

FIGURE 27.9. Liver metastasis in a patient with pancreatic cancer. Note the central hypolucent area of probable necrosis. There is also a characteristic hypolucent halo surrounding the mass.

FIGURE 27.10. Benign liver cyst with clear margins and no internal echoes.

edema. This suggested diverticulitis rather than carcinoma, and pathology confirmed this diagnosis.

In a large, very vascular lymphoma with multiple areas of necrosis, ultrasound localized a relatively avascular area with minimal necrosis where a wedge biopsy could be performed. In a patient with intra-abdominal carcinomatosis and an unknown primary tumor who underwent exploratory laparoscopy, an enlarged celiac artery node was identified by laparoscopic ultrasound. This appeared to contain metastatic adenocarcinoma. One patient with weight loss and extensive negative work-up underwent exploratory laparoscopy to look for intra-abdominal tumor. The exploration was negative. Laparoscopic ultrasound allowed the liver and pancreas to be evaluated to rule out tumor. In a patient with spontaneous splenic rupture, ultrasound did not identify any underlying pathology. It was subsequently found out that the patient was an alcoholic and often sustained falls she could not recall. During laparoscopic left adrenalectomy in a very obese patient, ultrasound helped to localize the adrenal tumor, thus aiding resection (Figure 27.14).

Influence of Laparoscopic Ultrasound. As has been mentioned, the operative plan for one patient changed because of information obtained by laparoscopic ultrasound: a planned resection was canceled due to a finding of two portal lymph nodes with metastatic adenocarcinoma.

The information obtained by laparoscopic ultrasound clarified some diagnoses, changed surgical plans, and assisted the execution of the operative procedure. Also, it was important for postoperative management of the patient. In many cases information was obtained with ultrasound that had not been suspected preoperatively.

FIGURE 27.11. Liver hemangioma. Note the discrete outline and hyperlucency.

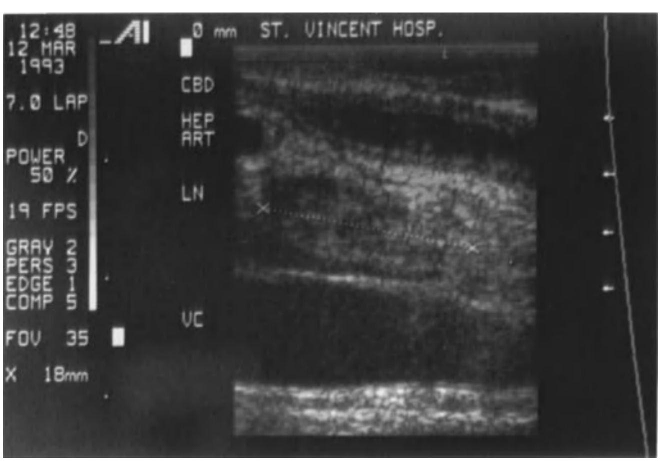

FIGURE 27.12. Inflammatory lymph node (18 mm) behind the common bile duct in a patient with acute cholecystitis. Note the thickening of the common bile duct wall. This patient also had choledocholithiasis.

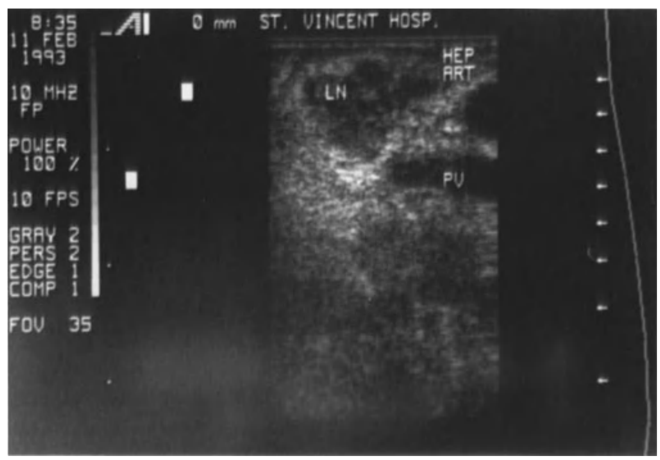

FIGURE 27.13. Metastatic lymph node in the porta hepatis in a patient with liver metastasis from a colon primary. This was histologically confirmed with a biopsy.

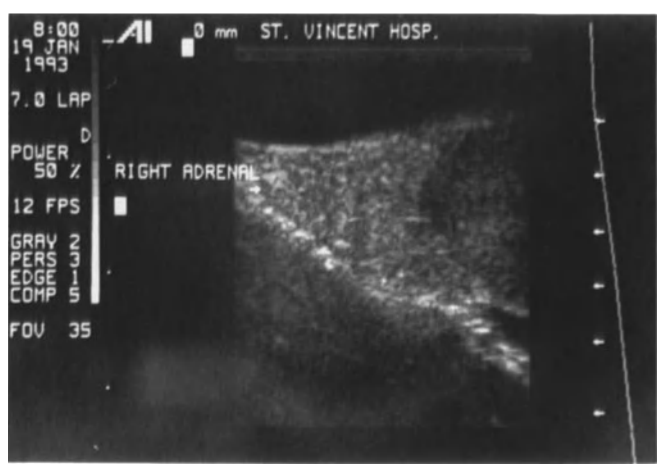

FIGURE 27.14. Normal right adrenal gland.

Limitations of Laparoscopic Ultrasound. The limitations of intraoperative ultrasound in this group of patients were similar to those in group 1 patients. The posterior segments of the medial aspects of the left and right lobes could not be seen well in most patients because of the limited penetration with the high-frequency probes. Also, the rigid straight shaft of the probe made it difficult to obtain good surface contact with the dome-shaped cephalad portions of the liver. An attempt was made to view the posterior aspects by placing the probe posterior to the liver, but adhesions or posterior penetration by a tumor often made this difficult. In the patient with appendicitis, only two of the three hypolucent areas in the liver found on preoperative CT scan were seen with laparoscopic ultrasound. Small superficial lesions with which the probe is in direct contact can also be missed. A fluid interface can eliminate this problem. Additionally, in one patient the colon interfered with visualization because it was distended due to distal obstruction.

Discussion

The differences between the two transducers are explained by their wavelengths. The 7-MHz probe has deeper penetration, and the 10-MHz probe has better resolution. The better probe depends on the organ studied, but, in general, the 7-MHz probe supplied better images. The "rainfall" pattern was more noticeable with the 10-MHz probe and seemed to be more noticeable when deeper penetration was required. The 10-MHz probe also seemed to give a more grainy picture. The probe configuration with the linear array projecting at a 90° angle from the shaft was felt to be suboptimal for some organs viewed. The angle between the probe and the anterior plane of the common bile duct was often 45°, which caused nonuniform compression of the common bile duct. Release of pneumoperitoneum was sometimes required to obtain good contact. The overall impression, however, is that with experience and improvement in technique, the present probe configuration works reasonably well for evaluation of the common duct. The limitations of our particular linear array are mainly the lack of penetration and the rigidity of the shaft which makes optimal probe positioning difficult. Most of the problems we encountered could have been overcome by introducing the probe through ports that allowed a more optimal angle. The angle of view is also small. Probes with a curvilinear array or mechanical sector scanning probes might have a wider angle of view.

In our practice IOCG always followed intraoperative ultrasound. This sequence had advantages and disadvantages. The information obtained with ultrasound, especially the finding of a stone, might have led to a more careful search for stones on intraoperative fluorocholangiography. This may have created a bias toward IOCG.

In the staging of colorectal cancer, ultrasound was useful in ruling out or better characterizing liver metastases. Ultrasound also helped clarify a hepatic cyst and characterize the features of yet unidentified hepatic masses in a patient who was HIV positive. Ultrasound was able to demonstrate enlarged metastatic lymph nodes. However, ultrasound does not allow metastases to be clearly distinguished from benign inflammatory lymph node processes. Indeed, we have seen enlarged portal lymph nodes associated with acute cholecystitis.

Based on our small preliminary experience and our review of the literature, we think that laparoscopic ultrasound has definite value. The probes are easy to use. The limitations include poor penetration, the inability to adjust the angle of contact, and the small field of view. Laparoscopic ultrasonography replaces some of the lost tactile information by allowing us to look through solid organs, vascular structures, and fluid-filled tubular and cystic structures. Many discoveries were made with laparoscopic ultrasound that were not made with preoperative imaging studies or laparoscopic visualization.

Laparoscopic ultrasonography will likely be most important in the staging of malignancies, especially in the laparoscopic management of colorectal cancers. It may also provide an alternative or complementary method of evaluating the common bile duct in the laparoscopic management of biliary lithiasis. Benign and malignant diseases of the pancreas are difficult to assess laparoscopically because of their retroperitoneal location and are therefore ideally suited to ultrasonographic evaluation. Experience with other organs will no doubt reveal additional applications for ultrasound. Also, with improvements and widespread use, the cost of the equipment may come down.

Summary and Conclusion

Although ultrasonography has progressed significantly in the past several years, laparoscopic ultrasound remains in its infancy. The technology of ultrasonography is fairly mature but until recently there was no application for it. The rapid progress in advanced laparoscopic techniques, including biliary tract exploration and surgery for malignancies, has provided a strong impetus for the development of laparoscopic ultrasound. The need is clear. Surgeons who do not acquire ultrasonography skills will be operating with incomplete information. Those dealing with malignancies will be performing inadequate staging. Although incompletely developed, laparoscopic ultrasound already has advantages that far outweigh its disadvantages.

Advantages of Laparoscopic Ultrasound

1. Substitutes for the sense of touch.
2. Allows visualization through tubular fluid-filled and solid organs as well as vascular structures.
3. Permits differentiation of solid and cystic masses.
4. Allows evaluation of the wall layers of hollow viscera.
5. Allows evaluation of the dimensions, infiltration, and dissemination of tumors for better staging.
6. Helps formulate an optimal surgical plan.
7. Avoids unnecessary tissue dissection.
8. Allows guided biopsies.
9. Easily performed, safe, and economic.
10. Does not use ionizing radiation and contrast media.
11. Can be employed at any time during surgery.
12. Can be used during pregnancy.
13. Has no contraindications.

Organ-Specific Advantages of Laparoscopic Ultrasound

Liver, Gallbladder, and Bile Ducts

1. Differentiates solid and cystic intraparenchymal lesions (for example, cysts, abscesses, tumors, hemangiomas, etc.).
2. Determines the extent of various lesions and their relation to the biliary tree and portal vessels.
3. Identifies intra- or extrahepatic biliary tract stones.
4. Can identify or confirm gallstones.
5. Can distinguish air from stones in the biliary tree.
6. Can accurately measure the biliary tree.
7. Allows guided biopsy or aspiration of cysts, abscesses, or masses.
8. Aids in tumor staging by identifying liver and nodal metastasis.
9. Complementary to cholangiography.
10. Can identify some anatomic variations.
11. Avoids unnecessary biliary tract explorations.
12. Helps in the evaluation of the resectability of liver lesions.

Pancreas

1. Helps differentiate solid and cystic lesions.
2. Helps in the diagnosis and localization of masses.
3. Determines the extent of local spread and the invasion of surrounding vascular structures.
4. Determines resectability.

Spleen, Kidney, and Adrenal

1. Identifies masses (cystic or solid).
2. Identifies dilation of the renal collecting system.
3. Identifies kidney stones.

Aorta and Vessels

1. Identifies aneurysms, thrombus, and atherosclerosis.

Hollow Viscera (Stomach, Small Bowel, Colon, and Bladder)

1. Identifies tumor location.
2. Determines depth of invasion.
3. Identifies infiltration of adjacent organs.

Abdominal and Retroperitoneal Lymph Node Chains

1. Evaluates node enlargement.

Limitations and Disadvantages

1. Equipment cost.
2. Posterior liver segments are difficult to view with rigid probes.
3. Intralumenal gas interference.
4. Some areas cannot be viewed.
5. Few surgeons have ultrasound training.
6. Limited availability of high-quality probes and units.
7. Limited experience and lack of clinical control studies.
8. Awkward probe configurations.

Future

1. Different frequencies (5, 7, 10, and 12 MHz).
2. Flexible and rigid tips.
3. Different transducer-surface configurations (flat, convex, etc.).
4. Transducers incorporated into laparoscopes.
5. Decreased equipment cost and subsequent popularization.
6. Clinical studies assessing indications and limitations.
7. Surgical training in laparoscopic ultrasound.
8. Incorporation of color Doppler.
9. Computer-generated 3D ultrasound images.

In many European countries, including Germany, ultrasound is widely used by general surgeons both intraoperatively and transabdominally. In the United States, by contrast, ultrasound is used primarily by gynecologists, urologists, and vascular surgeons. General surgeons should be considering the use of this important imaging modality.

In closing we would like to recall the remark Professor Hans Troidl of Cologne, Germany made during a talk at the annual Society of Gastrointestinal Endoscopic Surgeons (SAGES) meeting in 1989: "The ultrasound is the surgeon's stethoscope."

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28
Surgical Endoscopy

28.1 Combined Use of Flexible Gastrointestinal Endoscopy and Laparoscopy

Frederick L. Greene

The new minimal-access techniques might seem to be overshadowing traditional endoscopy, but they have actually increased the use of flexible endoscopic techniques by surgeons. The rigid laparoscope was developed for diagnostic evaluation of the abdomen and pelvis in the early part of the twentieth century. The flexible endoscope opened up new vistas when it was introduced in the late 1950s by Hirschowitz and colleagues for the evaluation of upper gastrointestinal pathology.[1] Fiberoptic technology, made possible the evaluation and confirmation by photography of lesions in the esophagus, stomach, and duodenum with a high degree of sensitivity and accuracy. Recently, the fiberoptic bundle has given way to charge-coupled devices, or CCDs, which now allow routine videorecording and high-resolution photography. In addition, videoendoscopy has permitted the gastrointestinal assistant and other colleagues to view procedures in the endoscopy suite as well as remotely. Many more individuals can participate in the consultative and learning process than before. These same electronic and engineering advances have created an environment in which laparoscopic and thoracoscopic procedures are also routine. In the process, use of the laparoscope and the flexible endoscope has become intertwined.

Upper Gastrointestinal Flexible Endoscopy and Its Relation to Minimal-Access Surgery

Using flexible upper endoscopes, the esophagus, stomach, and entire duodenum can be visualized and biopsied. Although endoscopes have been developed that are intended to be maneuvered into the small intestine,[2] these scopes are not commercially available or particularly successful, and they do not allow the small bowel to be routinely investigated by the oral route.

Upper endoscopy created the technology that allowed the introduction of endoscopic retrograde cholangiopancreatography (ERCP) in the late 1960s[3] and the introduction of endoscopic sphincterotomy in the mid-1970s.[4] Upper gastrointestinal endoscopy and ERCP are predominantly used to resolve symptoms. Esophagogastroduodenoscopy (EGD) is recommended primarily for patients with abdominal pain, dysphagia, melena, or unexplained weight loss. Studies have shown that endoscopic techniques are more sensitive than conventional radiography of the upper gastrointestinal tract.[5] Small lesions may be routinely identified through endoscopy and biopsied or studied cytologically. In addition to symptom resolution, endoscopy can be used to screen the upper gastrointestinal tract in cases of head and neck carcinoma; this is important because of the likelihood of finding squamous-cell carcinoma of the esophagus or pulmonary tree in association with similar lesions in the head and neck area. In addition, early evaluation and screening of patients with caustic stricture due to lye or acid burns has proved valuable in identifying early cancer related to continuing inflammation caused by these agents. Evaluation of patients with long-standing achalasia or reflux esophagitis and stricture has shown a small but definite increase in the finding of adenocarcinoma in the distal esophagus.[6] Annual screening with random biopsy has proven beneficial in these patients and should be continued even when surgical procedures have been performed to reverse both the achalasia and the reflux peptic disease.

Now that laparoscopic techniques are being used for acid-lowering procedures,[7] the flexible endoscope will play a greater role in the identification and follow-up of peptic-ulcer disease (Table 28.1.1). Early biopsy of gastric ulcers will lead to definitive treatment for gastric carcinoma, which can be missed by contrast radiologic techniques. Follow-up of those who are treated for acid peptic disease, either with H_2 blockers or with antibiotics effec-

TABLE 28.1.1. Combined uses of esophagogastroduodenoscopy (EGD) and laparoscopic and thoracoscopic techniques.

- Simultaneous evaluation of benign esophageal lesions (e.g. leiomyoma) and thoracoscopic resection.
- Intraoperative EGD to facilitate truncal or highly selective vagotomy.
- Intraoperative EGD to facilitate antireflux procedures.
- Intraoperative EGD to identify early neoplastic or benign gastric lesions to facilitate laparoscopic resection.
- Endoscopic ultrasound (intra- or preoperative) prior to laparoscopic or thoracoscopic resection of the esophagus or stomach.

tive against *Helicobacter pylori,* will identify patients who may be candidates for minimally invasive vagotomy or resection.

Esophageal Endoscopy

Where the esophagus is concerned, the most important use of flexible endoscopy is to identify early neoplasia in patients who present with dysphagia. It is obvious that it is important to identify both squamous-cell carcinoma and adenocarcinoma before patients present with symptoms. The earlier cancer is identified, the greater the likelihood of a cure. When patients present with dysphagia or odynophagia, it is likely that mediastinal lymphatic seeding and submucosal spread of disease have already occurred. Routine biopsy, both at the level of the lesion and at proximal and distal intervals, will be helpful to the surgeon who is called upon to do a resection or the radiotherapist who is asked to provide radiotherapeutic control of the mucosal tumor. A second use for endoscopy in this disease process is to identify tracheoesophageal fistulae in patients who present with coughing or evidence of pulmonary infiltrate along with dysphagia. Unfortunately, if fistulae are present the patients are unlikely to improve whatever the treatment modality. Palliative techniques may be employed for esophageal carcinoma and may be facilitated by endoscopy. These include dilatation with either rigid or balloon devices, laser ablation, and placement of devices that allow high-dose radiation to be applied directly to the tumor area.[8]

Flexible esophagoscopy has also been extremely useful in the therapeutic management of benign esophageal stricture, which is primarily due to esophageal reflux of acid or secondary to previous alkali or acid ingestion. These procedures may be accomplished under general or local anesthesia and may have to be repeated as the fibrotic and inflammatory process continues. As mentioned previously, early biopsy and brush cytology should be done to rule out dysplasia or early cancer associated with benign stricture.

The flexible endoscope has been applied to both diagnosis and therapy of portal hypertension that manifests itself in esophageal varices. In patients with significant alcohol history who present with anemia, early diagnosis and visualization of varices is important. In the past varices were treated by decompression of the portal system by surgical techniques. Currently, direct assault on bleeding esophageal varices, utilizing both injectional sclerotherapy and, more recently, banding techniques, has been quite successful.[9] Sclerotherapy for esophageal varices usually must be done repeatedly, but it has been effective in reducing the ongoing bleeding diatheses in patients with significant portal hypertension and cirrhosis. Banding techniques have reduced ulceration in the esophagus that has resulted from repeated episodes of sclerotherapy.[9]

Performance of Flexible Esophagoscopy

Flexible endoscopy in cooperative adults is generally performed in the outpatient setting, utilizing a combination of topical and intravenous sedation. Generally, Versed (midazolam), Demerol, or Valium is given intravenously in doses small enough to avoid significant respiratory depression. Topical pharyngeal anesthesia with lidocaine spray is quite effective and may be utilized without intravenous medications if done properly. Patients are required to fast for approximately 12 hours prior to the procedure and should be brought to the endoscopy suite by a friend or family member because of the sedative medications. Informed consent should be routinely obtained. The indications for esophagoscopy should be discussed with the patient, as well as potential complications, especially if biopsy is to be performed. Obviously only patients who are cooperative should undergo esophagoscopy under local anesthesia. Young children or patients who cannot cooperate should be endoscoped under general anesthesia.

The technical aspects of esophagoscopy have been described in several excellent atlases and monographs.[10,11] Since the esophagus is a straight tube, once peroral intubation is achieved and the upper constrictors are traversed by having the patient swallow, general examination is relatively easy, except when large bulky lesions or stenosis is present. As in any endoscopic procedure, the endoscopist must always have a clear view of the lumen before advancing the endoscope. The major difficulty of esophagoscopy is in the interpretation of findings. For the surgical endoscopist, the primary differentiations are between inflammatory and neoplastic lesions and between the presence or absence of varices.

The equipment for adjunctive techniques, such as biopsy and brush cytology, should be readily available when esophagoscopy is performed. Small lesions thought to be suspicious should be routinely biopsied, since these may indeed be the earliest forms of squamous-cell carcinoma or adenocarcinoma. If stenotic lesions or large bulky lesions that may require additional therapeutic maneuvers are noted, it is best to perform these procedures at another time if they have not been discussed with the patient.

It is important to note certain landmarks in the esophagus that will help localize lesions. One of the important and readily recognizable landmarks is the Z line, which is produced by the interface of the squamous mucosa and columnar mucosa of the stomach (Figure 28.1.1). This line is readily apparent because the esophageal mucosa is pale and the mucosa of the cardia of the stomach is hyperemic or salmon-colored. In most adults, the Z line, or gastroesophageal junction, is 40 to 42 cm from the upper incisors. The location of this landmark should be quantified during routine endoscopy, especially if a hiatus hernia, which will tend to shift the junction to a more proximal location, is present. In addition, the distances of any lesion from the upper incisors should be recorded.

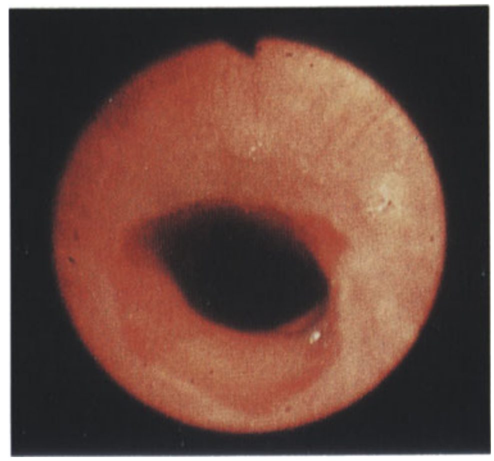

FIGURE 28.1.1. Classical appearance of Z line, or squamocolumnar mucosal junction, which occurs 40 cm from the upper incisors in the adult.

Flexible Gastroscopy

One of the main uses of endoscopic gastroscopy is the identification of cancer in patients with symptoms of pain, weight loss, and unexplained gastrointestinal bleeding. For many years, gastric ulceration was thought to be a precancerous event that, if left unchecked, would eventually develop into an adenocarcinoma. With the advent of routine gastrointestinal endoscopy, it has become apparent that most gastric ulcers are in fact benign and that ulcer patients have no greater likelihood of developing cancer than others. The importance of early endoscopy is to catch carcinomas of the stomach that present as ulcerations rather than as polypoid or exophytic lesions.

Flexible endoscopy is also important in the management of patients who have undergone gastric resection for benign ulcer disease. These patients have a propensity to develop marginal ulcer, reflux bile gastritis, anastomotic narrowing, and carcinoma in the remaining gastric pouch many years after the gastric resection.[12] Endoscopy in these patients is a challenge because the unusual anatomy makes it more difficult to identify lesions and biopsy some areas of the gastric or small-bowel anatomy. Endoscopic screening has led to local therapy for small gastric cancers, especially in areas of the world where gastric carcinoma has a high incidence.[13]

Recently, many studies have supported the association between *H. pylori* and both gastritis and duodenal ulcer disease.[14] It was endoscopy that allowed this organism to be cultured and its histologic changes identified. This led to the development of specific therapy that may revolutionize the management of acid peptic disease in the future.

Performance of Flexible Gastroscopy

Unlike the esophagus, the stomach is difficult to traverse, especially by neophytes. Although the cardia of the stomach can be intubated with ease, it is difficult to recognize the various walls of the stomach and even the lesser and greater curvature unless one is accustomed to the appearance of the gastric rugae and to the visual effect of moving the tip of the instrument or rotating the endoscope itself. Since the patient is generally endoscoped in the left lateral decubitus Sims position, the dependent wall first noted upon entering the gastric fundus is of the greater curvature. The lesser curvature is more readily seen because it is short and because it is apparent during the initial nondistended view of the stomach before air is insufflated. Although insufflation is of minimal utility in esophagoscopy, the only way to guarantee the absence of gastric pathology is to distend the stomach and flatten the rugal folds. Small ulcers or tumors may in fact hide between folds and not be apparent unless the stomach is insufflated.

The usual procedure for identifying gastric lesions is to pass the endoscope into the antrum and through the pylorus into the duodenum. The unpleasant eructation caused by duodenal intubation can be faced early in the procedure, and the full evaluation of the gastric fundus follows at leisure. Once the pylorus and duodenum are evaluated, one should retroflex the instrument in order to completely evaluate the region of the cardia and gastroesophageal junction. Unless this maneuver is performed, small tumors or ulcers may go undetected because most endoscopes are end-viewing. Following retroflexion, the antrum and body of the stomach is fully examined before the endoscope is withdrawn into the esophagus.

Since the surgical endoscopist is performing gastroscopy mainly to distinguish neoplastic from inflammatory or acid peptic disease, biopsy techniques are important. All tumors tend to have a superficial inflammatory exudate and therefore the small biopsy forceps that are readily utilized through flexible endoscopes, in fact, may not give representative biopsies of underlying tissue. It is important to aggressively biopsy beneath the surface of exophytic masses in the stomach in order to achieve an appropriate tissue sample. Three to four biopsies of different areas should be routinely performed and should be accompanied by biopsies of the mucosa in the surrounding, but apparently normal, mucosa. If obvious ulcers are noted, biopsy of the rim of the ulcer crater—not the base of the crater—should be performed. This will minimize the possibility that a neoplastic ulcer will be diagnosed as "inflammation only."

One of the most difficult diagnoses to make endoscopically is gastric lymphoma. Since in adults gastrointestinal lymphoma is most commonly found in the stomach, it is not unusual to encounter this entity during a career of managing gastrointestinal illness. Generally, gastric lymphoma presents as widened gastric rugae that are infiltrated by the lymphomatous process. Here again, unless aggressive biopsy is performed deep into the mucosa and submucosa, the diagnosis will be missed. Some have advocated snare biopsy of large areas of mucosa in order to make the diagnosis of gastric lymphoma.[15] This may be necessary when small pinch biopsies are nondiagnostic.

Colonoscopy and Its Relation to Minimal-Access Surgery

Since 1966, when the first complete flexible examination of the large bowel was performed,[16] the colonoscope has been of tremendous value in both the diagnosis and follow-up of patients with benign and malignant processes of the large bowel. Currently, the colonoscope is also a vehicle for performing therapeutic maneuvers that involve polyp resection, control of bleeding, laser ablation, and confirmation of findings utilizing both still photography and videoendoscopy. The colonoscope, which is routinely used by gastroenterologists, should be adopted by surgeons for preoperative evaluation and follow-up of patients whose colonic lesions are treated by either open or minimal-access procedures (Table 28.1.2). The colonoscope allows the surgeon to confirm the presence of abnormalities that require resection and to rule out additional lesions that might change the operative plan more accurately than barium studies.

TABLE 28.1.2. Combined uses of colonoscopy and laparoscopic procedures.

- Pre- or intraoperative endoscopy for identification of benign lesions to facilitate laparoscopic colonic resection.
- Colonoscopic polypectomy prior to segmental laparoscopic resection of synchronous neoplasm.
- Colonoscopic assessment of ulcerative colitis of Crohn's disease prior to laparoscopic resection.

Currently, videoendoscopy using the chip camera has replaced, for the most part, traditional fiberoptic colonoscopy. The change in instrumentation, however, has not led to a change in technique. The surgeon endoscopist must still develop hand-image coordination for both motion of the endoscope tip and rotation of the endoscope as a whole to ensure the safe introduction of the scope. Introduction of the colonoscope is more difficult than of the upper endoscope because of the length and mobility of the colon. Skill is required to traverse the many folds of the colon and to maneuver the tip as the endoscope is advanced toward the ileum.

Preparation of the colon is also important because fecal material or other debris can reduce visibility or affect the endoscopist's ability to safely introduce the scope. Generally, the colon is prepared using polyethylene glycol electrolyte solutions or several days of clear liquids, cathartics, and enemas. For therapeutic maneuvers, colon preparation with both mechanical and antibiotic means may be appropriate to reduce the bacterial count and to create a safer environment for laser or electrocautery.

Classically, the colon has been evaluated with barium contrast studies. These continue to be utilized and may be valuable, especially in patients with diverticulosis and carcinoma. It is generally believed, however, that colonoscopy can detect small lesions and mucosal abnormalities that are missed even by well-done barium studies.

Colonoscopy is generally performed following an abnormal or indeterminate barium enema and certainly must be performed if patients with chronic rectal bleeding are found to have a "normal" barium enema. Because of the magnification and the excellent optical quality provided by videoendoscopy, small mucosal abnormalities, such as arteriovenous malformations, may be clearly seen and can be documented with color photography or video footage. Colonoscopy is not recommended, however, if there is significant bleeding from the colon because the endoscopist's ability to visualize the colonic lumen is reduced, increasing the risk of perforation.

The colonoscopic evaluation is especially useful in determining the presence and extent of inflammatory bowel disease that is limited to or involves the colon. In the presence of chronic ulcerative colitis, which is associated with increased incidence of adenocarcinoma of the colon, repeated colonic examinations with biopsy may be required to follow patients. Repeat biopsy from multiple areas is especially important in patients with ulcerative colitis; it can identify early dysplasia, leading to a decision to undertake total abdominal colectomy. In patients who are being actively evaluated for complete colectomy, colonoscopy is important to rule out synchronous adenocarcinoma and to fully evaluate the distal ileum, if possible, for evidence of "backwash ileitis." The most important application of colonoscopy, however, is to help differentiate Crohn's disease from ulcerative colitis, conditions that require completely different operative approaches, especially if sphincter preservation and pouch-anal anastomosis are being considered. Although carcinoma is generally limited to patients with chronic ulcerative colitis, longstanding Crohn's disease may in fact be associated with adenocarcinoma and patients with Crohn's colitis should be repeatedly evaluated.

The most important group of patients to be evaluated with colonoscopy are those suspected of harboring adenocarcinoma that may require surgical resection. Patients above the age of 50, especially those with a family history of colon cancer, should undergo total colonoscopy if hematochezia or changing bowel habits are noted. It is only through early endoscopy that a positive identification, and early resection and cure can be achieved. A small percentage of patients will have synchronous cancers at the time an adenocarcinoma of the colon is discovered,[17] but the incidence of benign lesions in the form of tubulovillous polyps may reach 40 to 50% and the discovery of polyps may change the length of colon to be resected.[18] Isolated polyps, especially those that are pedunculated, may be resected during colonoscopy using a snare wire. This type of approach will become extremely important as early cancers are increasingly treated by minimal-access techniques. The surgeon who assumes the role of managing patients with colorectal carcinoma, however, must have a clear understanding of both luminal and transperitoneal endoscopic techniques.

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28.2 Endoscopic Retrograde Cholangiopancreatography in Surgical Practice: An Overview

Jeffrey L. Ponsky

Once thought to be an interesting but esoteric method of investigating biliary and pancreatic anatomy, endoscopic retrograde cholangiopancreatography (ERCP) has become an indispensable tool in the assessment and management of numerous conditions affecting the liver, bile ducts, and pancreas. Endoscopic cannulation of the papilla of Vater was first described by McCune and his coworkers in 1968.[1] Since that time, refinements in instruments and technique have enabled endoscopists to routinely employ this method for diagnosis and to expand its application to the treatment of benign and malignant conditions of the pancreas and bile ducts.

Indications and Contraindications

ERCP is useful in defining and treating a host of maladies affecting the hepatobiliary tree.[2] A careful history, laboratory assessment, and noninvasive imaging studies such as ultrasound or computed tomography are usually appropriate prior to the ERCP because they help define the need for the procedure, suggest the possible findings, and predict the need for therapy. Jaundice is a frequent indication for ERCP. The procedure can define the site of biliary obstruction, if any, and suggest therapeutic options. Suspicion of bile duct abnormalities, such as stones, strictures, or tumors, should also prompt performance of the procedure. Abnormalities of the ampulla of Vater and the occurrence of hemobilia can be investigated. ERCP is vital in the identification and treatment of bile duct injuries and leaks after cholecystectomy.[3]

Diseases of the pancreas, while often difficult to define, can be elucidated by ERCP. Visualization of the ductal system is useful in cases of recurrent pancreatitis, suspected gallstone pancreatitis, and chronic pancreatitis. More recently the method has been employed in the diagnosis and treatment of selected cases of acute pancreatitis. Suspected pancreatic malignancy is an indication for ERCP, and even some advanced cases may be palliated by therapeutic intervention. In preparing a patient for anticipated pancreatic surgery for ductal decompression, pseudocyst drainage, or resection, ERCP is useful in providing a ductal map that facilitates operative intervention. ERCP is also useful for following pancreatic disease after surgery.

ERCP should not be performed in patients with hemodynamic instability. Since fluid shifts may occur during the procedure and a variety of medications are administered, hemodynamically unstable patients may decompensate. Resuscutation should be carried out prior to ERCP, and adequate perfusion, as evidenced by satisfactory urine output, should be achieved. Although ERCP with immediate ductal decompression may resolve biliary sepsis, ERCP should not be undertaken in such situations unless the endoscopist is skilled in sphincterotomy and ready to provide ductal drainage. Although portal hypertension and severe coagulopathy do not preclude diagnostic ERCP, they significantly increase the risk of bleeding if endoscopic sphincterotomy is performed.

Technique

As with any upper endoscopy, the patient should fast overnight prior to the procedure. In those with medical histories consistent with coagulopathy, appropriate laboratory assessment should be completed and abnormalities addressed prior to ERCP. Intravenous access is mandatory during the ERCP and should be established prior to commencing the procedure. ERCP requires excellent fluoroscopic facilities and should be done in the radiology department or in an endoscopy suite with appropriate fluoroscopic equipment. Although the presence of a radiologist is not mandatory, these specialists can make the procedure more fruitful.

The patient is initially positioned in the left lateral decubitus position and then rolled to the prone position once the duodenoscope is positioned in the descending duodenum. Posterior pharyngeal anesthesia is applied, and intravenous sedation is administered. Atropine and glucagon are commonly employed to arrest duodenal peristalsis. A side-viewing duodenoscope is used to perform ERCP (Figure 28.2.1). This instrument allows *en face* visualization of the ampulla of Vater and is somewhat longer than the standard upper gastrointestinal panendoscope. Because of the side view, visualization of the esophagus is difficult, and it is usual to insert the instrument slowly, assessing the lumen occasionally as the tip is advanced into the stomach. Once the scope is in the gastric lumen, air is insufflated. Gastric fluid is aspirated, and the scope advanced through the body of the stomach into the antrum. Frequently, the tip of the scope will enter the fundus and obscure the distal lumen. In this situation, the instrument should be pulled back slightly, and the tip once again directed downward to demonstrate the correct path. Blind advancement of the scope should be avoided.

In the antrum, the endoscopist will frequently be able to see the pylorus and the cardia simultaneously (Figure 28.2.2).[4] This again is due to the side view of the scope. This view should alert the endoscopist that the tip of the instrument is indeed in the antrum. The tip of the scope is then turned downward and should approach the pylorus. As the pylorus is neared, the tip of the instrument should be slowly elevated. This will make the pyloric lumen appear to "set like the sun." In fact, the tip of the scope is aligning with the pyloric lumen. At this point, slight pressure can be applied to advance the scope through the pylorus and into the duodenal bulb. Once in the duodenal bulb, the instrument is rotated to the right, and the tip deflected downward to enter the descending duodenum. The ampulla of Vater will appear as a small vertical mound that crosses several of the circular duodenal folds. Initially, the ampulla will appear in the 9 or 10 o'clock position. The minor papilla may be noted just proximal and to the right of the major papilla. At this point in the procedure, it is useful to turn the patient to the full prone position. This will rotate the bowel on the instrument and bring the ampulla closer to the 12 o'clock position.

After initial insertion into the duodenum, a large loop of the instrument shaft is generally present in the stomach. This is called the "long scope" position (Figure 28.2.3). In most instances, it is advisable to pull back on the shaft of the scope and shorten this loop before attempting cannulation of the ampulla. This maneuver will bring the shaft of the scope along the lesser curvature of the stomach and closer to the ampulla. The "short scope" position usually makes cannulation easier (Figure 28.2.4). Small movements of the tip of the instrument and of the endoscopist's body will help to place the papilla directly in the view of the scope. No attempts at cannulation

FIGURE 28.2.2. When the endoscope is in the gastric antrum, the endoscopist will observe the antrum and gastric cardia simultaneously. This view is useful in orienting the scope.

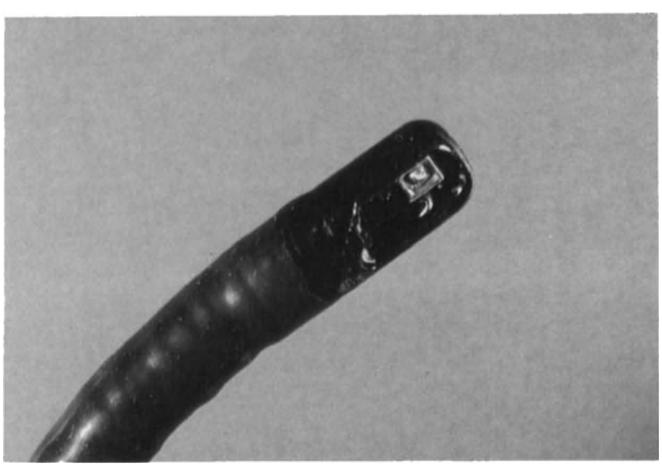

FIGURE 28.2.1. A side-viewing duodenoscope is used to perform ERCP. This permits an *en face* view of the ampulla of Vater.

FIGURE 28.2.3. The "long scope" position, with the instrument bowed against the greater curvature of the stomach.

FIGURE 28.2.4. The "short scope" position, with the scope along the lesser gastric curvature, is usually the best position for selective ductal cannulation.

FIGURE 28.2.5. The ampulla of Vater typically appears as a vertical fold crossing the horizontal duodenal plicae. The mucosa at the ampullary orifice is often slightly red and reticulated in appearance.

should be undertaken until the endoscopist has identified the ampullary orifice and can move the cannula directly toward it. The ampullary orifice is usually at the inferior end of the ampulla itself, the upper portion of the structure being the intramural portion of the common bile duct (Figure 28.2.5). The orifice is generally slightly darker than the ampullary wall and has a soft, reticulated appearance.

The cannula is gently placed at the orifice. Then, gentle pressure is applied to attempt entry. Slight upward lift with the cannula elevator may be effective. Slow injection of contrast at this point may fill both, one, or none of the ducts. All ducts will fill only if a common channel exists. Selective cannulation of the desired duct offers more information and is essential for therapeutic intervention.

The common bile duct generally courses parallel to the duodenal wall. Its orifice most often lies at 11 o'clock within the ampullary orifice and slightly superior to the pancreatic duct opening. The pancreatic duct orifice is usually at one o'clock within the papilla. The pancreatic duct emerges from the duodenum perpendicular to its wall (Figure 28.2.6). When selective cannulation is not initially achieved, variations in scope and cannula position may be tried, keeping the relative orientations of the ductal orifices in mind.

Once cannulation is achieved, injection should begin. Contrast should be injected slowly, the cannula having previously been flushed to remove air bubbles. The course of ductal filling is followed fluoroscopically, and only enough contrast is injected to demonstrate the desired anatomy. Overfilling of the pancreatic duct will opacify the substance of the gland, an event called "acinarization," and should be avoided if possible. As the ducts are filled, representative films should be taken to record the findings. The patient may be rotated to fully demonstrate various areas of the ductal system.

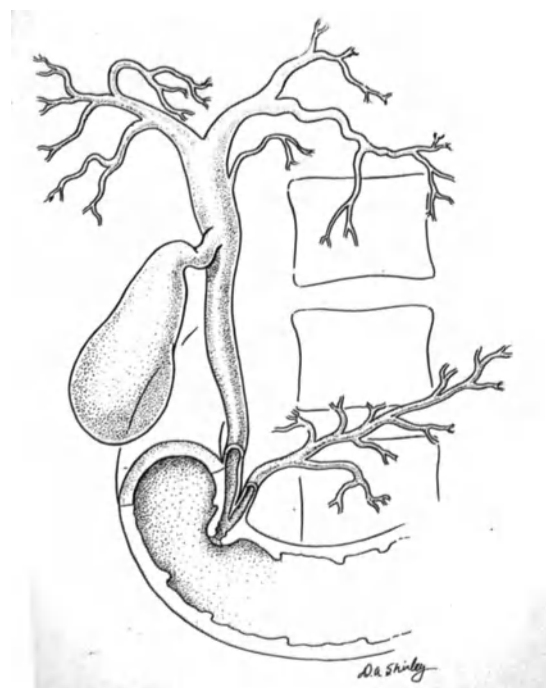

FIGURE 28.2.6. The bile duct usually runs parallel with the medial duodenal wall, while the pancreatic duct often takes a more perpendicular course away from the papilla. This may be important in directing the cannula into a particular duct.

Interpretation

The successful cannulation of the pancreatic and bile ducts is very satisfying to the endoscopist. However, success lies in accurate interpretation of the findings rather than in the cannulation itself. The films obtained must be carefully assessed. The normal biliary tree is quite familiar to surgeons. Even if a biliary tree looks relatively normal, however, subtle abnormalities of the system should be sought. These may include irregularities in the bile duct wall, ductal dilation, pruning of the intrahepatic branches, or failure to fill a particular hepatic segment (Figure 28.2.7). Areas of narrowing alternating with ectatic segments may indicate sclerosing cholangitis. Stones are usually quite obvious but may occasionally be obscured in hepatic radicals. If the gallbladder is intact, its filling, or lack thereof, as well as the details of its interior should be noted.

Pancreatic duct anatomy and pathology are less frequently encountered by the surgeon. The normal duct is about 3 to 4 mm in diameter at the head of the gland, and progressively tapers toward the tail. Numerous side branches emanate from the main duct, giving it the appearance of a fish skeleton. Areas of dilation or stenosis may indicate disease. A frequently noted configuration, the "double duct sign," occurs in carcinoma of the pancreatic head and is due to obstruction of both ducts as they course through the tumor (Figure 28.2.8). Chronic pancreatitis may demonstrate in a variety of ways from a small narrowed duct to a large dilated one. In general, tortuosity and ectasia of the ductal system are signs of chronic pancreatitis. Pancreas divisum, a congenital lack of fusion of the dorsal and ventral pancreas, may be present in up to 7% of patients. When this is the case, the ventral duct attenuates quickly after leaving the ampulla of Vater. The body and tail of the gland are drained by the dorsal duct, which drains via the duct of Santorini at the minor papilla. The condition of pancreas divisum in and of itself is not pathologic; however, ductal abnormalities may also occur secondary to conditions such as pancreatitis or tumor. Pseudocysts of the pancreas may be identified and localized by ERCP. These collections often have some communication with the ductal system. ERCP is useful in identifying associated smaller cysts, and may occasionally permit therapeutic intervention.[5]

FIGURE 28.2.7. An endoscopic cholangiogram after a difficult open cholecystectomy reveals an occlusive injury to the left hepatic duct.

Complications of ERCP

The complication rate after diagnostic ERCP is low and decreases as the experience of the endoscopist increases.[6] The most frequent problem following a diagnostic examination is pancreatitis, usually secondary to excessive distention of the ductal system with contrast. Cholangitis with resultant sepsis can occur following the introduction of bacteria into an obstructed biliary tree. When the endoscopist demonstrates an obstructed biliary system, he or she must be prepared to provide drainage of that system by performing a sphincterotomy or inserting a drain. If a drain is not inserted, sepsis is likely to result. Perforation and hemorrhage are rare with diagnostic ERCP but become more frequent after therapeutic interventions. In therapeutic ERCP, the morbidity approaches 10% and the mortality rate is close to 1%.

Therapeutic ERCP

The addition of a therapeutic arm to ERCP occurred with the introduction of endoscopic sphincterotomy. Endoscopic biliary and pancreatic therapy now includes

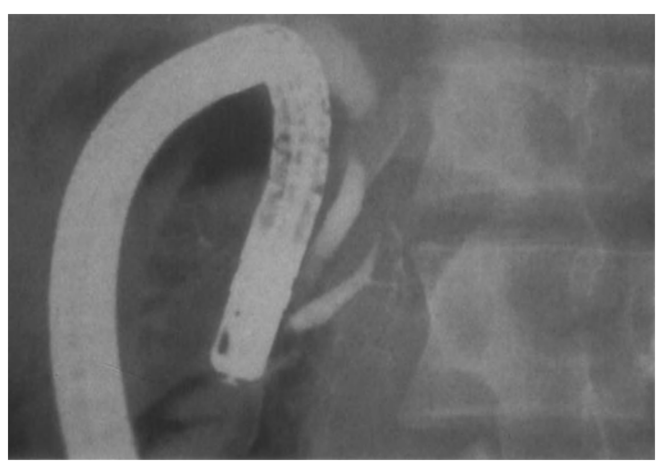

FIGURE 28.2.8. Occlusion of both the biliary and pancreatic ductal systems, the "double duct sign," is typical of carcinoma of the pancreatic head.

sphincterotomy for removal of common bile duct stones, balloon dilation of biliary strictures, placement of stents for treatment of benign and malignant obstruction of the bile duct, and treatment of biliary injury or leakage following laparoscopic cholecystectomy. Pancreatic therapy includes major and minor papilla sphincterotomy for stenosis, removal of pancreatic duct stones, drainage of pseudocysts, and placement of pancreatic duct stents for the treatment of pancreatitis. Further applications are likely to emerge in the future.

Conclusion

ERCP is a sophisticated endoscopic procedure that offers both diagnostic and therapeutic capabilities in the approach to hepatobiliary and pancreatic disease. Performance of the procedure requires great expertise in standard upper endoscopy, as well as considerable training in the cognitive and technical aspects of the procedure. As newer therapeutic applications of ERCP emerge, the modern gastrointestinal surgeon must become familiar with them, and must choose to commit himself or herself to the extensive training required to perform the procedure properly.

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29
Modern Thoracoscopy

B.M. Rodgers, J.K. Champion, and J.C. Wain

Introduction

Thoracoscopy is not a new procedure; it was first reported by Jacobaeus in 1910.[1] He described using a cystoscope to perform intrapleural pneumonolysis for tuberculosis and by 1925 had reported results in 120 patients. Several large series of patients reported from Europe between 1930 and 1970 documented the usefulness of thoracoscopy, primarily as a diagnostic tool.[2] The procedure never met with widespread acceptance in the United States, however, due to the abandonment of pneumonolysis for the treatment of tuberculosis and fear of iatrogenic infections in the pre-antibiotic era. Interest in the procedure in the U.S. was renewed in the 1970s by the report by Decamp on the use of thoracoscopy for pleural biopsy in 126 patients.[3] The procedure was further advanced by the report of Rodgers describing the use of thoracoscopy for therapeutic procedures.[4]

Up to this point thoracoscopy was limited by direct-view telescopes. Surgeons had to operate one-handed since the other hand was needed to hold and manipulate the telescope. Only one person could view the procedure and then only by crouching. With the development of video-imaging systems and advanced laparoscopic instruments, minimal-access surgery exploded. The video monitor allowed all operating room personnel to view the procedure and allowed the operating surgeons to use both hands for dissection. As a result of these improvements, thoracoscopic technique has grown rapidly over the last five years, especially in the therapeutic realm.

Operating Room Considerations

Preoperative planning should cover the following items, taking into account the type of procedure to be performed, whether diagnostic or therapeutic, and its anatomic location:

1. Patient positioning
2. Need for localization techniques
3. Use of trocars
4. Surgical technique
5. Type of anesthesia

Positioning

Patients may be positioned in the lateral decubitus or supine position (Figure 29.1). The lateral decubitus position offers the widest exposure of one hemithorax. Combined with one-lung general anesthesia with control of the airway, it is the position of choice for most therapeutic procedures. A distinct advantage is that it allows rapid conversion to open thoracotomy in the event it is required. The disadvantages of the lateral decubitus position are that it prevents bilateral thoracoscopy, limits access to the airway under local sedation, and may not be well tolerated in cases of advanced chronic obstructive pulmonary disease or interstitial lung disease. The supine position offers bilateral chest exposure and is better tolerated by the patient under local-sedation anesthesia. However, the supine position severely limits exposure of the posterior and inferior thorax. The patient's ipsilateral arm and the operating table obstruct the thoracoscope even when the patient is under general anesthesia. The supine position also prevents posterior-chest trocar insertion, which is vital to fully expose the hemithorax. The supine position is most useful for exams of the anterior and superior chest, which previously would have been accomplished by an anterior thoracotomy.

A proposed set-up for the operating room is depicted in Figure 29.2. The primary surgeon may stand on either side of the thoracoscope and the anatomic location of the lesion. If the surgeon keeps the lens between himself and the operative site, it will help prevent image disorientation. The primary surgeon may have to switch sides of the operating table during the procedure to accomplish

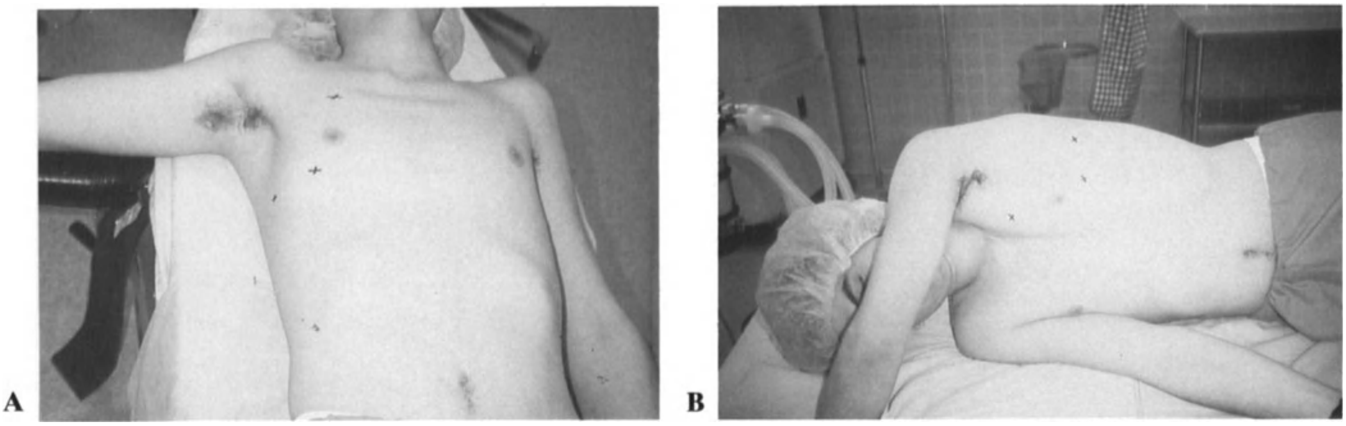


FIGURE 29.1. (A) Supine position. Note that arm and table block posterior and inferior access. (B) Lateral decubitus position. Note that upright arm should extend toward the head to maximize exposure.

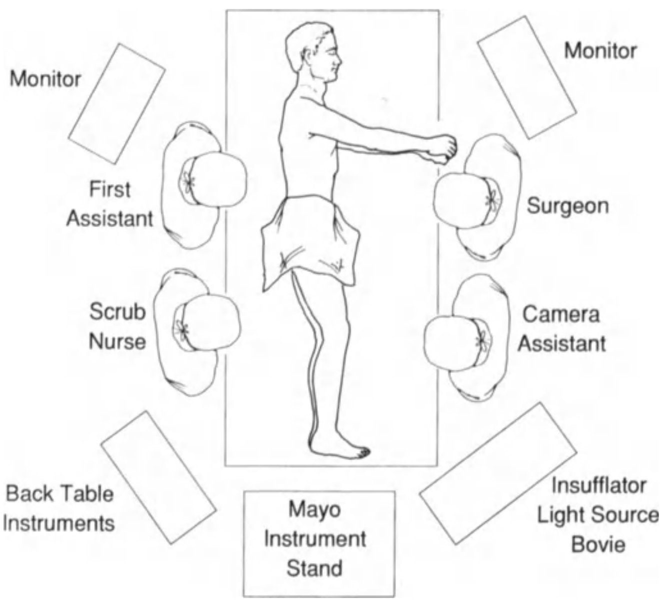


FIGURE 29.2. Operating room set-up.

this, but doing so will speed the exam and prevent confusion.

Localization

Preoperative or intraoperative localization techniques may be required in thoracoscopy because the surgeon is unable to manually palpate for pulmonary nodules. Small lesions and nodules located beneath the pleural surface can be localized preoperatively by injection of methylene blue or percutaneous computerized tomographic (CT)-directed needle-guided insertion.[5] Intraoperative ultrasound also aids localization in difficult cases.[6] Despite these innovative techniques, not every lesion will be detected. A multicenter review reported that in 7.5% of 865 cases the lesion could not be localized even by a combination of these methods.[7] Conversion to video-assisted minithoracotomy with insertion of a digit for manual palpation is indicated when indirect localization fails.[8] Ultimately open thoracotomy may be required to permit bimanual palpation of the parenchyma. If a known lesion cannot be localized and excised by thoracoscopy the surgeon should proceed immediately with open thoracotomy.

Trocars

Routine utilization of trocars in thoracoscopy benefits the surgeon by:

1. Decreasing the wear and breakage of expensive instruments
2. Speeding the repeated introduction of instruments into the chest
3. Avoiding inadvertent neurovascular injury to the intercostal bundle
4. Allowing the use of insufflation to aid exposure if necessary

There are no standard trocar insertion sites. The procedure and anatomic lesion will dictate the size, location, and number of trocars. Insertion of the first trocar via an open technique will avoid inadvertent lung injury due to adhesions, which are common.[9] Insertion of the first trocar in the anterior axillary line at the sixth interspace will provide a broad initial view of the hemithorax (Figure 29.3). Other trocars can be inserted under direct visualization aided by the video image. The use of multiple trocars allows the surgeon to change camera positions to facilitate inspection of the entire pleural space. The telescopic lens will require frequent cleaning to remove blood and prevent fogging; the trocar allows rapid access with minimal smearing of the ocular lens.

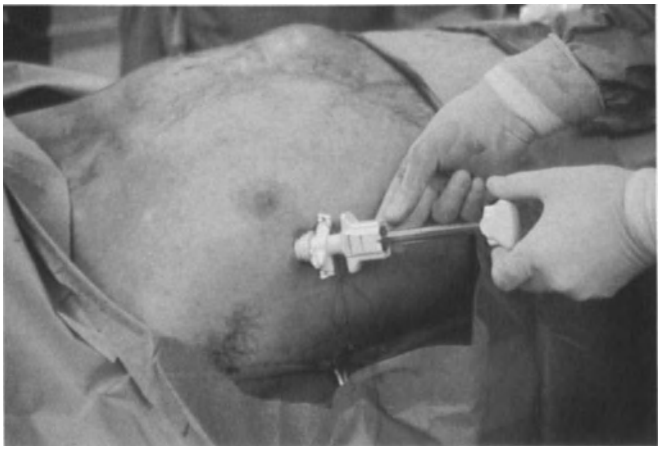


FIGURE 29.3. First trocar in anterior axillary line.

Insufflation may aid exposure during closed thoracoscopy. Intermittent use of positive pressure with local or general anesthesia can quickly decrease lung volume. Pressures of 5 mm Hg have been demonstrated to be safe in humans if they are accompanied by hemodynamic monitoring.[10] The hazard of insufflation is that the mediastinum may shift toward the contralateral hemithorax when a positive intrapleural pressure is created in the operative hemithorax. Mediastinal shift may interfere with preload and cardiac output and may compromise ventilation of the nonoperative lung.[10] The intrapleural pressure on the operative side should not exceed 5 mm Hg to limit these effects. However, since most therapeutic VAT procedures are facilitated by the larger field of view achieved with single-lung ventilation, the placement of double-lumen endotracheal tubes or bronchial blockers should be routine for these cases. Insufflation should be used only to achieve prompt deflation of the lung on the operative side.[11]

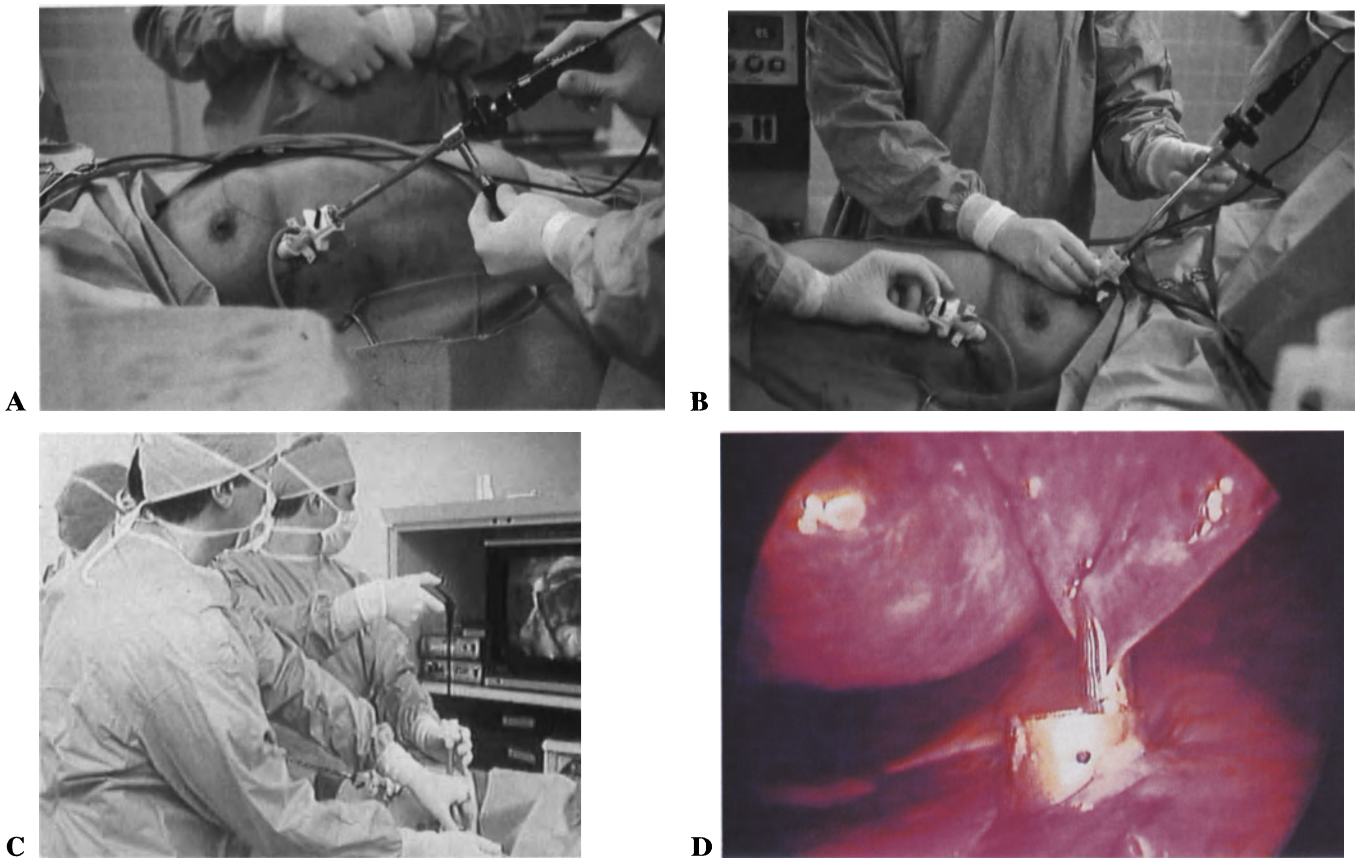
Surgical Technique

Modern thoracoscopy has evolved around two techniques: closed video thoracoscopy (CVT); and video-assisted thoracic surgery (VATS). Both techniques utilize video monitors and fiberoptic telescopes. CVT relies entirely on trocars for entry into the thoracic cavity (Figure 29.4). It employs thoracoscopic instruments and techniques that have been modified to allow the operation to be performed entirely via this minimally invasive technique. VATS utilizes video imaging for enhanced exposure, but the procedure is performed through a minithoracotomy incision (Figure 29.5). Standard surgical instruments and techniques are often employed. Not all procedures currently lend themselves to the CVT technique. Other procedures may begin with the CVT technique, but if dense adhesions, obscure anatomy, or complications are encountered, the surgeon may convert to VATS or to open thoracotomy. This possibility should be discussed with the patient preoperatively and appropriate permission obtained. The removal of large specimens usually necessitates the VATS procedure. A recent report from a video-assisted thoracic surgery study group indicated that of their first 1,358 cases performed by thoracoscopy, 64% utilized the CVT technique and 36% were performed via VATS.[7] An additional 439 cases (24%) had to be converted to open thoracotomy. Reasons listed for conversion to thoracotomy include: further resection required (50%); unable to find lesion (15%); lesion too large to remove (14%); adhesions (13%); equipment failure (5%); and bleeding (3%). Surgeons may utilize both techniques to achieve the least traumatic and safest procedure. The goal of the thoracoscopic surgery, after all, is to apply the same principles and same procedures as in thoracotomy via a less-invasive technique. Safety must not be compromised for the sake of the skin incision. Because conversion to an open thoracotomy is always a possibility, it is imperative that thoracoscopic surgery be performed only by those surgeons who have the training or experience needed to perform the equivalent open procedure. The surgeon should also have had supervised instruction, training, and practice in the techniques of thoracoscopy.

Operative Strategy

Unlike the peritoneal cavity, the bony thorax is a rigid structure. This both facilitates visualization, because the thorax can maintain a fixed volume without insufflation, and frustrates access to the operative field, because instruments can be introduced only through the intercostal space. When complete atelectasis of the lung on the operative side is achieved by using single-lung ventilation of the nonoperative lung, the view is comparable to that on open thoracotomy. The maneuverability of instruments in a cephalad-caudad direction, however, is severely limited by the bony confines of the intercostal space. Proper placement and use of intercostal access sites for thoracoscopy requires careful evaluation of the location of the operative site and of the proposed surgical manipulations.

Video-assisted surgery typically requires the placement of multiple rigid trocars. An initial intercostal trocar is inserted for the thoracoscope (the visualization port). This trocar is usually placed in or near the anatomic auscultatory triangle, because this site poses minimal risk to intrathoracic structures but allows a generous view of the pleural space. The trocar is inserted at right angles to the bony thorax and over the superior margin of a rib to avoid injury to the intercostal bundle. The lung is deflated prior to trocar insertion to minimize the risk of injuring it. Because insufflation is usually not necessary, the trocar



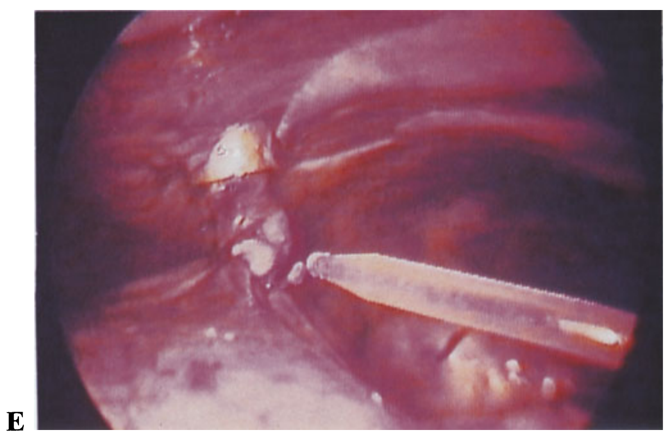


FIGURE 29.4. Thoracoscopy technique. (A) First trocar and camera in anterior axillary line. (B) Second, instrument trocar in place. (C) Surgeon and assistant applying Endoloop to ligate bleb seen on video monitor. (D) Video view of bleb being grasped for ligation. (E) Bleb ligated by Endoloop and then excised with scissors.

may be a simple port, without valves. The trocar helps prevent debris from obscuring the end of thoracoscope.

Intercostal access sites for instruments are created under thoracoscopic visualization as outlined above. These access sites do not usually require a rigid indwelling port. The diameter of a port limits the size of the instruments that can be inserted through it and the intrathoracic length of a port limits the arc through which an instrument can rotate. Once the access site is created, the trocar is removed, and the instruments are passed directly through the opening in the chest wall. Instruments of varying size, both standard and endoscopic, can be used with great facility through the thickness of the chest wall. Flexible trocars may prove useful by allowing a similar freedom of motion while minimizing trauma to the surrounding tissues.

The best placement of the intercostal access sites for the visualization port and instruments depends on the anatomic disposition of the operative site. Access sites should be placed at a distance from both the lesion and each other to achieve a panoramic view and prevent crowding of instruments within the thorax. Access sites should be positioned in an arc about the lesion, not a circle. Finally, additional intercostal access sites should

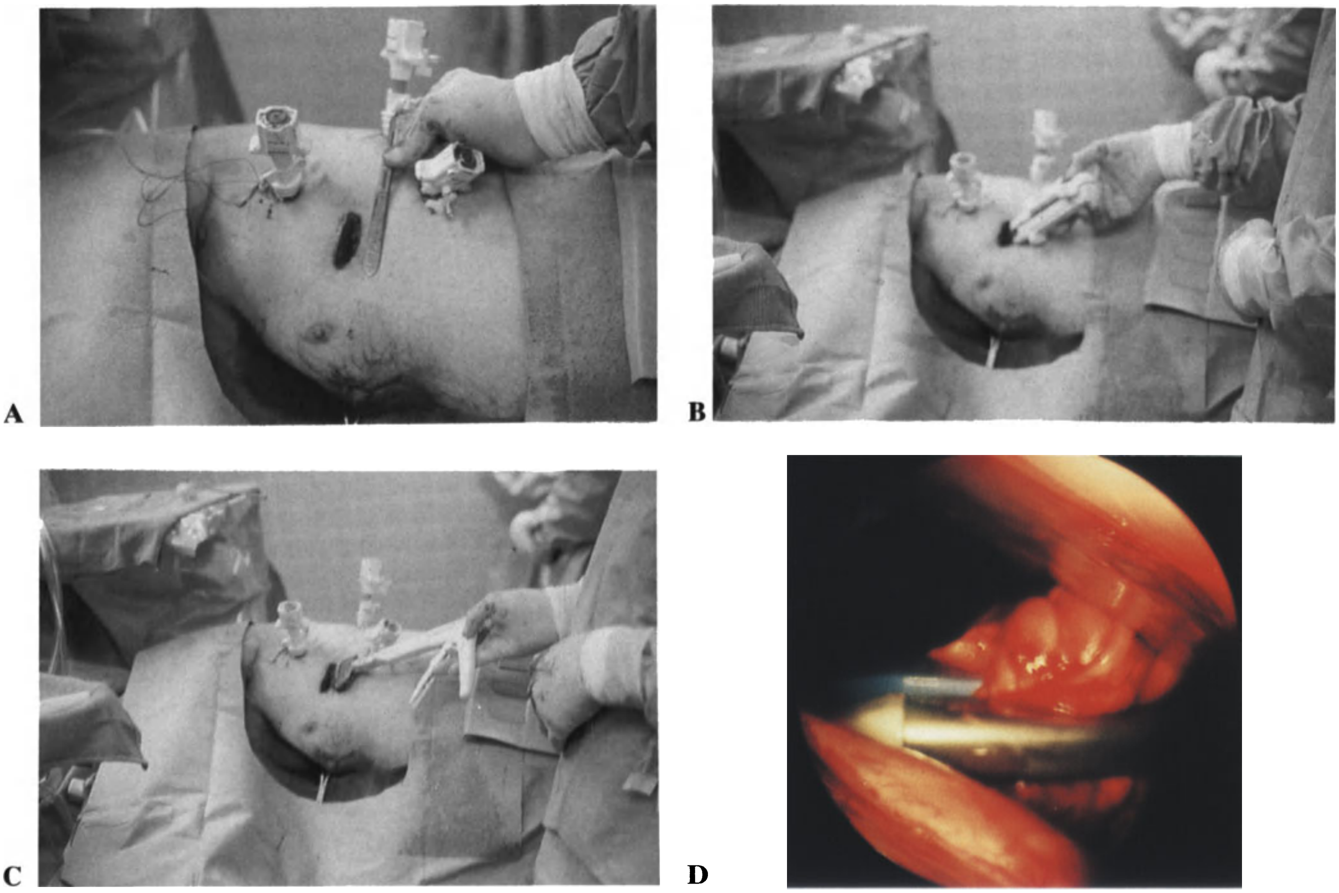


FIGURE 29.5. Video-assisted thoracic surgery (VATS). (A) Minithoracotomy incision with trocars in place that allow standard instruments to be utilized and large specimens to be removed (i.e. lobectomy). (B) Utilization of standard linear stapler. (C) Utilization of stapler to divide bronchus in lobectomy. (D) Internal view of wedge resection of nodule via VATS.

be freely created, and the instruments and visualization port should be repositioned as needed (Table 29.1).

The development of a routine for the placement of the visualization port and the other access sites is important.[12] Careful review of preoperative CT scans will help establish the location of the operative site relative to surrounding landmarks. The operative site may be characterized by its relation to the median coronal plane or to other intrathoracic or extrathoracic structures (e.g., lobar fissures, scapula) (Figure 29.6B). Two strategies for the placement of intercostal access sites have been developed. The most widely used is to place the sites in a triangle, or baseball diamond around the lesion.[11] All inter-

TABLE 29.1. Basic principles for VAT intercostal access sites.

1. Achieve a panoramic view
2. Avoid overcrowding within the thorax
3. Arc the access sites about the operative region
4. Additional access sites are created as needed
5. Alternate access sites can be used for visualization and instrumentation

FIGURE 29.6A. Chest CT scan (lung windows) demonstrating a mass in the left costovertebral sulcus. The mass appears to be parenchymal in origin and arises posterior to the diaphragm. This site is generally inaccessible to diagnostic needle biopsy.

FIGURE 29.6B. Chest CT scan (soft-tissue windows) of the lesion seen in Figure 29.6A. The orientation of the CT scan replicates the orientation of the patient during surgery (right lateral decubitus position). The location of the mass relative to intrathoracic landmarks can be ascertained. This information is helpful in positioning intercostal access sites about the lesion.

costal access sites are placed within a 180° arc, with the lesion at the center of the arc. An alternative is to place the access sites in sequential intercostal spaces. The former technique allows site placement to be tailored to lesions at different intrathoracic sites, while the latter technique is particularly advantageous for complex parenchymal resections or video-assisted resections via an access thoracotomy.[13]

Anesthesia

The choice of an anesthetic technique for a patient undergoing thoracoscopy depends on the procedure being contemplated as well as the age and stability of the patient. For many of the simpler diagnostic thoracoscopy procedures, local or regional anesthesia, usually supplemented with intravenous sedation, will be sufficient. For more prolonged procedures or those requiring manipulation of the mediastinal structures or visceral pleura, general anesthesia may be preferred. Local or regional anesthetic techniques do not require endotracheal intubation and facilitate rapid recovery of the patient. The parietal pleura is relatively easy to anesthetize, either with a formal intracostal nerve block or simply by local infiltration in the region of trocar insertion. With gentle technique, the majority of the pleural-space and mediastinal structures can be visualized with local anesthesia, although vigorous manipulation of the visceral or parietal pleura will create some discomfort. Biopsy of mediastinal structures or the lung will also cause the patient discomfort, but this may be obliterated with intravenous sedation (midazolam or fentanyl).

The technique of local anesthesia for thoracoscopy begins with premedication of the fasting patient with intramuscular atropine (0.02 mg/kg) one hour before the contemplated procedure. An intravenous line is established when the patient arrives in the operating room, and the patient is positioned in an appropriate and comfortable position on the operating table. During a thoracoscopy procedure performed under local anesthesia, supplemental oxygen is usually administered to a spontaneously breathing patient. The patient's blood pressure, electrocardiogram, and oxygen saturation are continuously monitored throughout the procedure. A four-rib intercostal block is then performed using 0.5% bupivacaine with epinephrine (1:200,000), centering the block in the region of anticipated trocar insertions. The chest is then prepped and draped in standard fashion. Immediately prior to insertion of the first trocar the patient is administered intravenous midazolam or fentanyl. The skin and subcutaneous tissues in the region of the initial trocar are infiltrated with 0.25% bupivacaine with epinephrine, down to the periosteum of the adjacent rib. The initial trocar is inserted, and a pneumothorax is induced. After insertion of the thoracoscope, care must be taken to avoid excessive torque of the trocar against the adjacent rib, because this may be uncomfortable for the patient. If lung biopsy is to be performed, further sedation is administered just prior to the biopsy because manipulation of the visceral pleura is uncomfortable. A stellate ganglion block, performed prior to prepping and draping the chest, will anesthetize the visceral pleura and allow somewhat more invasive procedures to be performed in selected cases. Additional trocars may be inserted in the region anesthetized by the intracostal block, using supplemental local infiltration with bupivacaine. Visualization inferiorly within the chest may be enhanced by asking the patient to maintain a deep inspiratory effort, which flattens the hemidiaphragm. At the completion of the thoracoscopy procedure, the trocars are removed. Prior to removal of the thoracoscopy trocars, a small epidural catheter is placed percutaneously into the thorax and positioned in the posterior pleural space. This catheter is used for interpleural anesthesia during the postoperative period.[14] One-quarter percent bupivacaine with epinephrine (1:200,000) (0.75 cc/kg up to 40 cc) is injected in the operating room and every four hours postoperatively, as needed.

Many authors have reported large series of adult patients who have successfully undergone diagnostic and therapeutic thoracoscopy under regional anesthesia.[15–18] Successful diagnostic thoracoscopy in 57 children utilizing regional anesthetic techniques was reported by Rodgers in 1979.[3]

Thoracoscopy procedures requiring more extensive retraction or manipulation of the visceral pleura or prolonged exposure of the mediastinum are usually best performed under general anesthesia.[20–22] Most of the more sophisticated therapeutic thoracoscopy procedures now being performed require the prolonged exposure afforded by general anesthesia. General anesthesia also has the advantages of providing complete patient comfort and facilitating exposure of the intrathoracic structures. The disadvantages of general anesthesia are that it usually requires endotracheal intubation and that the ipsilateral pneumothorax is often more difficult to maintain.

The technique for general anesthesia for thoracoscopy procedures also begins with premedication of the fasting patient with atropine. An intravenous line is secured when the patient arrives in the operating room. The patient's blood pressure, electrocardiogram, and oxygen saturation are continuously monitored during the procedure. A decision must be made to intubate the patient or to allow the patient to breath spontaneously under light general anesthesia. For rapid procedures not requiring much intrathoracic manipulation the latter technique has many advantages, but for more complicated procedures endotracheal intubation is preferred. In larger patients, in whom mediastinal dissection is contemplated, unilateral endotracheal intubation is quite helpful. This may be accomplished either with a bifurcated endotracheal tube or by selective mainstem intubation, depending on the size of the patient. Younger patients—those under two or three years of age—often will not tolerate unilateral ventilation without significant hypoxia, and tracheal intubation must be used. If tracheal intubation is employed, it is critical that the patient either be breathing spontaneously or that the positive pressure used to ventilate the patient be maintained at an acceptable level. Positive-pressure ventilation during thoracoscopy makes maintenance of an ipsilateral pneumothorax difficult. In patients who will not tolerate spontaneous ventilation or lower ventilatory pressures a rapid biopsy often may be obtained by using apneic ventilation, after ventilating the patient for a short period with 100% oxygen.

Unilateral ventilation allows complete collapse of the ipsilateral lung, which greatly facilitates visibility and dissection of the mediastinal structures. In addition, complete collapse of the ipsilateral lung often assists the identification of pulmonary parenchymal nodules because the lung surrounding these lesions collapses. Unilateral collapse makes identification of localized pulmonary infiltrations more difficult, however. These localized processes usually present as areas of atelectasis within an otherwise normally aerated lung. When the entire lung collapses, these local areas of atelectasis or inflammation are no longer distinctly visible on the pleural surface.

Even when general anesthetic techniques are employed it may be helpful to supplement them with infiltration of local anesthetic agents at the site of trocar insertions or with a regional rib block. This will reduce the discomfort of the procedure and allow a slightly lighter level of general anesthesia to be employed. It may also aid with immediate postoperative pain relief. At the completion of the thoracoscopy procedure, prior to removal of the thoracoscopic telescope, a pleural catheter is placed for administration of postoperative interpleural analgesia.

Equipment

Thoracoscopy may be performed with a basic laporoscopic video-imaging set-up. Basic items include:

1. Video camera and light source
2. Video monitor
3. Cautery or laser coagulation system
4. Suction/irrigation system
5. Telescope
6. Thoracoscopic instruments

Items 1 to 4 constitute the basic video surgery package and are discussed earlier in this book. Here we limit ourselves to comments about telescopes and thoracoscopic instruments and their use in thoracoscopy.

Telescopes

Surgeons may chose a rigid or a flexible thoracoscope. Rigid scopes are less expensive, more durable, offer a larger field of view with better illumination, and can be rapidly resterilized.[23] The field of view is determined by the cross section of the fiberoptic cable. Flexible scopes have a fiberoptic cable and a suction/instrument channel within the sheath, and thus the field of view of a flexible scope is smaller than that of a rigid scope with the same outside diameter. The disadvantage of the rigid scope is that multiple trocars are needed to fully inspect the thorax or to perform even simple procedures. The advantage of the flexible thoracoscope is its maneuverability; it allows many diagnostic and simple therapeutic procedures to be accomplished with a single trocar site. Flexible scopes may pose an infection risk unless they are gassterilized, and gas sterilization limits them to one procedure a day. Ideally both types of scopes will be available. If the rigid scope is utilized it is recommended the surgeon have access to the following lenses:

1. 10-mm 0° for direct viewing
2. 10-mm 30 to 45° for oblique viewing
3. 5-mm 0° for children

Fogging is a significant problem regardless of the telescope chosen. Since fogging occurs when a cold telescope is inserted into a warm moist thorax, the simple solution is to immerse the scope in warm water before and during the procedure.

Thoracoscopic Instruments

The rapid growth of thoracoscopic surgery has encouraged manufacturers to provide instruments specially designed for these procedures. Many of the instruments utilized for open thoracotomies have been modified for minimal-access surgery. Noncrushing clamps and pickups lead to less air leakage and iatrogenic lung injury. Fan lung retractors are essential for the full visualization of the thorax. The items below, which are particularly useful in thoracoscopy, should be available as well as the standard instruments shown in Figure 29.7.

A. Fan lung retractor
B. Lung clamp
C. Debakey-type pickups
D. Babcock clamp
E. Allis forceps
F. Glassman clamps
G. Right-angle mixter clamp

Surgeons should familiarize themselves with the various stapling and suture materials for minimal-access surgery on the market. Each surgeon must decide whether to use disposable or reusable products.

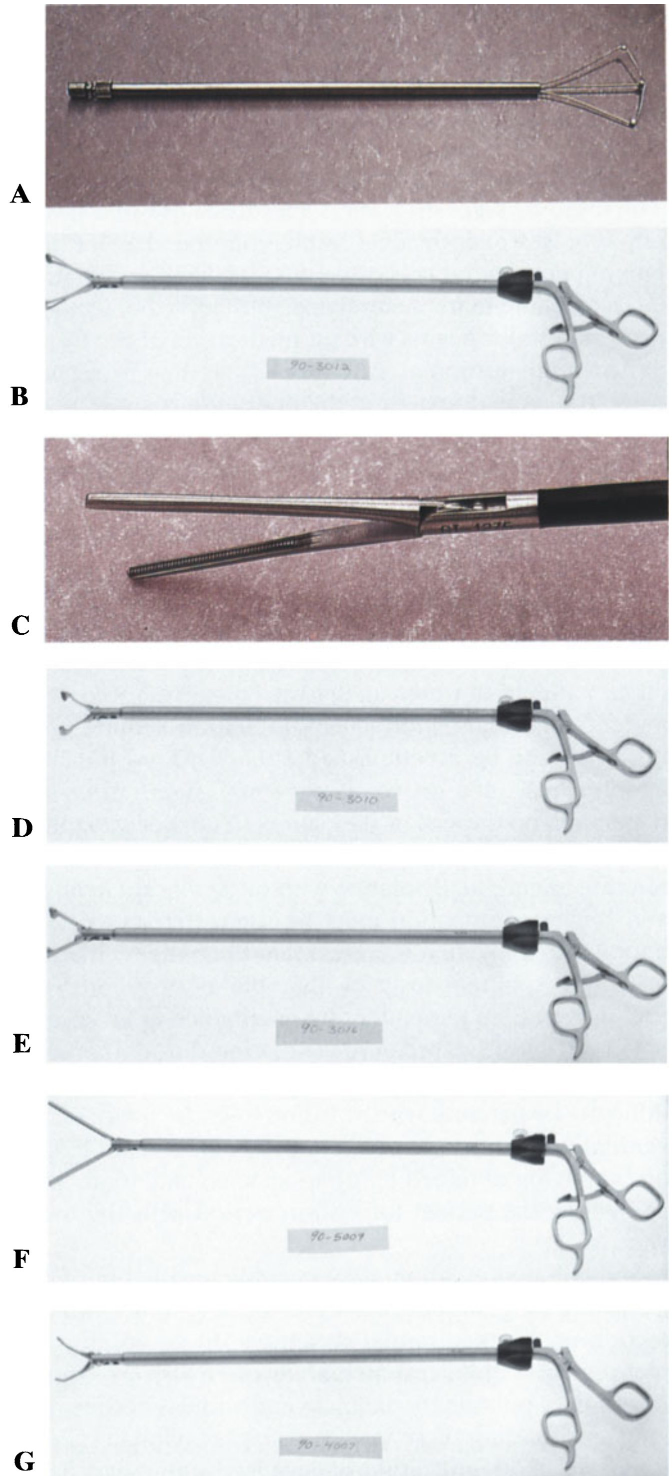


FIGURE 29.7. Instruments.

Mediastinal Disease

Thoracoscopy for evaluation of mediastinal lesions has become increasingly common as surgeons have gained familiarity with the technique. Currently, this is the most common indication for thoracoscopy in children in many centers, and it is becoming one of the most common indications for adult patients. Thorough preoperative imaging is essential in planning thoracoscopy for biopsy or resection of mediastinal masses. Frontal and lateral roentgenograms rarely suffice to adequately localize the mediastinal lesions. These patients should undergo some form of cross-sectional or coronal imaging, usually a chest CT or magnetic resonance imaging (MRI) examination (Figure 29.8). These studies allow determination of the precise anatomic location of the mediastinal lesion and visualization of its relation to nearby structures. This information allows the feasibility of approaching the lesions by thoracoscopy to be assessed. In addition, careful review of the radiologic evaluation helps define appropriate positioning of the patient on the operating table and the locations of the telescope and working trocars that will provide the best access to the lesion. Virtually the entire surface of the mediastinum can be visualized by thoracoscopy, although some areas are more difficult to approach than others. We have found lesions posterior to the inferior pulmonary vein to be some of the most difficult to approach, but division of the inferior pulmonary ligament with the electrocautery may facilitate exposure in this region.

General anesthesia is preferred for thoracoscopy for mediastinal lesions, except in situations where only simple superficial biopsies are required. In addition, unilat-

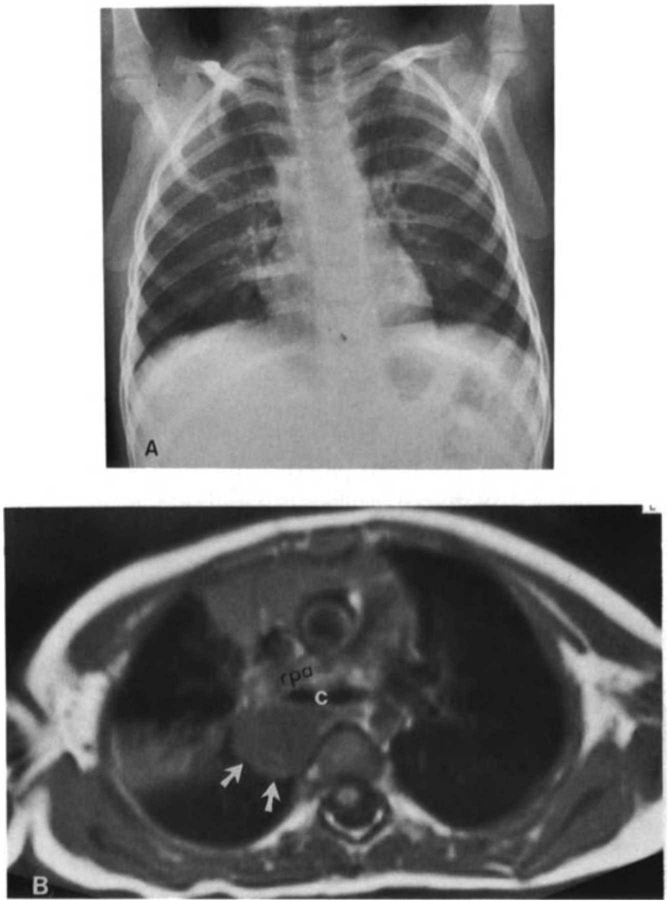


FIGURE 29.8. (A) Frontal radiograph of a three-year-old female with persistent cough demonstrates a subcarinal mass (*arrows*). (B) Cross-sectional MRI image demonstrates the relation of the lesion (*arrows*) to the right pulmonary artery (*rpa*) and carina (*c*). Thoracoscopy through the right chest revealed a bronchogenic cyst that was completely excised without thoracotomy. (By permission of G. Holcomb (ed.), *Pediatric Endoscopic Surgery,* Appleton & Lange, Norwalk, CT, 1993, p. 207.)

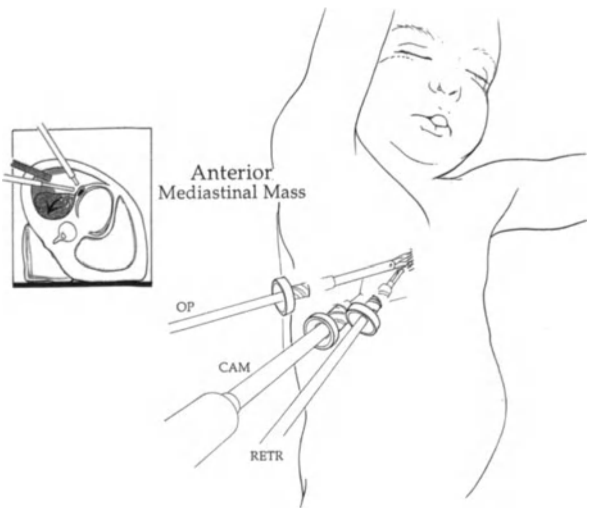


FIGURE 29.9. Thoracoscopic approach to an anterior mediastinal lesion. The telescope trocar is inserted in the anterior axillary line. Inset: The patient is placed in a 45° lateral decubitus position to allow better access to the anterior chest.

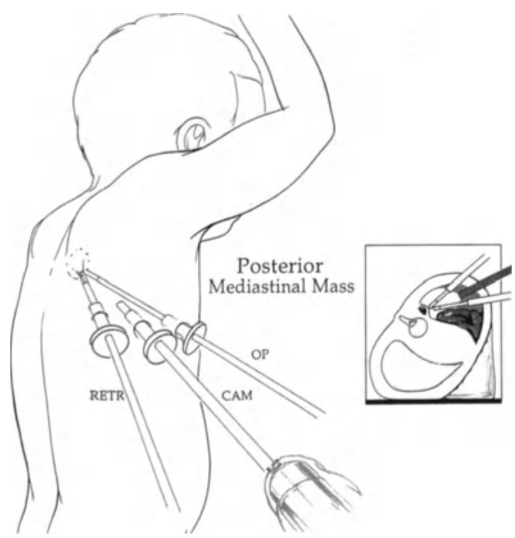


FIGURE 29.10. Thoracoscopic approach to a posterior mediastinal lesion. The telescope trocar is inserted in the posterior axillary line. Inset: The patient is placed in an exaggerated lateral decubitus position to allow better access to the posterior chest.

eral ventilation greatly facilitates the exposure of the mediastinal structures because it allows more-vigorous retraction of the lung on the hilum. Retraction of the visceral pleura is often uncomfortable for the patient when thoracoscopy is performed under regional anesthesia, and the cough reflex stimulated by this maneuver is difficult to suppress with intravenous sedation. The addition of a stellate ganglion block may provide additional anesthesia of the visceral pleural surface and facilitate mediastinal biopsy performed under regional anesthesia.

Proper positioning of the patient on the operating table is essential for these procedures. In the case of anterior mediastinal lesions the patient is generally placed in a 45° lateral decubitus position, allowing the lung to fall posteriorly on the pulmonary hilum (Figure 29.9). In the case of posteriorly located lesions the patient can be placed in an exaggerated lateral decubitus position that allows the lung to fall anteriorly (Figure 29.10). The Trendelenburg or reverse Trendelenburg position may facilitate exposure inferiorly or superiorly within the mediastinum. The initial telescope trocar is usually positioned in the mid- or posterior axillary line in the sixth intercostal space. This allows a broad view of the mediastinal structures (Figure 29.10). The optimum positions of the trocars for the retracting and dissecting instruments are determined once the mediastinal pathology is visualized. They are usually positioned on either side of the telescope trocar in a diamond with the pathologic lesion at the apex.[24] Before the dissection of the mediastinal lesion is initiated, the entire hemithorax and pulmonary surface should be carefully examined. Rodgers noted a 31% incidence of unsuspected areas of pathologic involvement in 16 patients with mediastinal malignancies.[25] Biopsy of these lesions and confirmation of more-distant involvement will often modify subsequent therapy. The primary mediastinal lesion is generally approached by opening the parietal pleura overlying the lesion and adjacent structures. Care must be taken to avoid the phrenic or vagus nerves in this dissection. In some cases, it may not be clear whether the mediastinal lesion is cystic or vascular in nature. In these patients the contents of the lesion can be aspirated by passing a long needle through one of the working trocars. Bronchogenic cysts will contain clear mucoid material, whereas blood will be aspirated from vascular lesions. Incisional biopsy of mediastinal lymphadenopathy and of many metastatic mediastinal tumors is usually sufficient for diagnosis. The biopsy can be performed by gently dissecting the mediastinal pleura and superficial mediastinal tissues from around the lesion and then excising a portion of the lesion with microscissors or cupped biopsy forceps. To adequately sample a lymph node, multiple pieces of it must be obtained. Often superficial biopsies will contain only a fibrous capsule or normal structures. Deeper biopsies must be obtained by incising tissue beneath the initial biopsy site. Rodgers has noted that the false-negative rate of this technique is 5% in the case of mediastinal malignancies and has suggested the use of directed core needle biopsies in addition to incisional biopsies to more adequately sample deeper tissues.[26] Advances in anesthetic technique and in instruments have greatly facilitated the use of thoracoscopy in the management of mediastinal lesions. These lesions are rapidly becoming one of the most common indications for the use of thoracoscopy and many new procedures and applications are being described.[27,28]

With the development of more sophisticated thoracoscopic instruments, many therapeutic procedures for mediastinal lesions are now possible. Several authors have described complete excision of bronchogenic cysts from the paratracheal and subcarinal regions using thoracoscopic techniques.[29,30] The biopsy of pericardial lesions as well as creation of a pericardial window may be accomplished by thoracoscopic techniques.[27,28] In carefully selected patients, the ductus arteriosus can be occluded with thoracoscopically applied vascular clips.[31] Wain and others have suggested the use of thoracoscopy for the staging of selected patients with peripheral lung carcinoma[32] and Rodgers has suggested its use for the direct obliteration of mediastinal lymphatic leaks in patients with acquired or congenital chylothorax.[33] The use of thoracoscopy for thoracic sympathectomy vagotomy and esophageal surgery will be described elsewhere in this chapter.

Pleural Disease

The technique of thoracoscopy was initially proposed for the management of pleural disorders, specifically for the lysis of pleural adhesions in patients with pulmonary tuberculosis. For many decades, this was the primary or exclusive indication for thoracoscopy in many centers, and it remains the principle indication for the procedure in adult patients. Thoracoscopy has the obvious advantage that the visceral and parietal pleural surfaces can be visualized without a large thoracotomy incision. A complete pleural symphysis is one of the few absolute contraindications to thoracoscopy, but patients with a history of extensive pleural infection must be carefully evaluated before undergoing this technique. Many thoracoscopy procedures for pleural disorders can be satisfactorily performed under local or regional anesthesia, although those requiring more extensive dissection of pleural adhesions or empyema loculations may require general anesthesia.

Approximately 25% of patients presenting with an idiopathic pleural effusion will remain undiagnosed even after careful evaluation of the fluid within the chest and closed needle pleural biopsy.[16] These patients are usually ideal candidates for thoracoscopy, which allows a thorough evaluation of the entire pleural space and directed biopsy of pleural lesions. Preoperative roentgenographic studies may indicate a dominant area of pleural involvement, and the patient should be positioned on the operating table in a manner that facilitates approach to this area. Otherwise, these patients are usually placed in a full lateral decubitus position. The initial telescope trocar is placed in the midaxillary line in the sixth intercostal space. A secondary working trocar is placed either immediately anterior or posterior to the telescope, depending in part on the area to be biopsied. The fluid within the pleural space is aspirated and sent for culture and cytologic evaluation. Any adhesions between the visceral and parietal pleural surface are completely dissected with sharp or blunt techniques to allow visualization of the entire pleural surface. It is important to visualize the entire surface because many malignancies create loculated areas of involvement. Directed biopsies of areas of abnormal appearance may be obtained using the cupped biopsy forceps. Both primary and metastatic carcinoma tend to preferentially involve the inferior portion of the pleural cavity, and this region must be carefully evaluated and biopsied.[34] Depending on the primary diagnosis, thoracoscopy has a diagnostic accuracy between 95 and 100% in patients with pleural disease.[15–17,22] In patients with symptomatic pleural effusions secondary to malignancy, consideration should be given to creating a pleural symphysis at the time of diagnostic thoracoscopy. Symphysis is best created by talc pleurodesis.[35,36] Between 2 and 6 g sterile USP pure talc is insufflated with an atomizer to cover the entire visceral and parietal pleural surface. This may cause transient pleuritis in patients undergoing thoracoscopy with local anesthesia, but the pleuritis can usually be relieved with intravenous sedation.

Thoracoscopy has proved to be an excellent method for the management of patients with recurrent pneumothorax.[37,38] The ability to visualize the entire pleural space allows directed therapy in patients with limited bleb disease and also allows creation of a pleural symphysis. If a talc pleurodesis is anticipated, local or regional anesthesia may be used, but those patients requiring resection of a pulmonary bleb or mechanical pleurodesis are usually best managed with general anesthesia. Unilateral ventilation may facilitate resection of a pulmonary bleb. After insertion of the telescope the entire pleural surface is visualized and any pleural adhesions are lysed. If localized pulmonary blebs are identified, the Endo GIA stapler (US Surgical Corporation, Norwalk, CT), placed through a 12-mm trocar inserted inferiorly in the hemithorax, greatly facilitates resection. The Endo GIA instrument is difficult to use in small children since at least 5 cm of the instrument must be within the chest in order to open the anvil. We have found this to be impractical in children under the age of four or five years. Patients with more extensive pulmonary blebs may be treated with laser resection or sclerosis of the blebs as described by Wakabayashi.[39] These patients should receive talc poudrage in addition to bleb resection. Although talc poudrage has proved very successful in the management of pneumothorax in patients with cystic fibrosis,[40] the pleural symphysis achieved with this technique may complicate future lung transplants. These patients may more appropriately be managed with a mechanical pleurodesis, which may produce a less dense pleural symphysis. For this purpose, we have used a small piece of Marlex mesh, held with a grasping instrument. Others have described use of a pot scrubber or cautery cleaner. In patients with simple bleb disease and spontaneous pneumothorax, thoracoscopy is nearly 100% successful in preventing recurrences. Patients with more extensive bullous disease are more difficult to manage and may have a relapse rate of 10% or higher.

Recently, thoracoscopy has been suggested as an adjunctive treatment for patients with pleural empyema.[41,42] This technique is especially helpful in treating patients with persistent loculated empyema who are in the fibrinopurulent stage of the disease. If the infected fluid is not completely removed from the hemithorax in one week either through repeated thoracentesis or through tube thoracostomy, the hemithorax should be evaluated with transthoracic ultrasound. If this study demonstrates multiple areas of loculated fluid, thoracoscopy may be quite helpful. These procedures are best performed under general anesthesia because they require considerable manipulation of the visceral and parietal pleural surfaces. The initial trocar is placed into the largest locule, as identified by transthoracic ultrasound. The fibrinous pleural adhesions are then completely dissected either bluntly or sharply, using electrocautery for hemostasis. All of the infected fluid is aspirated from the hemithorax, and the entire pleural space is lysed and mechanically debrided. We have used a pressure suction/irrigation device to assist with this maneuver. Ridley has employed pleural irrigation following debridement in 18 adult patients with a 33% success rate.[41] Kern used simple chest-tube drainage following pleural debridement in 10 pediatric patients, with successful resolution of the empyema in all cases.[42] Many of the failures in adult patients are related to the failure of the lung to completely expand after the infected fluid is removed. This may be avoided by undertaking thoracoscopy earlier, before the fibrotic stage of empyema is established.

The use of thoracoscopy in pleural disorders is historically important, and these disorders remain a common indication for this procedure. The ability to visualize the entire pleural surface without making a major incision is a significant advantage. New instruments have allowed more aggressive therapeutic pleural procedures as well as directed biopsies to be performed. The treatment of pleural disease will remain one of the best uses for thoracoscopy in both adult and pediatric patients.

Parenchymal Disease

A wide variety of diffuse and localized pulmonary diseases are amenable to surgical approach employing thoracoscopy (Table 29.2). The number of procedures performed using video techniques has continued to grow. However, difficulties in the identification of parenchymal lesions and in instrumentation, particularly that for vascular control, as well as the requirement of single-lung ventilation limit the effectiveness of thoracoscopy in certain situations. Contraindications to thoracoscopy for lung disease include dense pleural symphysis, central pa-

TABLE 29.2. Lung diseases—indications for thoracoscopy.

Diffuse lung disease
Interstitial pulmonary disease
Congenital blebs (spontaneous pneumothorax)
Acquired bullous disease/emphysema
Localized lung disease
Indeterminate pulmonary nodule
Primary neoplasm of the lung
Metastatic neoplasms

renchymal lesions, hilar pulmonary lesion, ventilator dependency or respiratory failure (Table 29.3). These states either impair visualization via the thoracoscope (e.g., plural symphysis), exceed current technical capabilities (e.g., hilar lesions), or are situations in which a less invasive approach offers no advantage (e.g., preoperative ventilator dependency).

Diffuse Lung Disease

Interstitial Lung Disease

Interstitial lung disease is a common indication for thoracoscopic resection of pulmonary parenchyma. Formerly termed "open lung biopsy," this procedure involves excision of a small portion of lung tissue in a patient who frequently has moderate to severe respiratory compromise. Parenchymal changes are frequently concentrated near the periphery of the lung tissue, making excision via the thoracoscope easier (Figure 29.11). The lower postoperative morbidity of thoracoscopy is especially critical for these compromised patients.[43] Thoracoscopy should be considered for such patients, however, only if less invasive means of obtaining a diagnosis have failed. Some diffuse lung diseases have characteristic clinical and radiographic features that permit reliable diagnosis without histologic study. In other circumstances, bronchoalveolar lavage (BAL) or transbronchial biopsy (TBB), which are both performed under local anesthesia and which both have lower morbidity than thoracoscopy, may provide material for diagnosis. Transthoracic parenchymal biopsy should only be performed when BAL or TBB have been unsuccessful or inconclusive.[44]

Thoracoscopic biopsy of interstitial lung disease involves the use of two or three access ports. The area to be biopsied is identified on preoperative chest CT scan. If the disease is truly diffuse and bilateral, the biopsies are usually done from the right side. Tissue is excised from the parenchymal margins of all available lobes using stapling devices. Inspection of resection lines will reveal any areas of defective hemostasis or pneumostasis, which are best managed by intracorporeal suturing of the site. A single chest tube should be inserted prior to reinflation of the lung.

Lung biopsy by thoracoscopy has an accuracy between 92 and 100%.[45,46] The accuracy rate for open lung biopsy is 92%.[47] The thoracoscopy approach is clearly comparable to open lung biopsy in diagnostic efficacy and offers distinctly lower postoperative morbidity for nonventilator-dependent patients.

TABLE 29.3. Lung diseases—contraindication to thoracoscopy.

1. Obliteration of the pleural space
2. Small, central pulmonary lesions
3. Hilar pulmonary lesions
4. Preoperative ventilator dependency
5. Inability to tolerate single-lung ventilation
6. Preoperative hemodynamic instability

Congenital Blebs

Congenital blebs arising in the apical segments of the upper lobes or the apical region of the superior segments of the lower lobes are the most common cause of spontaneous pneumothorax. These lesions are simple cysts at the periphery of the lung. Communication with the airway is at a microscopic bronchiolar level. Typically, patients with spontaneous pneumothorax due to congenital blebs are treated with chest-tube drainage. Over 80% of these patients will have resolution of their pneumothorax, cessation of air leakage, and no further recurrence of the pneumothorax. However, surgical intervention is recommended for patients with an air leak persisting for more than seven days after presentation and for patients in whom spontaneous pneumothorax has recurred. The surgery involves excision of the parenchymal pathology and pleurodesis. Thoracoscopy is ideally suited for this strategy. The entire pleural space can be visualized thoracoscopically, allowing all bleb sites to be inspected. Endoscopic excision of the peripheral margins of lung containing the bleb and endoscopic pleurodesis are easily accomplished.

Thoracoscopy for management of spontaneous pneumothorax employs three or four access sites in the mid- or upper thorax. Complete inspection of the pleural space and lysis of all adhesions is performed. Blebs are excised with an endoscopic linear cutting/stapling device. Pleurodesis is accomplished by mechanical abrasion of the

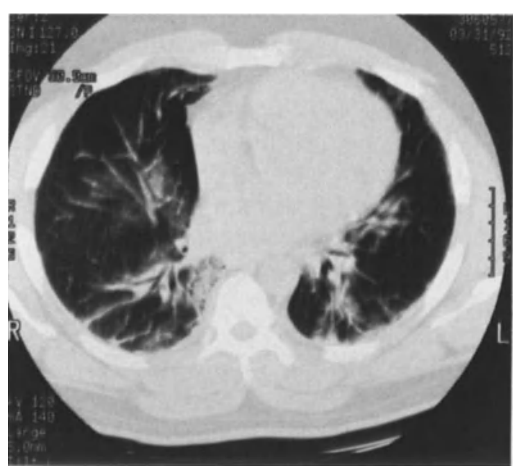


FIGURE 29.11. Chest CT scan (lung windows) of a patient with interstitial lung disease. Note the diffuse nature of the interstitial changes, which are more marked in the periphery of the dependent regions of the lung. VAT is ideally suited for excisional biopsy of such regions.

parietal pleura under direct vision or by instillation of a sclerosing agent.

Thoracoscopy for this indication has results similar to those obtained with a comparable procedure performed through a small axillary thoracotomy. Control of blebs and air leak in the immediate postoperative period is 100%; the long-term recurrence rate is less than 3%.[48,49]

Acquired Bullous Disease

Emphysematous bullae can be classified into four groups. Type 1 is a smooth, nontrabeculated structure with normal surrounding lung. Type 2 is the congenital bleb seen in spontaneous pneumothorax. Type 3 is a trabeculated structure found throughout the lung. This is the most common type of acquired bullous emphysema. Type 4 consists of a large bulla with remnants of trabeculae surrounded by type 3 bullae.

Types 1 and 4 bullae may slowly enlarge and compress adjacent lung parenchyma. On rare occasions, this may cause significant functional impairment (Figure 29.12). Excision of the giant bullae in such instances allows expansion of the adjacent lung and return of pulmonary function. It remains extremely difficult, however, to identify patients in whom excision of bullae will have this beneficial effect. High-resolution chest CT scanning may allow identification of bullous changes in compressed lung parenchyma, which excludes the patient from consideration for operative excision of giant bullae.

Thoracoscopy has been used for the evaluation and resection of giant bullae. Multiple access sites are used. The bullae are resected using electrocautery, laser cautery (both CO_2 and Nd:YAG), stapling devices, or a combination of these techniques. Frequently, air leaks at the site of excision must be controlled with intracorporeal sutures. Pleurodesis is generally performed at the conclusion of the procedure (Figure 29.13).

An approximate doubling of spirometric values follows excision. Prolonged ventilatory support is required in 25% of patients postoperatively. Mortality ranges from 0% for patients with type 1 bullae to 60% for patients with type 3 bullae who manifest respiratory failure preoperatively. Excision of compressive bullae via open thoracotomy has similar results. The major difference is in operative time; the thoracoscopic procedures take longer because the large lesion and intrapleural adhesions impair visualization.[49,50]

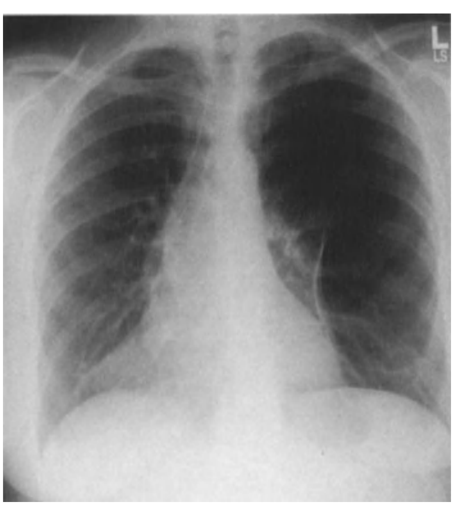
Localized Lung Disease

Indeterminate Pulmonary Nodule

A solitary pulmonary nodule is a discrete opacity surrounded by normal lung without associated atelectasis or adenopathy. The lesion is typically less than 3 cm in size and noncalcified. Such lesions are seen in 0.1 to 0.2% of radiographic surveys of adults.[52] Most of these lesions are inflammatory or benign neoplasms and will remain stable or diminish in size on radiographic follow-up. Solitary pulmonary nodules are surgically excised if malignancy is suspected or an increase in size is noted. A malignant neoplasm is suggested if the patient is older than 35 years and consumes tobacco. Of the lesions that are resected, either because of clinical criteria suggesting malignancy or because of enlargement on serial radiographs, 40% are found to be malignant neoplasms, most commonly lung cancers.

Several methods have been used to characterize the

A



B

FIGURE 29.12. Anteroposterior chest radiograph (A) and chest CT scan (B) of a 45-year-old female with a type 4 giant compressive bulla. The patient presented with symptoms of progressive exertional dyspnea. Note the mediastinal shift toward the right on the chest radiograph, indicative of the mass effect of the lesion. The chest CT scan demonstrates incomplete trabeculation and bullous changes in the surrounding lung.

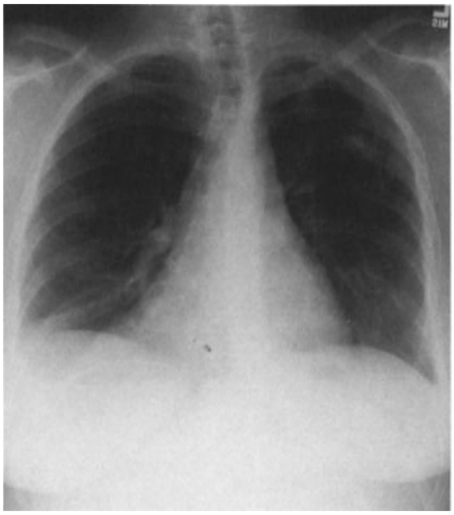


FIGURE 29.13. Anteroposterior chest radiograph of the patient in Figure 29.12, following thoracoscopic excision of the bulla and pleurodesis. The mediastinum and left hemidiaphragm have resumed their normal positions. The patient experienced marked improvement in exercise tolerance.

solitary pulmonary nodule. A stable radiographic appearance over a period of two years is a reliable indicator of a benign lesion. Bronchoscopy and cytologic study will identify a benign lesion in only 10% of cases.[53] Percutaneous needle biopsy has a sensitivity in the diagnosis of malignancy of approximately 85% and a false-negative rate of 3 to 11% for solitary nodules.[54] Aside from a stable radiographic appearance, therefore, excision of the nodule remains the only perfectly accurate method of determining the nature of such a lesion. Thoracoscopy may be used for excisional biopsy for such lesions. The use of thoracoscopy for these lesions, however, should be confined to cases where malignancy is suspected based on clinical criteria and where needle biopsy has either been indeterminate or is not technically feasible (Figure 29.6A).

The VAT technique for the indeterminate pulmonary nodule involves three access sites whose positions are determined by careful study of preoperative chest CT scans (Figure 29.6B). The possibility of malignancy should be foremost in the surgeon's mind, and a thorough pleural inspection to assess extension or metastasis should be completed. The nodule is identified by inspection or palpation. For lesions smaller than 1 cm in diameter or within the midportion of the parenchyma, preoperative needle localization may be of benefit.[55] The lesion is commonly excised with endoscopic linear cutting staplers. Every effort should be made to obtain an adequate margin of resection (> 1 cm in the atelectatic lung). The mass should be extracted by placing it within a surgical glove or specimen bag and withdrawing it through an enlarged intercostal access site. Intraoperative pathologic evaluation should be completed. If a diagnosis of malignancy is confirmed, lymph node sampling or further parenchymal resection should be undertaken.

Thoracoscopy is an effective method for the diagnosis of indeterminate pulmonary nodules. It is comparable to open thoracotomy in diagnostic accuracy (100%) and in the incidence of malignancy (40 to 50%). Thoracoscopy is superior to thoracotomy for this indication, however, because it requires less postoperative analgesia and causes less functional impairment.[43,45]

Primary Neoplasms of the Lung

The role of thoracoscopy in the management of primary neoplasms of the lung is controversial. Thoracoscopy may be used for both parenchyma-sparing resections and lobectomy.[13,55] The controversial issues are the adequacy of thoracoscopy rèsection (i.e., is a parenchyma-sparing resection appropriate) and the completeness of thoracoscopy resection (i.e., are margins free of tumor) in a patient with sufficient pulmonary function to tolerate resection by thoracotomy.

Although acceptable for patients with compromised pulmonary function, parenchyma-sparing (wedge or segmental) resections for lung cancer do not offer disease-free survival equivalent to that offered by anatomic resections such as lobectomy. The incidence of local recurrence after parenchyma-sparing resection is significantly higher than that after lobectomy. This is true even though the parenchyma-sparing resections are offered to patients who have less-malignant lesions. In a randomized trial of the two methods, with randomization occurring at the time of operation, 50% of patients were excluded as candidates for parenchyma-sparing procedures because of the location of the lesion or because of unexpected findings at thoracotomy (nodal disease or a lesion > 3 cm diameter).[57] Although thoracoscopy may provide staging information not obtained via less invasive measures, it is not equivalent to open thoracotomy for the assessment of primary lung carcinoma.[58] A thoracoscopic wedge or segmental resection alone, while technically possible, should not be considered adequate therapy for a primary lung cancer. Thoracoscopy parenchyma-sparing resections of lung cancer should be accompanied by extensive lymph node sampling from the peribronchial, hilar, and posterior subcarinal regions. Intraoperative pathologic evaluation of the lung and nodal specimens should be performed. Only patients with adequate parenchymal resection margins, negative peribronchial lymph nodes, and a contraindication to further lung resection should be treated by a parenchyma-sparing resection.

An alternative is to use thoracoscopy for anatomic resection via an access thoracotomy using standard instruments or stapling devices.[13,59,60] These methods are new and have been applied only to patients with stage-1 lung cancers. Mortality has been low, although some studies report that complications such as persistent air leak occur in 20% of patients.[60] Until additional experience is obtained and equipment is refined, these methods cannot be considered for wider application in the management of lung cancer.

Metastatic Neoplasms

Metastases to the pulmonary parenchyma are common for carcinomas, both extrathoracic and intrathoracic, soft-tissue sarcomas, and melanomas. The majority of these lesions are smaller than 3 cm in diameter and are amenable to resection by thoracoscopy if they are not centrally located. Complete excision of these metastatic lesions by open thoracotomy, in the absence of metastases at other sites, has been shown to prolong survival.[61–63] However, it has also been demonstrated that in the case of metastatic sarcomas and melanomas, additional lesions are frequently found at thoracotomy. Additional lesions are usually *not* identified at the time of thoracotomy for resection of carcinoma metastases. Since the greatest drawback of thoracoscopy at the present time is that it is a less accurate means of identifying *known* lesions and since its capability to identify unknown lesions is minimal, thoracoscopy is not appropriate for the excision of metastatic sarcomas and melanomas. Thoracoscopy may be used to excise carcinoma metastases only after high-resolution chest CT scans have shown that a finite number of lesions are present and that the procedure is technically feasible. The long-term results of the use of thoracoscopy for metastatectomy for any neoplasm are not known at the present time.[63]

Esophageal Disease

The role of thoracoscopy in the management of benign and malignant esophageal disease is rapidly expanding.

Pellegrini and coworkers reported their experience in the treatment of achalasia in 22 patients by thoracoscopic esophageal myotomy.[65] Excellent or good results were reported in 90% of their patients. Zenker's diverticulum and benign esophageal tumors also lend themselves to excision by thoracoscopy.[66,67]

Krasna and McLaughlin report that thoracoscopic lymph node staging for esophageal cancer provided accurate preresection staging in 13 patients.[68] Two patients thought to have positive nodes on preop CT and MRI scans were found to have negative nodes at thoracoscopy and formal resection. Two additional patients had pulmonary metastasis not evident on x-ray evaluation. Collard and colleagues reported their experience utilizing thoracoscopy for esophagectomies in benign (three) and malignant (seven) disease in 13 patients.[69] Two patients required conversion to open thoracotomy for technical reasons, and one patient had an esophageal bypass for invasion not recognized on preop evaluation. These early studies demonstrate that accurate evaluation and extensive esophageal resection can be accomplished by video-assisted thoracoscopy.

Ancillary Procedures

Thoracoscopy is now widely used for a variety of miscellaneous procedures that previously required open thoracotomy. Within this subgroup the incision is often a major cause of morbidity. The thoracoscopic approach to upper thoracic sympathectomy exemplifies this concept. Dorsal sympathectomy may be beneficial in: hyperhidrosis; Raynaud's phenomenon or disease; causalgia; reflux sympathetic dystrophy; and vascular insufficiency of the upper extremity.[70] Drott and coworkers reported a review of 900 cases with excellent long-term results. They concluded thoracoscopic sympathectomy's advantages are simplicity, expediency, less trauma, and few complications.[71] Thoracoscopic thoracic vagotomy has been performed when technical or clinical considerations prevent the transabdominal approach to peptic ulcer disease.[72] Thoracoscopy is proving a valuable adjunct in the treatment of thoracic trauma. Jones and coworkers reported utilizing thoracoscopy under local anesthesia via a chest tube to evaluate 36 patients with hemothorax. Management was altered in 44% of their patients as a result of thoracoscopy.[73] The bleeding of two patients in this series was controlled by electrocautery, thereby avoiding thoracotomy. In the case of four patients with penetrating trauma, diaphragmatic injury was ruled out. Ochsner and colleagues found that thoracoscopy correctly identified the presence or absence of diaphragmatic injury secondary to penetrating wounds in their initial 14 patients.[74] Invasive procedures on the anterior thoracic spine, which previously required an open thoracotomy, have also recently been described.

Complications

Thoracoscopy encompasses a wide variety of procedures ranging from simple pleural inspection to complex pulmonary and esophageal resection. Therefore, morbidity figures for the generic procedure are not particularly helpful. The incidence of complications depends on whether the procedure is diagnostic or therapeutic and on the specific procedure performed. The following data represent a general overview.

Combining figures from Viskum and Boutin for 12,301 diagnostic thoracoscopies gives a mortality of only

0.09%.[75,76] Morbidity and mortality for the more aggressive therapeutic procedures appear to be acceptable in preliminary studies and similar to those seen after standard thoracotomy. Complications most frequently reported are:

1. Prolonged air leak
2. Bleeding that requires transfusion
3. Infection
4. Conversion to open thoracotomy
5. Death

Kaiser and colleagues reported their experience in 266 cases with no mortality as: air leak, 3.7%; bleeding, 1.9%; infection, 1.9%; and conversion to open thoracotomy, 4.0%.[77] In 1,820 cases from 40 institutions over one year the thoracoscopy study group reported an incidence of air leak of 4.8%; bleeding, 1.0%; infection, 1.0%; and mortality, 2.5%.[7] There were no operative deaths in this group; mortality was secondary to underlying disease. Listing all conversions to open thoracotomy as complications is misleading, as this review demonstrates. Only 5.4% of VATS cases were converted to open thoracotomy for a reason that would be considered a complication (bleeding, equipment failure, inability to locate lesion). The remaining conversions were initiated to avoid compromising the extent of the resection. Conversion to open thoracotomy in this situation is a sound surgical decision, not a complication. The incidence of equipment failure is rarely reported, but failures are prevalent and surgeons should be aware of this. Thoracoscopy is an emerging technique and as more experience is gained, complication rates may diminish.

Future of Thoracoscopy

The application of video imaging to thoracoscopy has created a dynamic technique that is gaining increasing application in general thoracic surgery. Several significant drawbacks, however, must be overcome before the procedure is accepted as a standard approach to intrathoracic surgical problems.

The most urgent liability for thoracoscopy is the available equipment and instruments. Although the visual field obtained with the present cameras and optics is adequate, additional improvements, such as a three-dimensional image and high-resolution, self-illuminating flexible thoracoscopes, are needed. Potentially, enhancement of the video image by detection of wavelengths outside the visible spectrum or by the superimposition of a radiographic image (e.g., CT scan) on the operative field would improve the operative capabilities of thoracoscopy. Identification of lesions remains a significant problem, and these modifications might improve localization capabilities.

Further improvements of endoscopic instruments are necessary before thoracoscopy can be widely applied to more complex thoracic surgical procedures, such as pneumonectomy. The advent of flexible ports and articulating stapling devices are two examples of such improvements. Suitable endoscopic clamps to control major vascular and bronchial structures are also needed to achieve the full potential of thoracoscopy.

In the meantime, manual dexterity and endoscopic experience are prerequisites for thoracoscopy. Psychomotor and technical skills need to be refined by practitioners of thoracoscopy and operating room personnel. Acknowledgment of the requisite skills and incorporation of standardized thoracoscopy training into cardiothoracic fellowships should be priorities of the accreditation committees and specialty boards.

Finally, and perhaps most importantly, a systematic and objective evaluation of the advantages and limitations of thoracoscopy for selected indications is required. Comparison of the results of current thoracoscopy procedures is needed to guide growth of the technique. The Video-Assisted Thoracic Surgery Study Group (VATSSG) is an important factor in this process.[78] The VATSSG collates and coordinates information on thoracoscopy procedures from sites across North America, creating a standard for thoracoscopy. The same group has initiated randomized trials of selected thoracoscopy procedures and traditional methods. These efforts will allow a more accurate assessment of the capabilities of this technology. Along with the technologic improvements that are being made, this information will allow a more appropriate application of thoracoscopy to a greater number of thoracic surgical procedures.

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Section III
Laparoscopy in Subspecialties

30
Gynecology

30.1 The Laparoscopic Management of Endometriosis for the Relief of Pain

Gordon Davis

Laparoscopy has come to dominate the management of endometriosis because it allows easy access to the dependent aspects of the pelvis, where endometriosis is most frequently found, and because it provides magnification, which allows subtle lesions to be detected. Pain management dominates fertility concerns during that portion of adolescence prior to the childbearing years and after the patient's family is complete or the issue of childbearing has been resolved. During the latter period, the patient is more likely to want definitive therapy for endometriosis, whereas in the former, the patient wants to preserve reproductive potential and prevent progression of her endometriosis. In either case surgical intervention is usually required for pain relief.

Endometriosis-Associated Pain in the Adolescent

Adolescence is defined as the period between the onset of secondary sexual characteristics and the cessation of somatic growth. It is during this time that the earliest signs and symptoms of endometriosis are noted, although, sadly, such symptoms may be ignored or mismanaged. Delayed diagnosis of adolescents with endometriosis appears to be common. Unfortunately, even modern endometriosis textbooks imply that adolescents with endometriosis have lower-genital-tract lesions or development anomalies of the upper reproductive system that obstruct menstrual flow. Reports of adolescents with endometriosis typically concern small series of patients who presented with painful adnexal masses that proved to be endometriosis or small groups of adolescents whose menstrual outflow is obstructed by congenital defects. Yet these two clinical presentations represent less than 1% of adolescents with endometriosis.

Indeed the converse of the obstruction argument may be true; the most common indication of endometriosis in an adolescent is severe dysmenorrhea without detectable obstruction of menstrual flow.

Symptoms in Adolescents

Severe dysmenorrhea is a symptom complex that involves the reproductive system, the gastrointestinal tract, and apparently any smooth-muscle structure in the vicinity of endometriosis implants. Prostaglandins and leukotrienes as well as vasoactive compounds have been implicated in the etiology of severe dysmenorrhea and have been noted to be biochemical products of endometriosis implants.

The earliest implant of endometriosis is not known for certain, but it is believed to be a red lesion. This lesion is composed of endometriotic glands and highly vascularized stroma. Many implants have an atypical appearance, however. It has been suggested that implant pigmentation evolves with time. The red implant changes; it sometimes regresses and may gradually acquire pigmentation by repeated bleeding episodes. Eventually the classic blue-black powder-burn implant may replace the biologically very active red lesion. Histologically, the glandular elements of red lesions are quite active, showing mitosis and glycogen storage. Red lesions are more active histologically than older lesions.

The bioactivity of endometriosis lesions is currently the subject of intensive study. The chemicals synthesized and secreted by red lesions are believed to be mediators of pain. Therefore, endometriosis in the adolescent can be considered a disease in which there are multiple prostaglandin- and leukotriene-secreting tumors.

Red Lesions in Adolescents

Red lesions may be subtle in appearance, especially if they have acquired little pigmentation or if they are less richly vascularized. Exactly how the earliest endometriotic lesion arises has been the subject of debate for almost 100 years. The most commonly accepted theory is that retrograde menstruation somehow implants on the surface of the hormonally responsive posterior pelvic peritoneum of patients who are immunologically unable to clear the reflux of menstrual detritus. The ovaries have been reported to be the most common site of endometriosis in adolescents but this assertion is not supported by our observations. The most common lesions are peritoneal lesions. The overwhelming predominance of red lesions in adolescents and their close association with severe dysmenorrhea leads some to believe that a red lesion may be the earliest peritoneal manifestation of endometriosis and severe dysmenorrhea may be the earliest sign of morbidity.

The prevalence of adolescent endometriosis is probably similar to that in the reproductive-age population in general. Severe dysmenorrhea, which appears to be a marker for endometriosis, is the most common cause of absenteeism from work or school among adolescents. It accounts for the loss of 140,000,000 work hours yearly in the United States.

Laparoscopic treatment of subtle forms of endometriosis affords pain relief, but proper clinical management of adolescents with endometriosis requires knowledge of the early presentation of lesions and willingness to institute early laparoscopic intervention. Early intervention should limit the morbidity and scarring that occur if the disease progresses.

Endometriosis-Related Pain in the Patient Who Has Completed Childbearing

Endometriosis frequently requires hysterectomy and removal of all ovarian tissue for definitive therapy. Statistics reveal that between 1982 and 1984, 18.9% of all hysterectomies in the United States were done for endometriosis. This represents a doubling of the incidence of hysterectomy for this indication compared to the period between 1965 and 1967. Hysterectomy for endometriosis increased by 141% between 1965 and 1984. This increase probably reflects more frequent diagnosis in the era of modern laparoscopic equipment but might also reflect the failure of conservative therapy to provide definitive treatment of the disease. It is generally believed that cyclic ovarian function causes the progression of endometriosis. Endoscopy has allowed less-invasive definitive therapy for high-stage endometriosis. Stage III and IV endometriosis may still be approached laparoscopically; the reproductive organs may then be removed and the endometriosis cleared from the pelvis.

Operative Approach to Endometriosis for Pain in Adolescents

Therapeutic laparoscopy in adolescents is aimed at reducing the volume of disease in the pelvis and restoring pelvic anatomy. Generally postoperative hormonal therapy in the form of oral contraceptives is prescribed. It is widely believed to prevent recurrence of endometriosis by decreasing the load of menstrual reflux. Ovulation suppression also attenuates the severity of dysmenorrhea by reducing the prostaglandin level in the menstrual fluid.

Recognition

The laparoscopic surgeon must recognize the pleomorphic characteristics of endometriotic implants. In a series of 332 patients under 35 years of age with histologically proven endometriosis, 49 patients were 20 years of age or younger. This represents 16% of all the patients in the series. Thirty-six of the 49 patients under the age of 20 were remarkable because they presented with severe dysmenorrhea. In other words, one can expect that 12% of the patients in an endometriosis-oriented practice will be adolescents with the morbidity associated with severe dysmenorrhea. Some patients, approximately 4%, will come to laparoscopy for other reasons, such as ectopic pregnancy, ruptured ovarian cyst, or other emergencies. From 1986 to 1992, 36 patients between ages 13 and 20 years underwent laparoscopy for endometriosis associated with severe dysmenorrhea. Their mean age was 16.6 years. Most of these patients were between 15 and 17 years.

Location and Characteristics of Endometriosis Lesions

By convention, infiltrating lesions are defined as those that penetrate pelvic tissue 3 to 5 mm, and superficial lesions are defined as those that penetrate the peritoneum less than 3 mm. It is relatively easy to estimate 3 mm of invasion in a clinical situation but quite difficult, without microscopy, to accurately estimate 1 or 2 mm. Infiltrating lesions were most commonly found in the uterosacral ligaments. Most of these lesions were associated with old collections of blood and fibrosis, which distorted the architecture of the uterosacral ligaments. It is important to recognize infiltrating lesions because the treatment for them differs from that for superficial lesions. Infiltrating lesions are difficult to ablate because they rarely fit between the jaws of electrosurgical instruments, and laser vaporization does not reliably eradicate lesions. Further, coagulation of infiltrating lesions of the uterosacral ligaments risks thermal spread to contiguous structures and injury to the ureter. Dissection and excision of these lesions is more precise and allows such structures as the ureter to be avoided. Occasionally, small nodular lesions found on the uterosacral ligaments are amenable to bipolar coagulation, even though the depth of infiltration approaches 5 mm. Infiltrating lesions may be multiple, isolated foci, but they may also be connected by submesothelial fibrotic strands, a phenomenon called "tunneling." As a general rule, if the lesion cannot be grasped and elevated, attempts at coagulation will result in residual disease.

Finding the Red Lesion

As mentioned previously, the lesion most commonly associated with the symptom complex of severe dysmenorrhea is a colorful superficial lesion with a vesicular appearance. The red color derives from highly vascularized stroma. Identification of red lesions may require close inspection of the pelvic peritoneum. It is recommended that the laparoscope be brought within 2 or 3 cm of the peritoneal surface. Red lesions are commonly found in the cul-de-sac and on the broad-ligament peritoneum. Red lesions are generally surface lesions but may overlie infiltrating disease. The normally arcuate peritoneal vasculature may appear to radiate instead from the endometriosis implant. Red lesions appear even redder as the pneumoperitoneum is established and vasodilation occurs in response to the high concentrations of CO_2. The vesicular surface will develop hemorrhages as CO_2 is suffused across its surface.

Endometriosis rarely penetrates the fatty tissue of the central cul-de-sac. Perhaps the vasculature in this region is less favorable for infiltration, whereas the vasculature of the more muscular ligamentous structures and the fibromuscular septi allows invasion, accumulation of fibrosis, and deeper invasion. The mechanism of invasion is not understood, but the sites of invasion have been consistent in several studies. Red lesions rest on the fatty surface of the cul-de-sac or the perineum covering the mesenchyme of the broad ligament. It is also rare to find infiltration from the surface of the broad ligament into structures such as the ureter, although this has been reported.

The uterine serosa is probably involved in endometriosis more frequently than has been reported. Sometimes infiltrating adenomyomas are found just beneath the serosa of the uterus. The anterior cul-de-sac is less frequently involved by red lesions than the posterior cul-de-sac. When invasion occurs, it frequently occurs along the connective and vascular tissue of the bladder pillar and may have a periphery made up entirely of red lesions.

Surgical Treatment

If the lesions are invasive (deeper than 3 or 5 mm) excision is recommended, as long as tubo-ovarian damage can be avoided. In early studies of CO_2 vaporization and in coagulation series, a high failure rate was encountered when the lesions were extensive or deeply infiltrating. Excisional techniques require identification of the important structures of the pelvis, such as the ureter and veins, and appropriate safe peritoneal incisions near these structures. Some authors advocate fluid be infused into the retroperitoneal tissue around an area to be excised. Once the peritoneum is incised, the lesion is grasped and pulled upward. Medial traction is applied, and the infiltrating disease is dissected free. There is almost always an areolar space contiguous with the invasive lesion, and sharp as well as laser dissection may be used with very little distortion of anatomy.

The removal of deeply invasive disease may require entering the vagina or the rectum. As the dissection becomes more radical, fertility issues must be considered because adhesions cannot be completely prevented. Invasive disease sometimes affects the serosal and superficial muscularis layers of the rectum but frequently full-thickness invasion of the vagina is present. The apex of the vagina is quite thin, and there is little margin for error when resecting endometriotic lesions. Retrocervical fibrotic disease is almost always a full-thickness lesion. Uterosacral invasion is variable but almost never extends completely to the pelvic side wall; the "frozen pelvis" is an extremely rare condition.

Since clear vesicular and red endometriotic lesions are almost always superficial, they can be safely vaporized or coagulated with bipolar or unipolar instruments. Care should be taken when treating lesions overlying the ureter and in the region of the ovaries. Retro-ovarian excision of peritoneum is often followed by the development of dense fibrotic adhesions that immobilize the ovary and that may adversely affect fertility or produce chronic pain. Lesions on fallopian tubes should be treated under magnification and focal vaporization or coagulation should be the technique of choice. Relatively low-power-density laser coagulation of the mesothelium is an attractive approach for extensive superficial disease, but the same effect can be achieved using bipolar instruments. The bipolar forceps are operated with the paddles separated so that the electrical energy blanches the peritoneum near very superficial lesions. Operating the CO_2 laser at a low power density creates the same effect more rapidly.

When treating extensive superficial disease in adolescents, it is recommended that the ovaries be temporarily suspended from the anterior abdominal wall or lateral aspect of the round ligaments. This avoids the risk of thermal injury to the mesothelium of the ovary and allows the surgeon to operate in the floor of the pelvis without repeatedly traumatizing the ovaries by lifting them out of the surgical field. A small suture is passed through the distal pole of the ovary and then through the round ligament near the superficial inguinal ring. The suture is tied, suspending the ovaries for the duration of the operation. At the end of the procedure, the ovaries are cut free, and a barrier method of adhesion prevention may be used.

Ovarian Surface

When treating the surface of the ovary in adolescents we recommended that thermal energy be applied precisely to the individual implants. The ovary is a very unforgiving structure when it comes to adhesions. Minimal trauma to the ovary often produces adherence to the pelvic side wall or other structures, and this may be devastating to the young patient.

Peritoneal Pockets

Adolescent patients with severe dysmenorrhea and endometriosis sometimes have peritoneal defects. To identify these "pockets," the surface of the uterosacral ligament is grasped and traction is applied laterally. This allows a clear view of the most common site for these defects: the peritoneum under the right uterosacral ligament. These lesions, which are rarely bilateral, are believed to be congenital in origin. The defects are of variable depth and usually extend into the pararectal space. In some regards they are similar to hernias; a discrete ostium is present, but intestinal entrapment has not been reported. The opening may be quite subtle and identification difficult, but when fluid is placed in the dependent pelvis and aspirated, residual fluid will be seen to ooze from the ostium. The pocket should be everted and the peritoneum inspected for endometriosis. Currently we recommend that the peritoneum of the pocket should be resected. Sometimes significant veins will be encountered, but electrosurgical control is safe and effective in the dependent pelvis. The incidence of pockets is not known with precision, but it is suspected that they contribute to the symptom complex of severe dysmenorrhea.

Summary of Salient Points in the Treatment of Adolescents

It is important for the surgeon to remember that the most common lesion in the adolescent is not a black or powder-burn endometriotic implant or an endometrioma. Eighty-six percent of our group of adolescents had a preponderance of red lesions. It is also important to remember that the prostanoids secreted by endometriosis are apparently related to the bowel symptoms. There usually is no bowel lesion, despite the relatively high incidence of bowel complaints in adolescents. Peritoneal defects may be present and should be actively sought.

Future fertility must also be considered. Radical dissection aimed at clearing all endometriosis may help relieve pain but may prevent future childbearing.

The goal of intervention in the adolescent with severe dysmenorrhea is to decrease subsequent morbidity from endometriosis. It is interesting to note that many adolescents with severe dysmenorrhea already have high-stage disease. This is a function of staging systems that emphasize adhesions more than endometriotic implants.

Thermal energy sources are preferred to excisional techniques with or without suturing because there appears to be less adhesion formation when thermal energy sources, such as the CO_2 laser or electrosurgery are used. Suturing is associated with more fibrotic change than leaving the peritoneum open. While there may be no adhesion to relatively large areas denuded of cul-de-sac peritoneum, in the region of the ovary slight thermal damage or excision of tissue inevitably results in adhesion formation.

Suppressive Treatment

After laparoscopic surgical treatment of endometriosis in adolescents, we prescribe one-a-day oral contraceptive pills for several months. Some patients have been placed on cyclic therapy instead.

Results of Therapy

Major complications are rare when treating adolescents, but complications are related to stage and some adolescents will have high-stage disease. Of 36 patients with severe dysmenorrhea we treated, 96% were treated as outpatients. We followed 89% (32) of our 36 patients for between six months and six years. The mean follow-up was 2.8 plus or minus 1.2 years. Only four patients were lost to follow-up, indicating that adolescents with severe dysmenorrhea and endometriosis are good candidates for observation.

Satisfactory treatment may be defined as treatment that is not followed by further intervention. Conversely, therapy is unsatisfactory if it must be followed by adjunctive therapy that has a major impact on the patient's hormonal status or if the patient requires reoperation. In our group of patients, 27 of the 32 evaluated patients had a satisfactory outcome. Five patients underwent repeat therapy either with GnRH analogs, danazol, large doses of Provera, or reoperation. These five patients were considered unsatisfactorily treated by laparoscopy.

Conclusions

Adolescents with endometriosis and severe dysmenorrhea have a high incidence of bowel symptoms but tolerate ovulation suppression with oral contraceptives well. Those patients who fail oral contraceptive therapy initially often respond to operative laparoscopy followed by ovulation suppression.

There is generally no need for adjunctive measures, such as presacral neurectomy or uterine nerve ablation. A presacral neurectomy is indicated only if midline pain, particularly severe uterine cramping, is the major component of the symptom complex. This procedure may be performed laparoscopically when the endometriosis is resected. It is not recommended that presacral neurectomy be a routine part of the management of adolescents with endometriosis, however, because this procedure is associated with significant morbidity.

Definitive Therapy for Endometriosis

Laparoscopically assisted vaginal hysterectomy may be used as definitive therapy for high-stage endometriosis. If hysterectomy is indicated in patients who have low-stage endometriosis, the vaginal approach may be used without laparoscopy. The laparoscope is used during a vaginal hysterectomy to determine the course of the rectum and whether the adnexa are enlarged or fixed to the lateral or dependent pelvis.

Bowel may be adherent to the uterus in high-stage endometriosis, but often the predominant surgical concern is that the rectum or sigmoid colon may be drawn into the operative field and inadvertently damaged. Vaginal or uterosacral fibrosis or anatomic variations resulting from prior surgical therapy may prevent the surgeon from being certain of the course of these structures. Endometriosis that meets these conditions is usually approached by laparotomy. The need for laparotomy is confirmed by laparoscopy. Commonly adhesions and adnexal disease are present, but sometimes rectal wall disease, cul-de-sac obliteration, or other intestinal disease is noted. Our experience with 40 patients undergoing laparoscopically assisted vaginal hysterectomy revealed moderate rectal wall disease in 12 patients and cul-de-sac obliteration in nine patients. Clearly cul-de-sac obliteration makes vaginal hysterectomy less than safe, laparoscopy may be utilized to free the cul-de-sac.

Our technique for laparoscopically assisted vaginal hysterectomy for stage III and IV endometriosis includes a preparatory phase during which we perform an examination under anesthesia and apply uterine manipulators. The application of an intrauterine manipulator allows the uterus to be elevated, retracted, or displaced laterally during the operation. We insert a rectal probe that allows the rectal wall to be identified and downward or lateral traction to be placed on the rectum. A vaginal probe is also placed to permit proper identification of the vagina and to allow the rectum to be distinguished from the vagina. Prior to beginning the procedure we give prophylactic antibiotics.

We now divide the laparoscopically assisted vaginal hysterectomy for advanced endometriosis into three operative phases.

Operative Phase I

Operative laparoscopy is performed in the usual fashion. We mobilize bowel or adnexal structures in preparation for vaginal hysterectomy. To mobilize fixed ovarian tissue we enter the retroperitoneal space between the infundibulopelvic ligament and the round ligament. In this triangle we identify the ureter by blunt dissection. We mobilize the ovaries by extending the lateral peritoneal incision to the level of the round ligament and isolating the ovarian pedicle, leaving the ovary attached to the peritoneum. The broad ligament peritoneum is removed with the attached ovary. This lateral retroperitoneal approach permits freeing of the adnexal vasculature and infundibulopelvic ligament. The infundibulopelvic structures are isolated by perforating the medial leaf of the broad ligament. We then suture ligate or desiccate the infundibulopelvic pedicle, divide it, and dissect the fixed ovary and retro-ovarian peritoneum toward the uterus. This frees the adnexa and brings it into a retrouterine position. At this point the process is repeated contralaterally if required. If endometriosis involves the appendix, an appendectomy is now performed.

Dependent pelvic endometriosis is excised. Infiltrating disease is developed into a purely retrocervical position. The involved uterosacral ligaments and retrocervical nodules are mobilized so that the disease is no longer attached to the rectum or lateral structures. It is important to develop the infiltrating endometriosis of the vaginal cuff or uterosacral ligaments into a retrocervical position so that a colpotomy can be performed across tissue uninvolved with endometriosis. If vaginal cuff endometriosis or uterosacral endometriosis is not resected, there may be symptomatic persistence at the vaginal cuff. Too radical excision of endometriosis at the vaginal cuff may lead to painful scarring and dyspareunia or vaginal shortening and apical stenosis. Once the infiltrating disease is developed into a retrocervical position, we use a ring forceps placed in the posterior vaginal fornix to tent the vagina toward the laparoscope. We then use a thermal energy source to perform a transabdominal colpotomy. This provides the safety net necessary to protect the rectum during the vaginal hysterectomy.

The above maneuvers develop the diseased adnexa and the infiltrating endometriosis into a medial and retrouterine position so that it can be removed at the time of vaginal hysterectomy.

We do not recommend securing the uterine artery at laparoscopy. This procedure is time-consuming and is relatively easily accomplished vaginally.

Operative Phase II

We then abandon the laparoscopic approach and perform a vaginal hysterectomy with a salpingo-oophorectomy. The vaginal technique is dictated by uterine size, and we generally select one of the three commonly practiced vaginal hysterectomy techniques. The choice of technique should be dictated by the surgeon's level of comfort with it as well as anatomic factors.

Operative Phase III

We then occlude the vaginal cuff with packing and perform operative laparoscopy. At this time the pelvis is lavaged, hemostasis is ensured, and any residual endometriosis is removed. We insist upon coagulation of even small subvesicle bleeders and check pedicles to be sure they are secured. Residual gas is removed from the abdomen.

Evolution of Technique

Our experience with laparoscopically assisted vaginal hysterectomy continues to grow. We initially reported 40 patients with stage III and IV endometriosis. We excised all visible and palpable endometriosis and removed all visible ovarian tissue.

From 1987 through 1989 we performed intracorporeal suturing and extracorporeal knotting. We used slip knots, pre-tied knots, endoknots, and loop ligatures. From 1989 to 1990 electrosurgical desiccation replaced extracorporeal knotting as the principal method for handling pedicles. In 1990 and 1991 and automatic stapling device became available, but we found it difficult to use on the fibrotic pedicles and adnexal disease encountered with advanced endometriosis. By 1991 we were suturing all pedicles with 0 Vicryl and the Clarke knot pusher. This technique requires only basic surgical skills, is less traumatic to the tissue than electrosurgery, and is extremely cost-effective. The Clarke knot pusher allows us to execute square knots in any region of the pelvis. We had used the CO_2 laser for retroperitoneal dissection and often for tissue division after bipolar desiccation. Our current technique is electrosurgical with occasional suturing. Stapling devices are occasionally used and the CO_2 laser is still our thermal energy source of choice. Bipolar coagulation is utilized hand in hand with the CO_2 laser.

Reviewing pedicle technique, we have found that electrosurgical desiccation is associated with the shortest operating time and that slip knots, pre-tied loops, and intracorporeal knotting are associated with the longest operating time.

Complications

Of the 40 patients previously reported, 2 required transfusion. Rectal injury occurred in one patient from the use of bipolar coagulation. Thermal spread from bipolar coagulation is much more extensive than from unipolar coagulation, but hemostasis is more readily achieved with bipolar electrosurgery. One patient sustained ureteral injury that required stenting. Two other patients were noted to have postoperative anemia related to the operation but these patients did not require transfusion.

Operating Time

Laparoscopically assisted vaginal hysterectomy for advanced endometriosis is a long operation. Analysis of the factors other than pedicle technique that contribute to prolonged anesthesia time reveals that cul-de-sac obliteration with endometriosis routinely requires four hours. Deep bowel involvement increases operating time by as much as one hour. Bowel disease and cul-de-sac obliteration, both of which require careful retroperitoneal and deep pelvic dissection, are associated with the longest operating times. When adhesions account for the high-stage classification, operating time is three hours or less. Retrocervical deep fibrotic endometriosis without cul-de-sac obliteration also requires approximately three hours. Adnexal disease characterized by endometrioma formation requires slightly more than three hours of operating time, principally because the broad ligament and uterosacral ligament are frequently involved, and these require resection. Our operating times have ranged from slightly over five hours in early 1988 to a low of slightly over two hours in 1992. The average operating time plateaued in 1990 at approximately 3 hours and 15 minutes. In other words, patients undergoing laparoscopically assisted vaginal hysterectomy for endometriosis will have longer anesthesia times than similar patients undergoing total abdominal hysterectomy and bilateral salpingo-oophorectomy.

We believe that the surgeon should do laparoscopically only what is necessary to convert a total abdominal hysterectomy and bilateral salpingo-oophorectomy to a vaginal hysterectomy and salpingo-oophorectomy. This usually means adhesiolysis and mobilization of the adnexa. Dependent endometriosis should be excised but the vesicouterine space and uterine vessels are better dealt with vaginally.

Summary

The patient who requests definitive therapy may be safely treated with laparoscopically assisted vaginal hysterectomy and thus obtain the benefits of vaginal hysterectomy, which is associated with less morbidity than abdominal hysterectomy. The older-reproductive-age patient may suffer the same complications with laparoscopically assisted vaginal hysterectomy as are encountered with laparotomy.

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30.2 Pelvic Pain Syndromes: Endometriosis and Midline Dysmenorrhea

David B. Redwine and James J. Perez

Introduction

Pelvic pain can be gynecologic or nongynecologic in origin. Musculoskeletal pain or pain due to functional bowel spasm will not be discussed here.

In a general gynecologic practice, endometriosis is the disease most commonly found when pelvic pain is surgically investigated,[1] and it is the disease most often treated by operative laparoscopy.[2] Although some patients may be asymptomatic and some authors question whether endometriosis causes pain,[3,4] most clinicians believe this disease is a possible cause of female pelvic pain.

Too frequently all pelvic pain is blamed on endometriosis once this disease has been diagnosed. Lack of response to treatment is explained as the recalcitrance of the disease. In fact, specific gynecologic pelvic pain syndromes are predictably associated with particular derangements of anatomy or physiology.[5] Since endometriosis commonly occurs on pelvic peritoneal surfaces at a distance from the uterus, tubes, and ovaries,[1] an important clinical distinction immediately becomes apparent: patients can suffer from endometriosis pain, or pain due to uterine, tubal, or ovarian causes. Although endometriosis deserves most of the blame it receives, careful questioning can help distinguish midline uterine cramping with menses from the sharp, frequently nonmenstrual pain that is more characteristic of endometriosis. Ovarian endometriomas may cause lateral pain radiating up the respective neurovascular pedicle toward the flank. Frequently the pain of endometriosis may begin about the time of ovulation, increase throughout the luteal phase, and become incapacitating with menses. A clinician may mistakenly interpret this increased pain with menses as uterine cramping and direct treatment toward the wrong entity. Dyspareunia and painful bowel movements during menses are frequently due to endometriosis, since the disease usually occurs in the most dependent parts of the pelvis, adjacent to the vagina and rectum. Invasive disease of the uterosacral ligaments can cause pain radiating down the back of the leg. Dyschezia throughout the menstrual cycle is highly suggestive of a rectal nodule of endometriosis and obliteration of the cul-de-sac.[6] The incidence of pelvic pain among endometriosis patients is directly proportional to the invasiveness of the disease,[7,8] although patients with superficial disease can certainly have pain.[9] Pelvic examination may reveal focal tenderness or tender nodularity of the cul-de-sac or uterosacral ligaments, which is virtually pathognomonic of endometriosis.[10,11]

All medical therapy for endometriosis is based on the supposition that pregnancy or menopause physically destroy the disease, a supposition that derives from clinical observations of symptom improvement during these hormonal states rather than on biopsy-controlled studies of disease response. Given the epidemiologically unsound treatment, it should come as no surprise that the persistence of disease at the conclusion of therapy in patients with stages I and II disease according to the revised American Fertility Society (rAFS) classification[12] is at least 78%.[13] The only indication for medical therapy is to achieve temporary pain relief in patients who must delay surgery. Medical therapy for infertility associated with endometriosis is not FDA-approved.

This chapter reviews laparoscopic treatment of pelvic pain associated with endometriosis and laparoscopic treatment of uterine cramps.

Historical Review of Laparoscopic Treatment of Endometriosis

Operative laparoscopy in America dates from Ruddock's development in the 1930s of a practical peritoneoscope that closely resembled today's laparoscopes.[14–19] Ruddock treated abdominal and pelvic adhesions, drained abscesses, performed limited hepatic resections, and diagnosed and staged abdominal cancer, usually under local anesthesia. Although laparoscopic technology is over 60 years old, until the early 1980s, most surgical treatment of endometriosis was by laparotomy. A surgeon's choices in 1920 were identical to a surgeon's choices today: attempted destruction or removal of the disease, or removal of organs such as the uterus, tubes, or ovaries with retention of the disease. Although review of the literature indicates that relief from pain roughly correlated with the volume of tissue and number of organs removed, it is also clear that conservative excision of endometriosis with retention of pelvic organs resulted in significant relief.[13] The technique of conservative surgical excision at laparotomy (CSEL), which has been described in detail by many authors,[20] consists of aggressive resection of involved peritoneum and dissection of diseased tissue from underlying vital structures. Since 60% of the patients in one study had disease that had invaded more than 2 mm,[21] and since visual diagnosis at surgery alone cannot always detect invasive disease,[22] excision seems ideal for both diagnosis and treatment. So successful was CSEL that Meigs in 1953 stated that "cure by conservative surgery is usual."[23] This optimistic view of the results of surgical treatment of endometriosis contrasts sharply with the pessimistic view prevalent today. This may have less to do with the merits of CSEL than with the rapid adoption of unproven and frequently ineffective medical therapy and laparoscopic surgical modalities.

Laparoscopy began to be used to treat endometriosis in the late 1960s.[24] The techniques used at laparoscopy departed radically from those in contemporary use at laparotomy. Laser vaporization and electrocoagulation appeared from nowhere and were quickly adopted because they lent themselves to the small laparoscopic ports. It seemed plausible that heat generated by these modalities might destroy endometriosis, and the shorter recovery possible with laparoscopy was too attractive to ignore. The accumulated experience of several decades of CSEL was discarded overnight.

Although many new laparoscopic surgeons flocked to electrocoagulation, the materials and methods sections of the influential papers on electrocoagulation[25–30] do not contain sufficient details to allow replication of this work. Equipment, current densities, and techniques are not adequately described, and there is obvious confusion over the true meanings of such terms as "cautery," "coagulation," and "fulguration." Most authors mention avoiding treatment of endometriosis overlying vital structures to avoid damaging them. The efficacy of any therapy for endometriosis can be shown only by conducting a sufficient number of second-look surgeries to measure the absence or presence and extent of endometriosis and to compare it to conditions prior to therapy. To date, most studies of the efficacy of electrocoagulation have focused on *the response of symptoms* (usually infertility) rather than on *the response of the disease.* CO_2 laser vaporization of endometriosis has been described more adequately,[31,32] but this technique suffers from the same limitations of use and again its efficacy in eradicating endometriosis has not been validated. Neither modality returns a pathology report, so all therapeutic effects are the opinion of the surgeon.

In decided contrast, laparoscopic excision of endometriosis by sharp dissection has been described in detail,[33] and excision of endometriosis at laparotomy[34] and laparoscopy[35] have both been shown by long-term follow-up and re-operation to be highly effective in eradicating or reducing endometriosis. Excision of endometriosis can also be performed using CO_2 laser[36,37] or monopolar electrosurgery.[38,39] The five-year risk of a diagnosis of new, mild endometriosis following laparoscopic excision is only 19%,[35] which certainly seems to justify the optimism expressed by Meigs in 1953. If unproven modern surgical techniques are combined with disproven modern medical therapy, treatment failures and pessimism will be the inevitable result. Excision of endometriosis is the treatment of choice.

Laparoscopic Electroexcision of Endometriosis

The patient is placed in low lithotomy position using well-padded knee stirrups. An intrauterine manipulator is inserted, the bladder is drained by a retention catheter, and a vertical incision is made within the umbilicus. A triple-puncture technique is used. A reusable all-metal 10-mm trocar and sheath is inserted directly through the umbilical incision without prior insufflation, the only blind abdominal wall puncture. A 10-mm operating laparoscope is inserted through the umbilical port, and two reusable 5.5-mm fiberglass valveless sheaths (Richard Wolf, Chicago, IL) are inserted lateral to the inferior epigastric vessels. If the abdominal wall is "tented" with the shaft of the laparoscope, the secondary trocars can be inserted beneath the laparoscope and directed horizontally, eliminating the risk of injuring the iliac vessels. The patient is then placed in a steep Trendelenburg position. A 3-mm scissors is passed down the operating channel of the laparoscope. Although it is popular to view the operation on a video monitor rather than through the laparoscope eyepiece, some optical resolution is lost and an assistant is usually required to guide the video camera while the surgeon operates. This increases operative time and expense. Elevating the operating table brings the laparoscopic eyepiece high enough for comfortable direct vision. With the right hand the surgeon uses the scissors to press the eyepiece firmly into the right nasal bridge. The left hand controls a 5-mm grasper in the left-lower-quadrant port, and a suction/irrigator in the right-lower-quadrant incision. The 3-mm monopolar scissors is connected to a ValleyLab Force 4 electrosurgical generator set for between 70 and 90 W of pure cutting current and 50 W of coagulation current. These settings result in a high current density at the tip of the active electrode, allowing instant electrosurgical action. Lower current densities would result in coagulation and potentially in lateral thermal spread. The grasper pulls tissue medially, so that the active electrode can be brought into contact with tissue that is under great tension. When the electrode tip touches the tissue under tension, it cuts and the tissue separates. Loose tissue pillows around the large surface of the active electrode, where it is coagulated rather than cut. The voltage of the coagulation waveform is more than 10 times stronger than that of the pure cutting waveform. The greater electromotive force of the coagulation waveform is useful in cutting through retroperitoneal fatty tissue or through parenchymal tissue, such as the uterosacral ligaments. The pure cutting waveform is useful in making initial peritoneal cuts, although either waveform or blended current can be used on any tissue when necessary. The scissors can thus also be used to cut sharply, coagulate bleeders, blunt dissect, palpate, retract, grasp and rearrange tissue, and grasp and remove tissue from the abdomen. The use of one instrument to perform several functions minimizes instrument changes and drastically reduces surgical time.[40]

Need for a Bowel Prep

Certain symptoms and signs suggest the possibility of bowel involvement by endometriosis, and patients with these symptoms should receive a bowel prep before surgery. Rectal pain and pain with defecation throughout the month suggest the presence of a rectal endometriosis nodule. Previous surgery revealing bowel disease or cul-de-sac obliteration, as well as tender nodularity of the cul-de-sac or uterosacral ligaments are signs suggesting the presence of intestinal involvement. Obliteration of the cul-de-sac is sometimes identified as "severe cul-de-sac adhesions" or as "adherence of the rectosigmoid colon to the uterus." Thus, although a previous surgeon may have described the morphologic effects of a rectal nodule, its presence may still be unrecognized. If a rectal nodule is present, this increases the likelihood of disease of the midsigmoid, terminal ileum, appendix, or cecum.

Four liters of oral colonic lavage the afternoon before surgery followed by two enemas the evening before surgery results in a superb bowel prep.

Identification of Disease

Effective surgical treatment of endometriosis begins with accurate identification of disease. Inaccurate disease identification results in incomplete surgical treatment and confusion about the natural history of the disease.[41] The appearance of some endometriotic lesions changes with advancing age.[7,8] Laparoscopy combined with knowledge of the morphologic characteristics of normal peritoneum[42–45] appears to be a more effective way than laparotomy[46] to identify small lesions of endometriosis. This is due to the magnifying effect of the laparoscope in near-contact mode. Scientific studies of microscopic endometriosis predict that accurate identification and aggressive excision of disease would result in complete removal of disease in between 75 and 100% of patients.[43,44]

Since invasive disease is strongly associated with pain,[7,8] special attention must be paid to its appearance. Invasive disease is more likely to be undertreated than is superficial disease, in part because it frequently has a yellowish-white cast due to overlying fibrosis. Ironically, disease with this appearance has been characterized in the past as "burned out," when it is actually highly active "burned in" disease. Excision of endometriosis ensures that the surgeon will find invasive retroperitoneal fibrotic disease and completely remove it. Some innocuous-appearing lesions may actually have invaded several centimeters beyond the retroperitoneal fatty areolar tissue,[6,21] involving major pelvic nerves or even the periosteum of the ilium.[47]

Superficial Peritoneal Resection

Since most patients do not have invasive disease, this is the technique that is most commonly used. During palpation with the graspers, superficial lesions will slide easily over retroperitoneal vessels and can be grasped, elevated, and excised. The peritoneum to be removed is elevated and an electrosurgical touch cut made adjacent to it. The abnormal peritoneum is then bluntly dissected away from underlying vital structures as it is pulled medially toward the center of the pelvis. The last tendrils of retroperitoneal tissue can be severed with coagulation current once they are separated from vital structures.

Deep Peritoneal Resection

Invasive endometriosis should be suspected if blood vessels or the ureter cannot be seen because the normally transparent peritoneum is obscured by fibrosis. In this case, the normal peritoneum adjacent to the lesion should be elevated, opened with a touch cut, and the edge of the hole grasped and elevated medially, so that the scissors can bluntly dissect the lesion away from underlying structures. This frequently requires operating directly on the ureter or the rectum below the peritoneal reflection of the cul-de-sac. Then, while the surgeon grasps either the lesion or the adjacent normal peritoneum as required to maintain tension, electrosurgical cuts can be made to extend the line of incision around the lesion, followed by retroperitoneal dissection working toward the center of the bottom of the lesion. Either the ureter or bowel wall can be held with an atraumatic grasper to assist in keeping the tissue under traction. It is only during retroperitoneal dissection that the invasiveness of endometriosis will be appreciated. Once the invasive lesion is largely dissected from underlying vital structures, coagulation cutting can be used to quickly sever the last tendrils of attachment.

Resection of the Uterosacral Ligament

Resection of the entire uterosacral ligament is the only treatment that will ensure complete removal of invasive endometriosis, which can sometimes exist in a volume equal to that of a human thumb. The peritoneum lateral and parallel to the ligament is incised. When the uterus is elevated with a manipulator, this incision results in automatic retraction of the peritoneum, allowing retroperitoneal structures to be visualized. A blunt probe can be used to push the ureter and uterine vessels laterally to ensure that they are not near the uterosacral ligament. The ligament can be bluntly undermined along its length to define the direction of the ensuing dissection. Invasive fibrosis may extend laterally, involving the ureter or branches of the uterine vessels descending lateral to the ligament toward the lateral vaginal wall. In this case the dissection must begin more posteriorly in uninvolved peritoneum along the broad ligament and then work along and around the ureter toward the uterosacral ligament. Medial to the point where the ureter passes beneath the uterine vessels, care must be taken to avoid the inferior branches of the uterine vessels coursing lateral to the uterosacral ligament. Blunt dissection and occasional use of monopolar current is necessary to separate the uterosacral ligament from these vessels. Since the ureter has been previously identified and pushed aside, bleeding from these vessels can be safely controlled with unipolar coagulation. Next, a peritoneal incision is made medial and parallel to the ligament, and the insertion of the now-isolated uterosacral ligament into the posterior cervix is transected with coagulation cutting. As the edge of the transected uterosacral ligament is grasped and dissected off of the pelvic floor using a combination of sharp and blunt dissection and electrodissection, it will be seen that the uterosacral ligament is becoming less dense and spreading out into the surrounding perirectal connective tissue. At an appropriate distal point the ligament is transected with coagulation cutting and removed, carrying with it all invasive endometriosis. Patients do not seem to experience pelvic relaxation after either transection or resection of the uterosacral ligaments.[35]

Ovarian Endometriosis

Small areas of superficial ovarian endometriosis do not appear to cause pain. To preserve ovarian tissue, it would be prudent to fulgurate or vaporize larger superficial lesions and probe the interior of the ovary with a needle to search for underlying chocolate cysts.[48] Many red-colored superficial lesions are nothing but hemorrhagic adhesions, and not all chocolate cysts are endometriotic.[49]

Endometriotic cysts are frequently adherent to the pelvic sidewall, uterus, or sigmoid colon at points of previous rupture. When dealing with such cysts, the likelihood of endometriosis in the opposing structure should be considered and dealt with by deep peritoneal resection. Endometriotic cysts frequently rupture during surgical treatment. After irrigation and suction of the cyst fluid, the edge of the cyst wall is grasped, and the scissors are used bluntly to dissect away the normal ovarian cortex. If the cyst wall is indistinct and cannot be easily grasped, the scissors can be used to cut along the normal ovarian cortex adjacent and parallel to the open cavity. This incision extends no further than the fibrotic capsule of the cyst. The graspers now may close on a small "handle" of ovarian cortex attached to the edge of the cyst, allowing more positive purchase and facilitating the dissection. The endometriotic cyst is then dissected out of the ovarian stroma.[30] It is occasionally necessary to coagulate bleeders at the base of the cyst. Suture of the cyst wall is not recommended, since this may result in more adhesions.

Endometriosis of the Large Bowel

Electrosurgery on the bowel is not as easy as electrosurgery elsewhere in the pelvis. This is because the bowel wall is thicker than other tissues and the pressure of the scissors against the bowel wall causes the wall to pillow around the scissors, decreasing current density and resulting in coagulation. Subsequent necrosis of the bowel wall may result in a leak. Electrosurgery on the bowel requires high current density, which can best be delivered with a needle electrode using 50 W of cutting current. The sharp point of the needle electrode introduces the risk of puncture or laceration and should be used with caution. Although electrosurgery of the bowel is possible, it is safer and often more efficient to use the scissors to perform sharp incisions and blunt dissection, avoiding the risk of coagulation necrosis.

In descending order, the most common sites of intestinal involvement by endometriosis are the rectum, sigmoid, ileum, cecum, and appendix. The large bowel is composed of four layers: the serosa; outer longitudinal muscularis; inner circular muscularis; and mucosa. The serosa does not extend below the peritoneal reflection. Endometriosis almost never penetrates into the bowel lumen, and intestinal diagnostic studies will fail to detect most cases of endometriosis involving the intestines.[50] Many invasive bowel lesions have a yellowish, fibrotic appearance and blend well with the bowel wall. For ease of identification, it is helpful to palpate the bowel wall with the graspers or to slide a ring forceps up and down within the bowel to identify a mass effect. If laparoscopic bowel surgery is anticipated, antibiotic prophylaxis and preoperative osmotic bowel evacuation are prudent. Small, superficial lesions may be excised by serosal resection, and suturing the bowel wall is not necessary.

The layering of the bowel wall allows partial-thickness resection of some larger lesions. The scissors cut through the serosa and muscularis to a depth sufficient to allow the lesion to be undermined. This will occasionally require exposure of the mucosa by a technique known as "mucosal skinning."[39] In many cases, the lesion can then be dissected from the bowel wall without penetration of the lumen. The planes offered by the layers of muscularis result in a clean, almost bloodless dissection, but the surgeon can easily dissect beyond the edges of the lesion and should strive to remain aware of its extent at all times. The defect in the bowel wall is then closed with interrupted 3–0 silk sutures. If disease and its accompanying fibrosis extend to the submucosa, the dissection will frequently enter the bowel lumen. In this event the boundaries of the lesion can be palpated through the mucosa. The ring forceps in the bowel creates a dependent space within the bowel where the remaining bowel prep fluid can collect. As a result, spillage of bowel contents into the pelvis is uncommon. If spillage occurs, copious irrigation is done after closure of the bowel. Full-thickness defects can be repaired with a running stitch of 3–0 chromic to close the mucosa followed by interrupted stitch of 3–0 silk to close the muscularis and serosal layers.[39,51] If multiple full-thickness resections are anticipated, each defect should be closed before the next is created to limit bowel spillage.

Obliteration of the cul-de-sac (Figure 30.2.1) is highly predictive of disease invading the wall of the rectum, as well as invasive disease of the uterosacral ligaments and the hidden cul-de-sac. Surgical treatment involves more than an attempt at mechanical separation of the rectum from the cervix and vagina. The surgeon must recognize that unless all invasive endometriosis is removed, persistent disease will remain.[38] Removing all endometriosis will frequently require an *en bloc* resection of the uterosacral ligaments, posterior cervix, and cul-de-sac, as well as of the rectal nodule. If the ovaries are involved by large endometriomas adherent to the pelvic sidewalls, consideration should be given to converting to a laparotomy rather than continuing with laparoscopy. Ovarian and pelvic side wall involvement by endometriosis, combined with treatment of an obliterated cul-de-sac, requires a lengthy surgery that may be beyond the stamina of the average gynecologist.

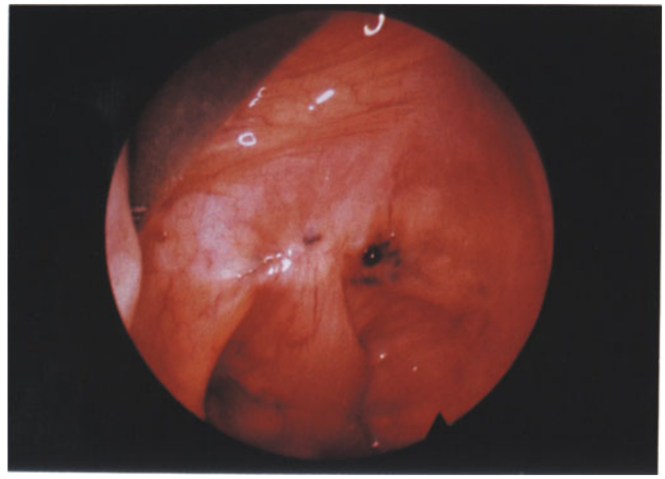


FIGURE 30.2.1. Partial obliteration of the cul-de-sac showing the lower rectosigmoid adherent to the left uterosacral ligament. Invasive endometriosis is frequently present in the uterosacral ligament, adjacent cul-de-sac, and broad ligament, as well as the wall of the rectum itself. In this patient, it had penetrated to the adjacent vaginal mucosa. Surgical treatment begins by incising in the normal peritoneum lateral and parallel to the uterosacral ligament and then across the posterior cervix above all invasive disease.

Laparoscopic surgical treatment of the obliterated cul-de-sac follows specific, consistently reproducible steps, which will allow an experienced laparoscopist to complete this surgery successfully.[6] These surgical steps include: lateral isolation of the uterosacral ligaments; transverse incision across the cervix above the adherent bowel; intrafascial dissection down the cervix toward the rectovaginal septum; medial isolation of the uterosacral ligaments by development of the rectovaginal septum; transection of the uterosacral ligaments at their insertion into the posterior cervix; mobilization of the rectum by transection of the lateral rectal attachments; and *en bloc* resection of the mobilized mass. This may result in partial-thickness, full-thickness, or segmental resection and end-to-end anastomosis of the bowel.[52–55] Deep partial and full-thickness resections are repaired as discussed above.

Segmental bowel resection with end-to-end anastomosis is occasionally required for large nodules or multiple nodules along a length of bowel. This can be accomplished with a totally internal technique,[52,53] or a transanal pull-through technique.[54,55] Although laparoscopic segmental bowel resections are feasible, the patient may still require four days in the hospital and three to six weeks for full recovery. Therefore, for extremely difficult laparoscopic surgery, the surgeon must judge whether the time spent in surgery will result in any benefit for the patient or the healthcare system. If not, a laparotomy should be done.

Endometriosis of the Small Bowel

Superficial lesions of the terminal ileum probably cause no symptoms and can either be left untreated or removed by mucosal skinning. Since the wall of the ileum is thinner than that of the colon, penetration into the lumen is more likely to occur. If it does, the mucosa can be repaired with 3–0 chromic and the seromuscularis closed with interrupted 3–0 silk suture. Larger obstructive lesions could potentially be treated laparoscopically, but the typical placement of the laparoscope and accessory ports makes extensive surgery in this area difficult. After completion of laparoscopic treatment of all other pelvic endometriosis, consideration can be given to making a short incision over the ileum and delivering the involved loop onto the abdominal wall for extracorporeal treatment.

Nonendometriotic Causes of Pelvic Pain

Not all pelvic pain is due to endometriosis. Other common gynecologic sources of pain include traction on periovarian adhesions caused by functional ovarian cysts, ectopic pregnancy, adenomyosis, and fibroids. These frequently have a direct operative treatment which will be obvious at surgery. When laparoscopy is negative, musculoskeletal causes of pain can be considered.

One prospective randomized study of chronic pelvic pain compared a standard surgical approach consisting of initial laparoscopy followed by psychological counseling to an integrated nonsurgical approach based on manipulation of psychological, dietary, environmental, and physiotherapeutic factors. Only 35% of the 49 patients in the laparoscopy group were found to have any pathology at surgery, and only four patients had endometriosis. One year later, it was found that 75% of those in the integrated approach group may have had improvement, compared to only 41% of the standard-approach patients. There was no significant difference in the rates of improvement as judged by the McGill pain questionnaire, however.[56] In another study, for 58 of 60 patients with chronic pelvic pain, the simple knowledge that the laparoscopic examination was normal was associated with improvement in their pain syndromes six months later.[57] These somewhat contradictory results could be interpreted as showing that laparoscopy is either unimportant or important in the management of pelvic pain. Generally, however, laparoscopic findings relate positively to patient-reported pelvic pain.[58]

Clinical Results: Pain Relief Following Laparoscopic Excision of Endometriosis

Assessment of pain is subjective, but any of several scales can be used to assess a patient's subjective preop or postop pain.[13] Most pain scales mentioned in the endometriosis literature are four- or five-point verbal-analog scales.[13] For several years, the Endometriosis Institute of Oregon has used preop and postop five-point verbal-analog pain scales to gauge response of pain to conservative excision of endometriosis or to laparoscopic presacral neurectomy (Table 30.2.1). No pre- or postop medical therapy is used for endometriosis, so the results represent fairly pure surgical results. In the cases of four of the most common pain syndromes associated with endometriosis, significant and long-lasting reduction in pain was noted for each symptom in the complex (Figure 30.2.2). In Figure 30.2.2 the results for patients followed for 12 to 24 months are tabulated in the "1 year" interval, the results for patients followed for 24 to 36 months are listed in the "2 year" interval, and the results for patients followed for 36 to 48 months are listed in the "3 year" interval. Although the results were truncated at 48 months for brevity, later results are similar and actually improve for as many as eight years. The apparent continuing improvement at follow-up is explained by the fact that some patients subsequently underwent hysterectomy for persistent or recurrent pain. While their postop pain scale responses were included in the data for construction of the bar graphs up to the follow-up year preceding their hysterectomy, once hysterectomy was performed, the data from these patients were censored. Therefore, with time the number of patients with good outcomes increased. The ongoing follow-up in this study contrasts sharply with the follow-up of medical-therapy studies. A review of the medical-therapy literature shows that follow-up for medical therapy of endometriosis has actually been getting shorter and the number of patients has been decreasing.[13] In one paper, the data on patients with the worst outcomes were eliminated, thus artificially boosting successful results obtained with nafarelin acetate.[59,60]

Laparoscopic excision of endometriosis has been shown by careful follow-up and life-table analysis to result in a low rate of persistent or recurrent disease.[35] Most re-operated patients did not have endometriosis, and when endometriosis was found, it was always minimal and never invasive, regardless of the interval between reoperation and the index surgery. The response of symptoms to excision of endometriosis, while encouraging, does not exactly parallel the response of the disease to treatment. This indicates that not all pelvic pain in patients with endometriosis is due to that disease. Some patients who fail to achieve satisfactory pain relief with aggressive excision of their disease should seek an alternate explanation for their pain. Some may benefit more from removal of their pelvic organs than from further therapy directed at a disease they may no longer have.

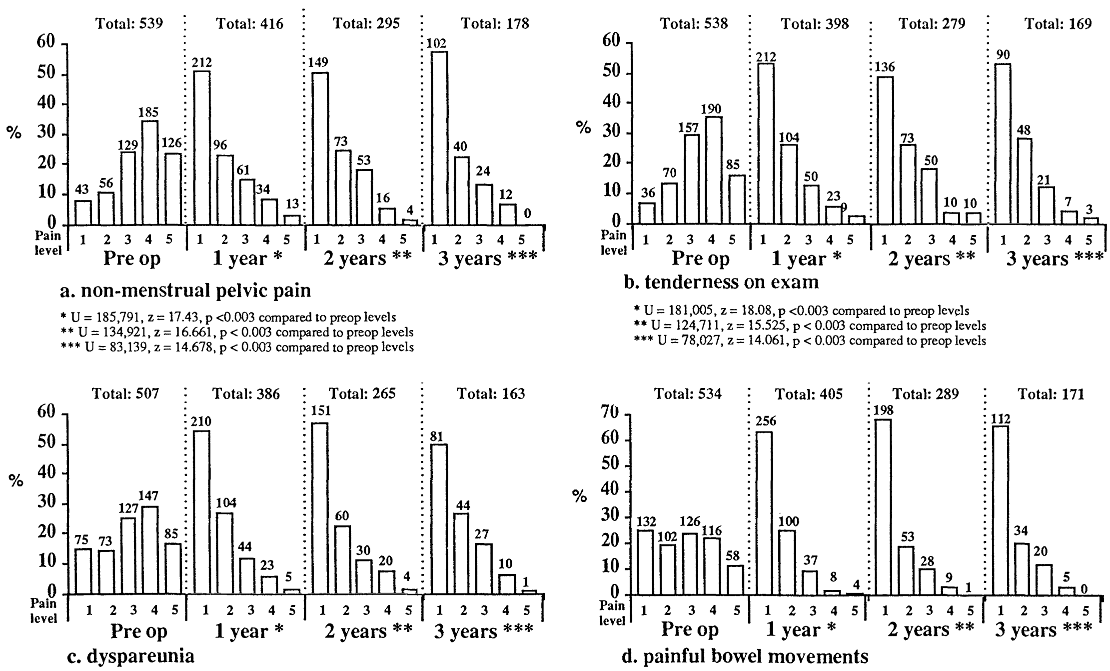
The profession still awaits data on the persistence/recurrence rates and response of pain to laser vaporization and electrocoagulation/fulguration of endometriosis.

TABLE 30.2.1. Preop patient questionnaire to assess endometriosis-associated symptoms.*

Please rate on a scale of 1 to 5 the severity of symptoms you experienced *before surgery* at St. Charles. Circle the *one* number that most accurately reflects the severity of your symptoms. *We define "debilitating" pain as pain that keeps you from performing daily tasks or severely limits your activity on at least one day per month.*

Before surgery:	Not a problem	Slight	Moderate	Severe	Debilitating
a. Pelvic pain away from menstrual flow	1	2	3	4	5
b. Pelvic pain (other than cramps) with flow	1	2	3	4	5
c. Uterine cramps with menstrual flow	1	2	3	4	5
Were you sexually active? ☐ yes ☐ no					
d. Painful intercourse with deep penetration	1	2	3	4	5
e. i. Pain with bowel movements	1	2	3	4	5
ii. Constipation	1	2	3	4	5
iii. Diarrhea	1	2	3	4	5
iv. Intestinal cramping	1	2	3	4	5
Did you exercise regularly? ☐ yes ☐ no					
f. Pelvic pain with exercise	1	2	3	4	5
g. Backache	1	2	3	4	5
h. Tenderness on pelvic exam	1	2	3	4	5

*A similarly worded questionnaire has been mailed annually to patients for the past several years.



a. non-menstrual pelvic pain

* U = 185,791, z = 17.43, p <0.003 compared to preop levels
** U = 134,921, z = 16.661, p < 0.003 compared to preop levels
*** U = 83,139, z = 14.678, p < 0.003 compared to preop levels

b. tenderness on exam

* U = 181,005, z = 18.08, p <0.003 compared to preop levels
** U = 124,711, z = 15.525, p < 0.003 compared to preop levels
*** U = 78,027, z = 14.061, p < 0.003 compared to preop levels

c. dyspareunia

* U = 156,587, z = 15.383, p <0.003 compared to preop levels
** U = 103,874, z = 13.683, p < 0.003 compared to preop levels
*** U = 65,037, z = 11.033, p < 0.003 compared to preop levels

d. painful bowel movements

* U = 164,721, z = 13.748, p <0.003 compared to preop levels
** U = 118,976, z = 12.845, p < 0.003 compared to preop levels
*** U = 69,670, z = 10.360, p < 0.003 compared to preop levels

NB: for all charts, 1 = not a problem, 2 = mild, 3 = moderate, 4 = severe, 5 = debilitating (unable to perform normal functions for at least 1 day each month)
Patients followed for 1 - 2 years are included in the '1 year' category, patients followed for 2 - 3 years are in the '2 year' category, etc. Mann-Whitney U test (two-tailed) was used to calculate significance of reduction of postoperativ symptoms

FIGURE 30.2.2. Response of symptoms to conservative laparoscopic excision of endometriosis.

Historical Review of Laparoscopic Treatment of Uterine Cramping

Treatment of midline pelvic pain and dysmenorrhea by presacral neurectomy at laparotomy was first described in Europe in 1899[61,62] and has been discussed by several authors.[63–78] Although many of the studies are observational and the pain under treatment is described and measured in different ways, all support the apparent efficacy of presacral neurectomy. Trials with historical[73] or randomized[69] controls confirm the efficacy of this procedure for the treatment of midline pelvic pain or uterine cramps.

An alternate approach to the treatment of midline pelvic pain and uterine cramping was offered by Doyle,[79] whose procedure for abdominal and vaginal interruption of the uterosacral ligaments became the basis for modern laparoscopic uterine-nerve ablation (LUNA).

Beginning in the 1960s, surgical management of pelvic pain was replaced to a large degree by medical management with oral contraceptives, nonsteroidal anti-inflammatory drugs, progestins, and other agents promoted for the treatment of endometriosis. While medical management controls symptoms adequately in some patients, many patients do not respond well or discontinue medication because of side effects. The incomplete response of uterine cramps and midline pelvic pain to medical therapy, combined with the desire to avoid hysterectomy in young women, led surgeons to develop laparoscopic approaches to this type of pain.

The LUNA procedure was first described by Feste in 1985.[80] Since then, several authors have reported their experience with the procedure.[81–85] A randomized prospective double-blind study of the LUNA procedure for the treatment of severe dysmenorrhea showed that three months after surgery 9 of 11 patients treated by LUNA had experienced relief but no control patients had.[82] By 12 months, however, only 5 of 11 patients had continuing relief of dysmenorrhea. Although adding the LUNA procedure to a presacral neurectomy did not lead to a success rate higher than that of a presacral neurectomy alone,[74] there is theoretical support for the application of both procedures in some patients.[83]

Laparoscopic presacral neurectomy was first performed by Perez[87] in 1987 through a suprapubically placed laparoscope. In 1988, Redwine first employed a simplified umbilical approach.[88] Since then, Nezhat[89] and Perry and Perez[90] have accumulated experience with laparoscopic presacral neurectomy.

Anatomy

Sensory fibers from the cervix, uterine corpus, and proximal fallopian tubes exit the sides and bottom of the uterus, traveling first as the inferior hypogastric plexus across the cul-de-sac region. Some but not all of this neural tissue exits along the uterosacral ligaments, which may explain the failure of the LUNA procedure in some patients. These wisps of neural tissue coalesce into larger bundles as they travel up the hollow of the sacrum and across the sacral promontory, where they form the intermediate hypogastric plexus. Finally coalescing into between one and three bundles, the neural tissue passes anterior to the bifurcation of the aorta as the superior hypogastric plexus. Sensory and motor fibers to the lower uterine segment and cervix are also found in sympathetic and parasympathetic nerves communicating with the second, third, and fourth sacral nerves, and this may explain the failure of presacral neurectomy to relieve pain in some patients.

Laparoscopic Technique for LUNA

The uterus should be elevated toward the anterior abdominal wall by an intrauterine manipulator, stretching the uterosacral ligaments. In patients with undeveloped uterosacral ligaments, a LUNA procedure may be impossible to complete. The uterosacral ligaments are normally rather thin structures no larger in diameter than a pencil. If a uterosacral ligament appears wider than this, it may be because the ureter or uterine vessels travel medially. This places them at risk of injury during a LUNA procedure. A 2-cm peritoneal incision in the posterior broad ligament lateral to the junction of the ligament with the posterior cervix and parallel to the course of the ligament allows a blunt probe to be inserted retroperitoneally to push the ureter and uterine vessels away from the ligament. The ligament itself can be undermined with the probe, thus displaying the anatomy perfectly. The ligament can then be transected at its junction with the posterior cervix by any of several methods, including CO_2 laser, unipolar coagulation current, Nd:YAG contact-tip laser, KTP/argon laser, or bipolar coagulation followed by scissors transection. The ligament should be transected to a depth of about 1 cm toward the posterior vaginal vault. Lichten and Bombard advocate an incision across the posterior cervix that joins the areas of transection to interrupt neural fibers that do not traverse the uterosacral ligaments.

Laparoscopic Technique for Presacral Neurectomy (PSN)

Suprapubic Approach (After Perez)

After completion of pelvic surgery through an umbilical port, the surgeon assumes a position between the patient's legs. A second 10-mm trocar is inserted suprapubically and, with the patient in steep Trendelenburg position, the sacral promontory and bifurcation of the great vessels are viewed in the same orientation as at laparotomy. A dilute solution of vasopressin (50 U/100 cc normal saline) can be injected retroperitoneally. The peritoneum is incised vertically from just below the aortic bifurcation to several centimeters down the hollow of the sacrum. The sigmoid colon can be retracted to the left with the umbilical laparoscope, and the peritoneal edges can be retracted laterally with two 2.3-mm instruments passed through the abdominal wall. The base of the sigmoid mesentery constitutes the left margin of the dissection, and the right margin is defined by the common iliac vessels. Blunt dissection to the periosteum at the lateral margins allows isolation of the presacral tissue from the adjacent large vessels. The presacral tissue is grasped and elevated up and away from the periosteum and any vessels coursing over it. The elevated tissue is then coagulated and cut near the superior and the inferior margins of the dissection, and the specimen is removed (Figure 30.2.3).

Umbilical Approach (After Redwine)

After completion of all pelvic surgery with triple-puncture laparoscopy, the table is rolled to the left, displacing the sigmoid colon laterally. The suction/irrigator in the right lower quadrant is used to push the sigmoid mesentery further, thus exposing the sacral promontory.

The vascular structures most likely to be damaged during the performance of a laparoscopic PSN are the left common iliac vein, the bifurcation of the inferior vena cava, and the presacral veins. These low-pressure veins may be partially collapsed by the pressure of the pneumoperitoneum and may not always be visible through the peritoneum. However, specific steps can be taken to avoid damaging these veins. A vein can sometimes be seen through the peritoneum as a large, dark expanse. The graspers passed through the left lower quadrant port are used to tap the area below the aortic bifurcation. If the left common iliac vein is present beneath the peritoneum, the waterbed sign will be elicited: the low-pressure blood in the vein will be perturbed and the vein will shake like a waterbed. The sacral promontory should also be examined for the waterbed sign; its presence indicates that dissection must occur more caudally.

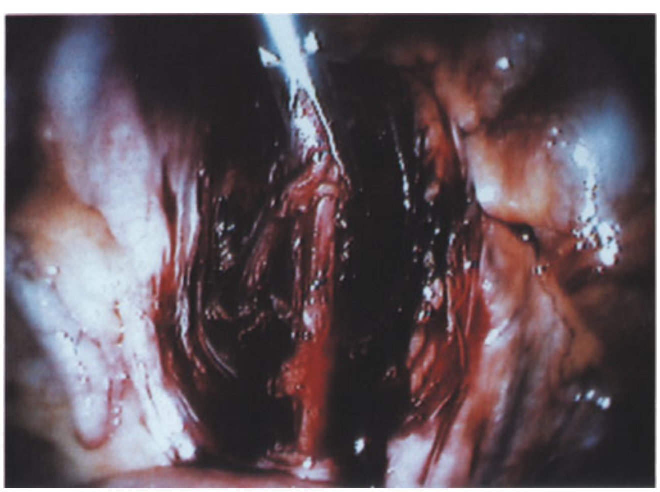


FIGURE 30.2.3. Laparoscopic presacral neurectomy—suprapubic approach. The superior hypogastric plexus is seen in the midline following blunt dissection. The appendix is to the left.

Once a safe area of bare sacral promontory is found, the peritoneum is incised transversely with 70 to 90 W of pure cutting current passed down a 3-mm monopolar scissors within a 10-mm operating laparoscope inserted in the umbilical port. This peritoneal incision is made from the base of the sigmoid mesentery on the left to the right common iliac vessels. Careful blunt dissection to the periosteum is now done at each lateral margin of the dissection. On the left, this dissection may proceed adjacent to the left common iliac vein. A superficial layer of presacral tissue is grasped and elevated away from the periosteum and any presacral vessels. The elevated tissue is transected with 50 W of coagulation current. The presacral tissue is transected at successively deeper layers and from left to right until the periosteum is laid bare. Presacral vessels are frequently present, but it is possible to spare these by elevating the presacral tissue before transection. Although it is occasionally difficult to differentiate neural from areolar or lymphatic tissue, a nerve approximately 1 mm in diameter is sometimes encountered, particularly along the left side of the dissection. After complete transection of all presacral tissue, the tissue is dissected down the hollow of the sacrum for several centimeters. The presacral tissue is then stripped from the overlying peritoneum and transected distally with 50 W of coagulation current to obtain a specimen. During this distal transection, care must be taken not to injure a loop of sigmoid colon that may lie immediately adjacent to the peritoneum in this area. It is not necessary to close the peritoneum or treat the cut edges of the presacral tissue.

Clinical Results: Pain Relief Following LUNA or Laparoscopic PSN

Sutton, who evaluated 126 patients over five years, found that only 13 patients had no improvement in their symptomatology,[83] and Feste reported a failure rate of 12.9% in 196 patients.[80] Daniell reported that 70% of 200 patients followed for six months described a reduction in their menstrual pain.[81]

Perez's initial report on 24 patients followed for 12 months was that almost 80% had significant relief of midline pelvic pain as measured by a multidimensional pain scale.[87] In an unpublished prospective multicenter study, Perry and Perez studied 87 consecutive patients and found that 79 (91%) experienced improvement in their pain scores, with a majority experiencing over a 50% reduction in pain scores. Pain relief seemed to persist at 24-month follow-up (Tables 30.2.2–30.2.4), and pain reduction occurred in over 89% of endometriosis patients regardless of disease stage. Eighty percent of patients with pelvic inflammatory disease had reduction of pain scores with laparoscopic PSN. Complications were uncommon; only one patient required a laparotomy for bleeding (the bleeding had stopped by the time the abdomen was opened). One patient had postop constipation, and two patients had vaginal dryness. Unpublished data from this group have found an unanticipated benefit from presacral neurectomy: improvement in sexual sensation and function in many patients, although 12% reported lubrication difficulty.

TABLE 30.2.2. 10-point pain scale (after Perez).[87]

0	No pelvic pain.
1	Mild cramping not requiring medication.
2	Moderate cramping completely relieved with BCP* or NSAID.**
3	Mild cramping while on BCP or NSAID.
4	Moderate cramping while on BCP or NSAID. Can function adequately at work or school.
5	Severe cramping while on BCP or NSAID. Relieved by narcotics. Patient functions adequately at work and school most of the time.
6	Severe cramping and pelvic pain intolerant to BCP, mild to moderate relief with NSAID and narcotics. The patient has missed work due to pelvic pain, but can function at work and school most of the time.
7	Severe cramping and pelvic pain, intolerant to BCP, minimal relief with NSAID and narcotics. Patient frequently misses work or school.
8	Severe cramping and pelvic pain, moderate relief with NSAID, BCP, narcotics. Patient has missed work or school but can function adequately at least 50% of the time.
9	Severe cramping and pelvic pain, mild relief with NSAID, BCP, narcotics. Has missed work or school due to pelvic pain and has reduced effectiveness at work or school while symptomatic.
10	Severe cramping and pelvic pain, no relief with NSAID, BCP, or narcotics. Patient frequently misses work or school due to pelvic pain.

*Birth control pill.
**Nonsteroidal anti-inflammatory drugs.

TABLE 30.2.3. Preoperative and postoperative pain scores (after Perez).[87]

	Number of patients	
Pain score	Preoperative	Postoperative*
0	0	2
1	0	6
2	0	10
3	0	3
4	0	2
5	0	1
6	0	0
7	5	0
8	6	1
9	4	0
10	9	0

*All patients were followed for at least three months; 24 were followed for more than six months. No postoperative pain scores changed after three months.

Although reduction in symptoms is gratifying, since many studies do not have a control group, it is not always clear whether the reduction is due to the laparoscopic PSN or to the treatment of concurrent pathology. In an effort to resolve this issue, Redwine used a five-point pain scale to compile prospective data on laparoscopic PSN by the umbilical approach. Since cramps with menses are a uterine symptom, not necessarily a symptom of endometriosis, it is not surprising that he found that uterine cramping is the symptom that responds least well to excision of endometriosis alone.[13] When patients undergoing laparoscopic excision of endometriosis alone were compared to a nonrandomized control group undergoing laparoscopic excision plus presacral neurectomy, it was found that uterine cramps are reduced by either procedure (Figure 30.2.4). However, the addition of laparoscopic PSN appears to significantly reduce the frequency of severe or debilitating cramps between one and two years postop. The outcome is even more significant when the preoperative pain levels are compared, since the patients undergoing presacral neurectomy had significantly more severe dysmenorrhea than patients not undergoing presacral neurectomy. Because fewer patients were followed for two and three years postop, the difference between their outcomes was not significant but the trend is similar. Of 160 patients who underwent this procedure, only one repeat laparoscopy was required. It was done to investigate possible bleeding, but no active bleeding was found. Thus, all the available data suggest laparoscopic PSN is consistently effective and has low complication rates.

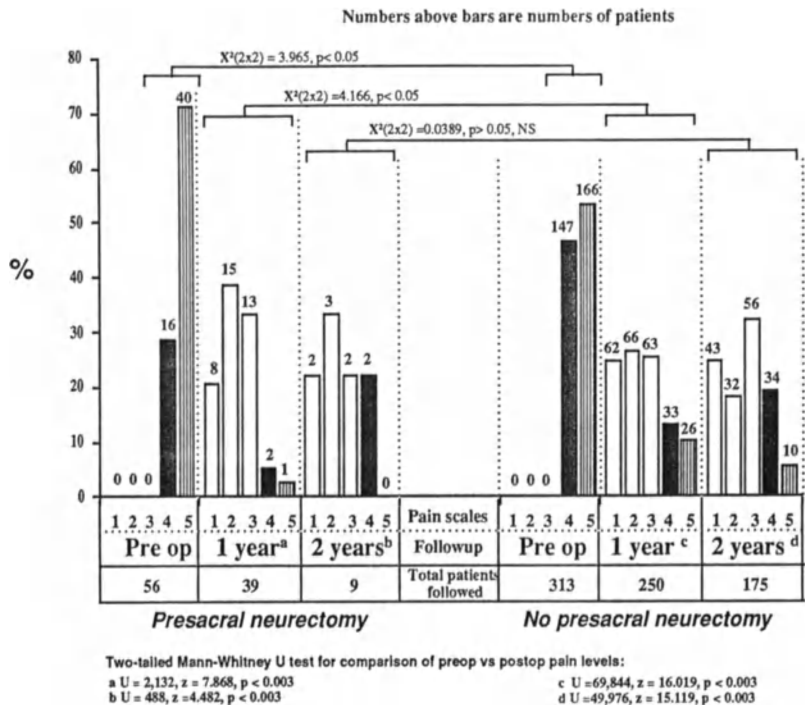
Discussion

The decided advantages of laparoscopic treatment of pelvic pain have caused it to replace laparotomy for most cases. Shorter hospitalization and recuperation are only part of the story. Laparoscopic treatment of pelvic pain

TABLE 30.2.4. Long-term pain relief following laparoscopic PSN (Perry and Perez, unpublished data).

Time of evaluation	N	Mean pain level on 10-point scale
Preop	87	7.9
3 months	87	2.8
6 months	73	2.7
12 months	38	2.4
24 months	20	2.1

FIGURE 30.2.4. Response of uterine cramps with menses to laparoscopic excision of endometriosis with or without presacral neurectomy.



can allow superior treatment on several clinical levels because of improved visualization and dissection. The subtle lesions of endometriosis can be better seen laparoscopically, thus increasing the likelihood of complete treatment of the disease. However, the method by which the disease is extirpated is of primary importance. Since there is no long-term follow-up validating the efficacy of laser vaporization and electrocoagulation, and since these two methods of treatment have obvious limitations in treating invasive endometriosis, their use should be restricted. If laparoscopic laser vaporization or electrocoagulation are performed initially, these modalities should not be used again if the patient does not achieve satisfactory pain relief. Clinicians unable to perform laparoscopic excision of endometriosis by sharp dissection, electrosurgery, or laser excision should consider referring the patient to a surgeon skilled in the identification and excision of endometriosis or excision at laparotomy. Some cases of intestinal endometriosis will require laparotomy for treatment.

It seems clear that laparoscopic presacral neurectomy is as effective as the same procedure performed at laparotomy. Since the procedures have identical anatomic results, this should not be surprising.

Techniques that make use of simple, inexpensive instruments currently exist for laparoscopic treatment of all pelvic pain syndromes. Since society is demanding cost-effective medical care, it seems unlikely that future technology will significantly enhance current techniques for treating pelvic pain. For over 5,000 years, surgeons have been the main "technology" in the practice of surgery, and a prime goal of surgery has been to remove disease from the body. Modern technology has caused us to stray from this goal. Surgeons have become enslaved to expensive surgical methods that require them to devote much of their effort to manipulating and maintaining an ever-changing operating system, and thus dilute their effect on the disease. Our current aim should be to encourage rapid diffusion of existing effective techniques rather than to add layers of expensive, ineffective technology that insulate the surgeon from the disease.

Laparoscopic treatment of endometriosis is jeopardized by recent actions by the Coding and Nomenclature Committee of the American College of Obstetricians and Gynecologists (ACOG). This committee has invented the notion that laparoscopic excision of endometriosis is equivalent to laparoscopic fulguration or laser vaporization.[91] This notion is embodied in the Current Procedural Terminology (CPT) code book of the American Medical Association (AMA): CPT code 56303 is "Laparoscopy, with fulguration or excision of lesions of the ovary, pelvic viscera, or peritoneal surface by any method." No references and no data are offered by the ACOG committee in support of this notion, which is not supported by experts in gynecology or laparoscopy. The marked differences between these methods in descriptions of technique, limitations in use, degree of difficulty, and outcome analysis have been documented above. The code for laparoscopic treatment of endometriosis has been assigned 12.68 relative value units on the Medicare Resource-Based Relative Value Scale (RBRVS) by the ACOG CPT code committee.[92] This means that laparo-

TABLE 30.2.5. Final Medicare Resource-Based Relative Value Scale (RBRVS) of selected gynecological surgical procedures for 1993 (Federal Register. November 25, 1992. 57:56053).

CPT code	Description	Relative value units	
		Final (1993)	Proposed (1992)
56302	Laparoscopic occlusion of fallopian tubes by device (band, clip, etc.)	7.77	7.99
56300	Diagnostic laparoscopy	9.59	10.34
56305	Laparoscopy with biopsy, single or multiple	10.24	11.04
56306	Laparoscopic puncture of ovarian cysts	10.59	11.42
56301	Laparoscopic fulguration of fallopian tubes	11.44	7.17
56304	Laparoscopic lysis of adhesions	11.52	11.86
56309	Laparoscopic myomectomy, subserosal, single or multiple	11.65	*
58600	Mini-lap bilateral tubal ligation (BTL)	12.40	12.75
56303	Laparoscopic treatment of endometriosis, any stage, any method	12.68	11.95
56307	Laparoscopic salpingo-oophorectomy	14.72	11.07
58720	Salpingo-oophorectomy, laparotomy	15.70	15.13
49200	Excision of endometriosis by any method (except laparoscopy)	20.30	19.73
58260	Vaginal hysterectomy	23.41	24.82
58262	Vaginal hysterectomy with removal of tubes and/or ovaries	25.12	*
58150	Total abdominal hysterectomy with or without bilateral salpingo-oophorectomy (BSO)	25.25	25.97
56308	Laparoscopically assisted vaginal hysterectomy	25.94	*
49201	Excision of extensive endometriosis by any method (except laparoscopy)	29.70	28.88

*New code for 1993.
Instructions for use of this table: To determine the approximate Medicare surgical fee for a procedure in 1994, multiply the relative value by the Medicare conversion factor for your area (eg, ≈ $34 in Oregon).

scopic treatment of any stage of endometriosis is equivalent to laparoscopic puncture of an ovarian cyst or tubal ligation by minilaparotomy (Table 30.2.5), and all laparoscopic procedures for endometriosis are equivalent. Since all governmental and third-party payers will adopt the RBRVS system by 1996, laparoscopic excision of endometriosis may fall into disuse since surgeons will not be paid fairly for the more difficult work performed. Quick superficial electrocoagulation or laser vaporization may become the preferred laparoscopic treatments, as the professional bureaucracy discourages the most effective laparoscopic treatment. These changes actually jeopardize all laparoscopic procedures, however, since significantly less will be paid for them than for laparotomy procedures. The federal government agreed to a 3.8% increase in 1993 RBRVS values for surgical services because governmental projections of a volume increase did not materialize, but the volume of most gynecological surgical procedures actually declined.

Conclusion

Laparoscopic treatment of pelvic pain could replace laparotomy treatment in most instances, but it will do so successfully only if proven laparoscopic techniques are used, such as excision of endometriosis rather than laser vaporization or electrocoagulation/fulguration. Future efforts should be directed at disseminating existing techniques rather than developing new technology. Although there is more published data showing the efficacy of laparoscopic excision than of laser vaporization or electrocoagulation, economic and political forces may combine to eradicate this most effective form of laparoscopic treatment by 1996.

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30.3
Laparoscopically Assisted Reproductive Technique

Jose P. Balmaceda and Alejandro Manzur

Introduction

The application of gynecological endoscopy is continuously expanding.[1] Operative laparoscopy has largely replaced more invasive procedures previously used to treat pelvic peritoneal causes of infertility. Undoubtedly, one of the most interesting applications of laparoscopy is in assisted reproductive technique (ART).

In this review, we will describe the following ART procedures in which laparoscopy plays a major role: follicular aspiration for oocyte retrieval; gamete intrafallopian transfer (GIFT); zygote intrafallopian transfer (ZIFT); and concomitant diagnostic laparoscopy and GIFT.

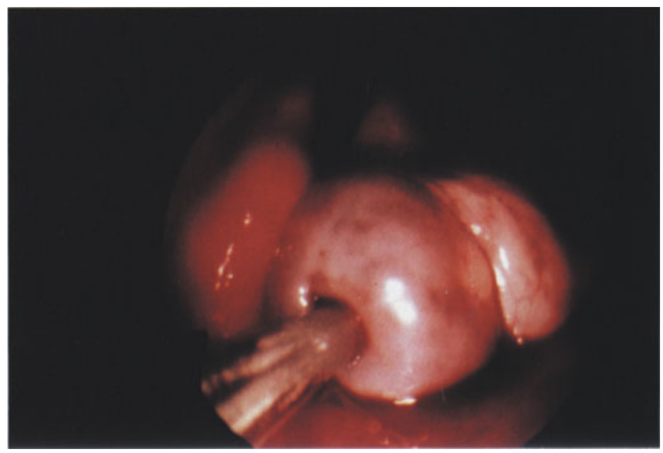

FIGURE 30.3.1. Laparoscopic aspiration of a human ovarian follicle.

Follicular Aspiration for Oocyte Retrieval

Laparoscopic oocyte retrieval was the first method employed in in vitro fertilization (IVF) programs,[2] and it is still frequently used. In this technique, the follicles are entered with a large-bore needle (14 to 16 mm), and either syringe or wall suction is applied (Figure 30.3.1). The pressure is about 100 mm Hg. The technique requires a subumbilical incision of approximately 1 cm to introduce the laparoscope after insufflating the abdomen with CO_2. A second entry site, usually 2 cm over the symphysis pubis, allows the passage of a grasping forceps that is used to hold the utero-ovarian ligament to rotate the ovaries. Finally, a third lateral entry site is used for the aspiration needle. The follicular fluid is generally collected in a trap that contains tissue-culture medium or phosphate-buffered saline, and the content of each follicle is then inspected by a biologist with the object of identifying the oocyte. The whole procedure takes about 15 to 30 minutes, depending on the number of follicles being aspirated.

In the beginning, many programs noted that additional oocytes could be obtained by flushing each follicle once all the content had been aspirated. More recently other reports show no improvement with this practice, if the follicle is properly visualized and suctioned.[3–5]

According to the 1990 United States In Vitro Fertilization–Embryo Transfer (IVF-ET) Registry, 78% of oocyte retrievals for GIFT were performed laparoscopically.[6] Nevertheless, transvaginal follicular aspiration with an echographically guided needle has become the routine form of oocyte retrieval in IVF and is widely accepted in modern GIFT programs as well.[7] This simple approach offers the advantage of not requiring general anesthesia, and in GIFT cases, allows egg retrieval to be separated from the final surgical procedure (laparoscopy or minilaparotomy). In other words, it avoids committing the patient to an unnecessary surgical procedure, before oocyte quality can be assessed. Moreover, it permits better access to follicles deep in the ovarian parenchyma, because they are more easily visualized with ultrasound than with laparoscopy.

On the other hand, laparoscopic oocyte retrieval minimizes the chances of undiagnosed intra-abdominal bleeding as a result of follicular aspiration, or uterine or bowel punctures. These complications, although rare, are potential risks of transvaginal follicular aspiration. However, because the presence of severe pelvic adhesions limits ovarian accessibility, this technique is inadvisable for that group of patients.

GIFT

This technique was originally described in 1984 by Asch and coworkers who envisioned it as an alternative to IVF for patients with patent fallopian tubes.[8] Its clinical use followed extensive research performed in primates by the authors, in which the method proved to be effective.

The procedure itself involves the placement of sperm and oocytes directly into the ampullary portion of the fallopian tube, so that fertilization occurs at the natural site (Figure 30.3.2). It is assumed that the resulting embryos, which develop in the protective ambiance of the tube and enter the endometrial cavity atraumatically, have a higher chance of implantation.

The main indications for GIFT are unexplained infertility and pelvic endometriosis in patients with functionally normal fallopian tubes. Other less frequent indications are mild or moderate male factor, failure of previous donor artificial-insemination cycles, iatrogenic pelvic adhesions, cervical factors, premature ovarian failure, and immunologic factors.

A GIFT program includes several aspects. Controlled ovarian hyperstimulation induces multiple follicular development. The ovaries are stimulated by administering gonadotropin [human menopausal gonadotropin (hMG) or pure follicular stimulating hormone (FSH)]. Best results, in terms of the number of oocytes retrieved and the avoidance of spontaneous premature ovulation, are obtained with simultaneous use of gonadotropin-releasing (GNRh) agonistic analogues to downregulate the anterior pituitary (i.e., leuprolide, nafarelin, buserelin).[9] The patient's ovarian response is carefully followed by means of serial transvaginal ultrasounds. In certain circumstances, plasma estradiol (E_2) measurements are required, such as if a cystic ovarian lesion is present when the stimulation protocol is initiated, if there is no echographic evidence of ovarian response, and finally, to assess the risk of hyperstimulation in cases where more than 15 follicles have been identified.

Human chorionic gonadotropin (hCG) 10,000 IU IM is indicated when the leading follicle has reached a largest diameter of 20 to 22 mm. Oocyte retrieval is scheduled 34 to 36 hours later. Two hours before oocyte recovery, the male partner produces a semen sample by masturbation. After allowing time for liquefaction, it is examined for count, motility, and morphology, and washed with culture medium to remove the seminal plasma. By the swim-up technique, the most motile fraction of the sperm are obtained.[10] An average of 300,000 to 700,000 motile sperm are used, adjusting the volume of fluid to be injected to 30 μL or less. This measure prevents significant reflux from the ampullary portion of the fallopian tube to the peritoneal cavity.

The sperm and oocytes are loaded into a special Teflon catheter, which can be easily threaded into the fimbriated end of the tubes (Figure 30.3.3). There are several types of catheters, but none of them has been proven to be superior to the others, so surgeons should choose the one they prefer. We have used the Marrs catheter, which is easy to handle and have achieved excellent results with it.

Laparoscopic oocyte retrieval requires general anesthesia and three abdominal punctures. The same subumbilical incision is used to insufflate the abdomen with

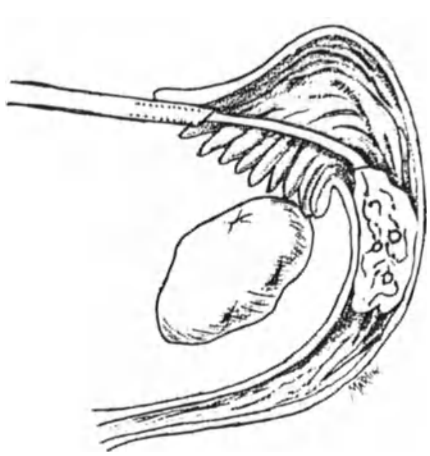

FIGURE 30.3.2. GIFT procedure. Sperm and oocytes are placed into the ampullary portion of the fallopian tube.

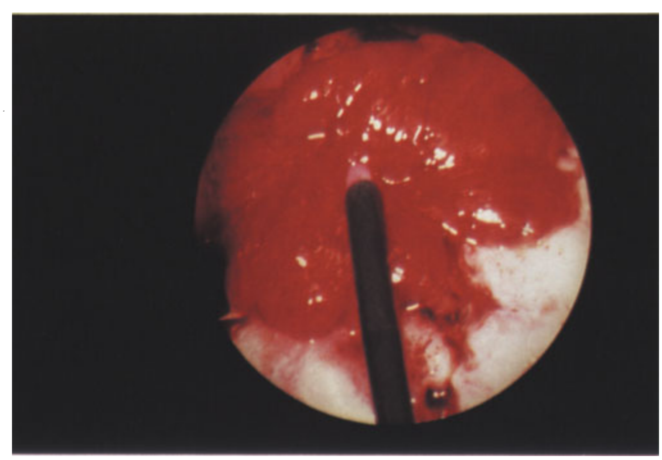

FIGURE 30.3.3. Cannulation of the fimbriated end of a human fallopian tube with a Teflon catheter during the GIFT procedure.

CO_2 and to introduce the laparoscope, which, in turn, is connected to a video monitor. A second suprapubic incision allows passage of an atraumatic grasper, which is used to handle the fimbriated end of the tube while it is cannulated. After inspecting both fallopian tubes, the surgeon chooses the one for transfer. If both appear to be normal, the right tube is usually preferred by a right-handed operator. Finally, a third entry is needed for the Teflon catheter that will cannulate the tube. The incision is generally made on the ipsilateral flank, 2 to 3 cm below the umbilical line. If the tubes are tortuous, it may be necessary to place this third incision in the contralateral flank, especially if the fimbriated end of the tube is pointing toward the midline. It is extremely important to carefully study the angle of the fimbriated ostium to minimize the risk of trauma during cannulation. Visible graduation at the tip of the catheter makes it easier to gauge the degree of penetration. Initially, the gametes in the catheter were separated by air spaces to avoid mixing them in vitro. Today, however, gametes are separated only for those couples who request it due to religious or ethical beliefs; otherwise sperm and oocytes are placed together. After its contents are released, the catheter is removed and inspected by the biologist to be sure that the gametes were transferred.

The transabdominal surgical procedure used for transfer has no direct influence on the results. Laparoscopic transfer has the advantages of prompt postoperative recovery and minor discomfort for the patient, whereas minilaparotomy offers accurate transfer of gametes into the tubes. A well-trained laparoscopist should be equally successful with the two methods. If, in a specific program, the results with laparoscopic GIFT are significantly lower than those reported in the literature, it is worth changing the modality of transfer before discarding the technique.

Some technical variables of laparoscopic GIFT are the number of tubes to which gametes are transferred and the depth of penetration of the catheter. Bilateral tubal transfers do not offer any advantage over single transfers, as demonstrated by Yee and colleagues.[11] Moreover, Haines and coworkers have found a significantly higher pregnancy rate (PR) in cases where one tube was used than in cases where both were used (57.1 versus 25.4%). They concluded that single-tube transfer reduces operating time and avoids damage to the contralateral tube at the moment of catheterization. The ideal depth of penetration of the catheter has also been studied by Yee and coworkers, who reported it to be at least 3 cm.[11] The authors obtained 32% PR when this condition was achieved, versus 16.7% when it was not. Their results were independent of the number of eggs transferred and the number of tubes used.

Balmaceda and coworkers pointed out that the outcome of GIFT depends on oocyte quality. The authors performed experimental GIFT in two groups of monkeys (*Macaca fascicularis*). One group received only immature oocytes, and the other received only mature oocytes. Twenty-four hours after the transfer they flushed the genital tract of the animals and recovered the oocytes or embryos. Not a single embryo was recovered from the group that received immature eggs, whereas the other group showed a 37% fertilization rate. A clinical study of 218 GIFT cycles was reported by Guzick and colleagues.[14] The authors achieved a 39.6% PR when one to five mature oocytes were transferred, compared to 16.5% when only immature eggs were used. They concluded that oocyte quality is a critical variable to consider, even more important than number of oocytes transferred.

The number of oocytes transferred represents a trade-off between the risk of multiple implantation and the chances of achieving pregnancy. There is general agreement that increasing the number of oocytes from one to four significantly raises the clinical PR, but that if more than five oocytes are transferred, it only results in a higher incidence of multiple pregnancies.[6,11,13] Table 30.3.1, which summarizes the results reported to the 1990 United States IVF-ET Registry for GIFT, bears out this rule of thumb.

Another important variable that must be considered is the age of the patient, because there is a natural decline in a woman's fertility with increasing age. This difference becomes apparent in women over 35 years old and is notorious in patients over 40. It is not surprising, then, that the outcome of GIFT, like that of any other ART procedure, is affected by this factor. Nevertheless, GIFT has consistently shown the best results among ART procedures with this special age group, as is clearly seen in Table 30.3.2. Craft and colleagues, reviewing 1,071 GIFT cases, found a PR that fluctuated between 33.5 and 40.2% in different age groups of patients, all under 40 years old. In the group above 40, the pregnancy rate was only 19.2%. The incidence of multiple pregnancy was 29% in the group under the age of 40 and 16.2% in the group over that age. The authors concluded that the chance of pregnancy and, particularly, of multiple pregnancy is significantly lower for patients over age 40, even when 10 or more oocytes are transferred. Defective oocytes, rather

TABLE 30.3.1. Number of oocytes transferred and GIFT outcome. United States 1990 results from the IVF-ET Registry.*

No. of oocytes transferred	Clinical pregnancy rate (%)	Delivery rate (%)	Multiple delivery rate (%)
≤ 3	34/296 (11)	27/296 (9)	4/296 (1.4)
4	157/527 (30)	129/527 (24)	42/527 (8)
5–6	187/574 (33)	146/574 (26)	49/574 (8.5)
≥ 7	87/204 (43)	58/204 (28)	26/204 (12.7)
Total	465/1,601 (29)	260/1,601 (22.5)	121/1,601 (7.6)

*Data from *Fertil Steril* 57:15–24, 1992.

TABLE 30.3.2. Comparative results of GIFT and IVF according to woman's age.*

	GIFT/IVF					
Age group	No. transfers	Clinical preg. (%)	Ectopic preg. (%)	SAB (%)	Deliveries (%)	Multi. del. (%)
< 25	18/27	11.1/25.9	0/0	50/28.6	0/18.5	0/0
25–29	200/436	34/20.2	4.4/6.8	8.8/18.2	30/16.1	12.5/5.1
30–34	634/1,331	36/23.7	5.7/7.6	15.8/15.9	28.9/19.3	10.1/5.6
35–39	532/1,256	26.7/19.4	5.6/4.5	17.6/22.2	20.5/14.8	6.2/3.7
> 40	214/350	16.8/10.9	2.8/7.9	38.9/28.9	8.9/6.6	1.4/1.7
Total	1,599/3,405	29.8/20	5.3/6.3	17.2/19	23.2/16	7.8/4.4
Significance		$p < 10^{-6}$	n.s.	n.s.	$p < 10^{-6}$	n.s.

*Data from *Fertil Steril* 57:15–24, 1992.

than poor endometrial receptivity, may be the cause for this decrease in a woman's fertility with age. This hypothesis is supported by the results of oocyte donation programs; we have achieved PRs as high as 57.9% among poor responders or true ovarian-failure recipients.[15] Cohen and colleagues have postulated that zona pellucida hardening is the main defect of oocytes in older women.[16]

Finally, sperm parameters must also be evaluated when deciding whether to offer a GIFT procedure to an infertile couple. Guzick and colleagues reported that sperm motility and morphology appear to have the largest impact on the chances of pregnancy, as we illustrate in Table 30.3.3.[13] The authors found a threefold increase in PRs when normal morphology was present in more than 50% of the ejaculate, and a fivefold increase when motility was over 30%. High sperm counts did not produce an additional increase in pregnancy rates. Although GIFT can certainly overcome mildly to moderately low sperm counts, it cannot resolve major functional alterations, such as very low motility or abnormal morphology, as Wiedemann and colleagues have demonstrated.[17]

Among ART procedures the GIFT technique is considered reliable and reproducible. Overall PRs fluctuate between 21 and 28%, according to an international collaborative study on IVF-ET and GIFT for 1989[18] as well as to the 1990 United States IVF-ET Registry.[6] Realistic patient selection is crucial to good results. The number of gametes transferred should reflect variables such as age of the patients and the quality of the gametes.

For those patients with severe male factor, which makes proof of fertilization useful, an IVF or ZIFT technique is recommended.

TABLE 30.3.3. Sperm parameters and outcome of GIFT.*

Sperm parameters		No. of pregnancies	Preg. rate (%)	Statistical significance
Sperm count (million)	≤ 20	35	25.7	n.s.
	21–50	42	21.4	
	≥ 50	141	31.2	
Motility (%)	< 20	30	6.7	$p < 0.05$
	> 30	185	31.9	
Morphology (% normal)	< 50	64	10.9	$p < 0.01$
	> 50	154	35.8	

*Data from Guzick DS et al. *Fertil Steril* 57:15–24, 1992.

Zygote Intrafallopian Transfer (ZIFT)

This new assisted reproductive technique has been available since 1986, when Devroey and colleagues[18] and Yovich and colleagues[19] first published it. The technique involves the transfer of human embryos generated in vitro into the fallopian tubes. It can be performed either laparoscopically or via minilaparotomy. As is true of GIFT, the laparoscopic approach is now the method of choice in infertility practices.

This procedure is called ZIFT (zygote intrafallopian transfer), PROST (pronuclear stage transfer), or TET (tubal embryo transfer), depending on the stage of development of the embryos being transferred. For simplicity, we will refer to all tubal embryo transfers as ZIFT.

Like GIFT, ZIFT allows chronologically appropriate entrance of the embryo to the uterus and allows the embryo to travel through the protective fallopian tube. In addition, ZIFT allows fertilization to be documented, and compared to direct intrauterine transfer, avoids endometrial trauma.

ZIFT includes the same steps as GIFT, that is, a controlled ovarian hyperstimulation with gonadotropins, hCG administration, sperm preparation, and follicular aspiration done either transvaginally or through the laparoscope. Once the oocytes have been retrieved, the biologists carefully classify them, incubating the eggs for the following six hours. Then, sperm and eggs are put together for fertilization. Approximately 41 to 48 hours later, the resulting two- to four-cell embryos are transferred into the fallopian tube, using the same techniques and instruments as for GIFT. An average of four embryos are transferred at our center, but of course this decision should be individualized. If more embryos are produced than are needed, we offer the possibility of cryopreserving them for future frozen embryo transfers [intratubal or intrauterine frozen-embryo transfer (FET)]. We have reported a 17% PR for each FET cycle, which represents a great advance in efficiency and therefore lower cost for the patients.[24] Our cumulative PR may surpass 50% per single stimulated cycle.

Even though this technique has been in existence for more than six years, it is difficult to judge its results from the literature, because few centers perform it and they often use embryos in different stages of development. We have achieved good results with this therapeutic option, especially in couples who were poor candidates for GIFT due to severe male factor. Our PR ranges between 20 and 53%, as reported in the literature.[20–23]

The outcome of this technique is also influenced by the patient selection, and the variables described for GIFT are applicable. The age of the patient has a clear impact in the success of the procedure, with women younger than 35 years having higher pregnancy and implantation rates and a lower abortion rate. As Table 30.3.4 shows, we have obtained only a 6% PR and 1% implantation rate in women over 40, and this group had a significantly higher abortion rate than younger patients (66 versus < 17%).

Many publications have compared the outcome of ZIFT and IVF or GIFT. Apparently, the results achieved with this method are no better than those achieved with the other two.[21,25,26] In our oocyte donation program, working with recipients receiving cyclic hormonal replacement (estradiol and oily progesterone), we have not observed any advantage to transferring embryos to the tubes rather than directly to the uterus.[24] This suggests that embryo quality and endometrial receptivity may be more important than the chronology of entry into the uterine cavity.

TABLE 30.3.4. Results of gamete intrafallopian transfer and zygote intrafallopian transfer for different age groups.

	GIFT	ZIFT
Pregnancy rate (%)		
< 30 years	25	36
30–34 years	37	35
35–39 years	42	24
≥ 40 years	46	6
Implantation rate (%)		
< 30 years	11	13
30–34 years	15	8
35–39 years	9	7
≥ 40 years	10	1
Abortion rate (%)		
< 30 years	25	0
30–34 years	8	10
35–39 years	11	17
≥ 40 years	50	66

*Data from Balmaceda JP et al. *Current Opinion Obst Gyn* 4:743–9, 1992.

Today, some infertility centers do not offer ZIFT as a therapeutic option because the technique does not seem to achieve better results than GIFT or IVF and is more complex to perform than uterine transfers. Nevertheless, it is still a reasonable alternative for women with functional fallopian tubes and associated male-factor infertility, especially those 35 years old or older. It is the technique of choice for couples with these characteristics who also have a cervical stenosis that makes cannulation of the cervical canal extremely difficult or even impossible. Although transmyometrial uterine transfer is available for this group of patients, it is a complex technique that requires an experienced and skilled physician.

Concomitant Diagnostic Laparoscopy and GIFT

Evaluating an infertile couple demands methodical clinical and laboratory examinations. In the majority of centers, if pregnancy has not been achieved after excluding male factor and ruling out or treating ovulatory disorders, the next step is diagnostic laparoscopy. This procedure gives accurate information about the integrity of a woman's genital organs and reveals the presence of pelvic endometriosis, which is prevalent among the infertile population. Although a hysterosalpingogram can be very useful for diagnosing intrauterine abnormalities, such as septum, polyps, or submucous myomas, it is less precise than laparoscopy for evaluating tubal patency. The absence of contrast media in a segment of a tube could be due to tubal spasm rather than obstruction. On the other hand, tubal permeation does not necessarily mean the tube is functional.

There is also a tendency to piggyback diagnostic laparoscopy on therapeutic operative procedures, the most common being adhesiolysis and fulguration of endometriotic implants. By this means, the cost of the procedure and the patient's discomfort are significantly reduced. To make this procedure even more cost-effective, Pampiglione and colleagues proposed combining diagnostic laparoscopy and GIFT.[28] They reported a 24% pregnancy rate in patients who received clomiphene citrate for ovulation induction. Later on Gindoff and coworkers published a similar PR in patients undergoing diagnostic and operative laparoscopy after ovulation induction with hMG and hCG.[29] They concluded that by using laparoscopy it was possible to serve three purposes without compromising the success of the method: to provide important diagnostic information; to attempt therapeutic measures; and to achieve good PRs. Another study using clomiphene citrate alone, reported by Johns, achieved a 24.6% PR.[30] Our experience with an ongoing study is consistent with these reports. We have already treated 18 cases, obtaining five clinical pregnancies (28% PR, 11% implantation rate), with only one abortion observed thus far (Table 30.3.5).

Our ovarian stimulation protocol for these patients is 100 mg clomiphene citrate given from day 3 to day 7 of the menstrual period. We indicate hCG 5,000 IU when the leading follicle has reached a diameter of between 18 and 20 mm, and laparoscopy/GIFT is scheduled for 36 hours later. Premature ovulation sometimes occurs in these patients who are not under pituitary downregulation, and we have canceled eight procedures for this reason. We do not use gonadotropins for ovulation induction because they increase the number of follicles and the ovarian size to the point that pelvic structures cannot be correctly visualized.

TABLE 30.3.5. Results of concomitant diagnostic laparoscopy and GIFT.

Authors (ref.)	No. of patients	No. of clinical pregnancies	Preg. rate (%)
Pampiglione et al.[28]	21	5	23.8
Johns[30]	62	15	24.6
Gindoff et al.[29]	15	4	26.7
Balmaceda et al.[20]	18	5	27.8

Conclusion

Laparoscopy is an invaluable technique for assisted reproduction, with both diagnostic and therapeutic applications. Hence, this simple method has become very popular among physicians dealing with infertile couples. Patients suffer less discomfort and need less postoperative care than after a traditional laparotomy. Moreover, the results obtained with GIFT and ZIFT procedures are comparable to those achieved with IVF uterine transfers.

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30.4 Laparoscopic Ovarian Surgery

Harry Reich and William H. Parker

Laparoscopic treatment for ovarian cysts or masses is controversial, though cystectomy or oophorectomy can often be easily accomplished. However, laparoscopic evaluation should be performed when a mass persists for over three months to rule out malignancy. In most cases, the mass will be a serous cystoma, endometrioma, or dermoid cyst. This chapter will discuss advanced laparoscopic techniques and their application to specific ovarian conditions. The controversy regarding ovarian masses will also be discussed.

Techniques

Incisions

Three laparoscopic puncture sites including the umbilicus are used: 10-mm umbilical, 5-mm right, and 5-mm left lower quadrant. The left lower quadrant puncture is the major portal for operative manipulation. The right trocar sleeve is used for atraumatic grasping forceps to retract tissue as needed.

Placement of the lower quadrant trocar sleeves just above the pubic hairline and lateral to the deep epigastric vessels (and thus, the rectus abdominis muscle) is preferred. These vessels, an artery flanked by two veins (venae comitantes), are located by direct laparoscopic inspection of the anterior abdominal wall. They are found lateral to the umbilical ligaments (obliterated umbilical artery), and cannot be consistently found by traditional transillumination. The deep epigastric vessels arise near the junction of the external iliac vessels with the femoral vessels and make up the medial border of the internal inguinal ring. The round ligament curls around these vessels to enter the inguinal canal. When the anterior abdominal wall parietal peritoneum is thickened from previous surgery or obesity, the position of these vessels is judged by palpating and depressing the anterior abdominal wall with the back of the scalpel; the wall will appear thicker where rectus muscle is enclosed, and the incision site should be chosen lateral to this area, near the anterior superior iliac spine.

Aquadissection[1]

Aquadissection is broadly defined as the use of hydraulic energy from pressurized fluid to aid in surgical procedures. It differs from the mechanical energy applied with a blunt probe, a unidirectional force. The force vector of hydraulic energy is multidirectional within the volume of expansion of the noncompressible fluid. Installation of fluid under pressure displaces tissue, creating cleavage planes in the least resistant spaces. Aquadissection into closed spaces behind peritoneum or adhesions produces edematous, distended tissue on tension with loss of elasticity, making further division easy and safe using blunt dissection, scissor dissection, laser, or electrosurgery.

Aquadissectors (suction-irrigators with the ability to dissect using pressurized fluid) should have a single channel to maximize suctioning and irrigating capacity. Separate suction and irrigation channels, either side by side or one inside the other, result in diminished suction capacity and reduced hydraulic effect. An aquadissector with a solid (not perforated) distal tip is necessary for atraumatic suction-traction-retraction, direct irrigation, and developing surgical planes (aquadissection). Small holes at the tip impede these actions and spray the surgical field without purpose. The shaft should be specially treated by bead blasting to provide a dull finish. This prevents CO_2 laser beam reflection, allowing the shaft to be used as a backstop.

Suturing

Suturing is facilitated by using a trocar sleeve without a trap when making the knot outside the peritoneal cavity (extracorporeal). Most trocar sleeves have a trap or valve that makes it difficult to slip knots down to the tissue. A short trocar sleeve that does not protrude far into the peritoneal cavity, has a screw grid for retention, and has no trap, is ideal.[2] Both a reusable (Richard Wolf), and a disposable version (Apple Medical) are available. The former is better for rapid instrument exchanges, but the Apple has a much tighter seal, preventing loss of pneumoperitoneum. With practice, laparoscopic surgeons can make instrument exchanges so fast that losing pneumoperitoneum is not a concern. An excellent technique for laparoscopic suturing was developed in 1970 by Dr. H. Courtenay Clarke using a knot-pusher (Marlow Surgical, Willoughby, OH) to tie in a manner very similar to the way one would hand-tie suture at open laparotomy.[3] This device is like an extension of the surgeon's fingers.

To suture with a straight needle, the surgeon applies the suture to the tissue, pulls the needle outside, and then, while holding both strands, makes a simple half-hitch, but not a surgeon's knot, which will not slip as well. The Clarke knot-pusher is put on the suture. It is held firmly across the index finger and the throw is pushed down to the tissue. A square knot is made by pushing another half-hitch down to the knot to secure it, while exerting tension from above.

The Endoloop is a preformed, knotted loop designed to fit over vascular pedicles and then be tightened. Over the last 15 years, this author has used it for appendectomies and omentectomies, but never for oophorectomy. Bipolar desiccation works better and eliminates any chance of slippage. Postoperative pelvic pain is less in desiccated pedicles; an endolooped pedicle leaves living cells distal to the loop to necrose and release lysozymes.

Suturing with large curved needles requires a special technique to put them into the peritoneal cavity without a large incision, that is, through a 5-mm lower quadrant incision.[4] The lower abdominal incisions are placed lateral to the deep epigastric vessels, and thus, lateral to the rectus muscle. The trocar sleeve penetrates skin, external and internal oblique, transversalis, and peritoneum. A tract is obvious upon removing the trocar sleeve and is very easy to re-enter. To suture with a CT-1 needle, the trocar sleeve is taken out of the abdomen and loaded by introducing a needle holder through the sleeve to grasp the distal end of the suture, pulling the suture through the trocar sleeve, reinserting the instrument into the sleeve, and grasping the suture about 2 to 3 cm from the needle. The needle driver is inserted into the peritoneal cavity through the original tract, as visualized on the monitor; the needle follows, and thereafter, the trocar sleeve is reinserted. Even large needles can be pulled into the peritoneal cavity in this manner. At this stage, the Semm straight needle holder (WISAP) is replaced with a Cook oblique curved needle driver (Cook OB/GYN, Spencer, IN), and the needle applied to tissue. Afterward, the needle is stored in the anterior abdominal wall parietal peritoneum (like a pin cushion) for later removal, after the suture is tied. The needle is cut, the cut end of the suture pulled out of the peritoneal cavity through the trocar sleeve, and the knot tied with the Clarke knot-pusher. To retrieve the needle, the trocar sleeve is unscrewed. Then the needle holder inside it pulls the needle through the soft tissue, after grasping its attached suture remnant. The trocar sleeve is replaced easily with or without another suture.

Underwater Surgery at the End of Each Procedure[5]

At the close of each operation, an underwater examination is used to document complete intraperitoneal hemostasis in stages; this detects bleeding from vessels and viscera tamponaded during the procedure by the increased intraperitoneal pressure of the CO_2 pneumoperitoneum. The CO_2 pneumoperitoneum is discontinued and displaced with 2 to 5 L of Ringer's lactate solution, and the peritoneal cavity is vigorously irrigated and suctioned with this solution until the effluent is clear of blood products, usually after 10 to 20 L. Underwater inspection of the pelvis is performed to detect any further bleeding that is controlled using the Vancaillie microbipolar forceps (Storz) to coagulate through the electrolyte solution. First, complete hemostasis is established with the patient in Trendelenburg position. Next, complete hemostasis is secured per underwater exam with the patient supine and in reverse Trendelenburg. Finally, complete hemostasis is documented with all instruments removed, including the uterine manipulator.

To visualize the pelvis with the patient supine, the 10-mm straight laparoscope and the actively irrigating aquadissector tip are manipulated together into the deep cul-de-sac beneath floating bowel and omentum. During this copious irrigation procedure, clear fluid is deposited into the pelvis and circulates into the upper abdomen, displacing upper abdominal bloody fluid that is suctioned after flowing back into the pelvis. An underwater examination is then performed to observe the separated tubes and ovaries and to confirm complete hemostasis.

A final copious lavage with Ringer's lactate solution is undertaken and all clots directly aspirated. At least 2 L of lactated Ringer's solution are left in the peritoneal cavity to displace CO_2 and to prevent fibrin adherences from forming by separating raw, operated-upon surfaces during the initial stages of reperitonealization. Displacement of the CO_2 with Ringer's lactate diminishes the frequency and severity of shoulder pain from CO_2 insufflation. No other antiadhesive agents are employed. Hyskon is not used as it pulls intravascular fluid into the peritoneal cavity. No drains, antibiotic solutions, or heparin are used.

Preopertive Preparation

Endometriosis surgery is not made easier by perioperative medical therapy with GnRH agonists or danazol. Ovarian suppression is expensive, has a significant rate of side effects, and prohibits fertility during its administration. The hormonal responsiveness of deep endometriotic fibrotic lesions is unpredictable and inconsistent. Hormonal suppression does not improve the long-term outcome in women with extensive disease and should be abandoned.

Patients are informed preoperatively that they are at high risk for bowel injury during laparoscopic procedures when extensive cul-de-sac involvement with endometriosis or adhesions is suspected from the clinical presentation. A mechanical bowel preparation (Golytely or Colyte) is administered orally the afternoon before the surgery to induce brisk, self-limiting diarrhea to cleanse the bowel without disrupting the electrolyte balance. Antibiotics are not given as preoperative prophylaxis for laparoscopic surgery, but are administered during operations lasting more than two hours.

Adhesion Prevention

Adhesion prevention regimens that are more expensive than Ringer's lactate solution should be used only at centers doing clinical research. Dr. Jaroslav Hulka said in 1988 that "Reich's solution to pollution is dilution," and that opinion has not changed. This author believes that adhesion reduction requires: minimal thermal damage to tissue; absolute hemostasis; clot evacuation; copious irrigation to dilute fibrin and prostaglandins arising from operated surfaces and bacteria; and leaving 2 to 3 L of Ringer's lactate in the peritoneal cavity at the end of each operation to physically separate normal and compromised structures.

Many surgeons currently use intraperitoneal Ringer's lactate solution to prevent adhesions, but prospective studies are rare. Rose determined by weighing patients that lactated Ringer's solution is absorbed over two to three days.[6] A recent study found that Ringer's lactate was superior to Gore-tex and Interceed in adhesion prevention.[7] The Gore-tex Surgical Membrane (WL Gore, Flagstaff, AZ) is probably the best of the presently available surgical barriers. It is a nonabsorbable, inert membrane with pore size $< 1\mu m$. It is used after division of severe adhesions, retroperitoneal ovary, for example, and is sutured in place. Interceed (Johnson & Johnson, New Brunswick, NJ) is impossible to use successfully with laparoscopy as it requires absolute hemostasis at the applied site and no fluid. Bleeding from vessels and viscera tamponaded during the procedure by the increased intraperitoneal pressure of the CO_2 pneumoperitoneum cannot be detected without an underwater examination. This author suspects that bleeding from a raw site after the pneumoperitoneum is expelled results in the filling of the Interceed with blood, making it adhesiogenic.

Pelvic Mass Evaluation and Controversies

The operative approach to the pelvic mass has routinely been laparotomy for early detection, resection, and proper staging should ovarian cancer be found. Most adnexal masses, however, are benign with malignancy found in 7 to 13% of premenopausal and 8 to 45% of postmenopausal patients. Preoperative evaluation may help select candidates for operative laparoscopy.[8] Careful inspection of the pelvis and abdomen at the time of laparoscopy is helpful to detect obvious signs of malignancy. The presence of peritoneal or pelvic excrescences, ascites, or dense adhesions involving a pelvic mass should alert the physician to the possibility of malignancy. If malignancy is suspected by visual inspection or diagnosed on frozen section, the pelvis should be filled with distilled water to lyse malignant cells, and laparotomy done immediately. Laparoscopic treatment should be considered only in cases where the surgeon can do the same operation as open surgery without compromise.

There is now extensive literature available on the use of operative laparoscopy for premenopausal women found to have a pelvic mass. Recent studies have shown good results for operative laparoscopic management of dermoid cysts, with low risk of recurrence and only rare evidence of mild adhesion formation seen at second-look laparoscopy.[5,9,10] Management of endometriomas by operative laparoscopy has been associated with low risk of recurrence and good fertility rates.[11,12] Operative laparoscopy also has a role in management of paraovarian cysts (paratubal cysts), and adnexal torsion.[13]

The role of operative laparoscopy in postmenopausal women has been more controversial.[14] Laparoscopic drainage or removal of pelvic masses has been avoided because of the risk of "spilling" cancer cells into the peritoneal cavity and causing the cancer to metastasize. Dembo and colleagues have presented evidence in 519 patients with stage I ovarian cancer suggesting that the only factors influencing the rate of relapse were the tumor grade, the presence of dense adhesions, and the presence of large volume ascites.[15] The prognosis was not influenced by rupture of the tumor. Parker and Berek published a study in which 22 of 25 (88%) carefully selected postmenopausal patients with adnexal masses were successfully managed by operative laparoscopy.[16] Mann and Reich reported successful adnexectomy in 42 of 44 postmenopausal women, with no selection criteria; cysts ranged from 1 to 12 cm.[17] Laparoscopic treatment of stage I ovarian cancer has been described.[18]

Preoperative Evaluation

The patient's age, the clinical exam, and the ultrasound findings provide important information that helps determine the best operative approach. Postmenopausal women should also have a serum CA125 (cancer antigen 125) assay.[19] Transvaginal sonographic examination of the pelvis is a reliable and consistent method for evaluation of a pelvic mass and should be performed to determine the size and consistency of the mass.[20] Granberg, in a study of 94 postmenopausal and 86 menstruating women, found that ultrasound correctly predicted benign masses in 92% of patients.[21] The presence of irregular borders, papulations, solid areas, thick septa, ascites, or matted bowel should raise concern for the possibility of malignancy. If suspicious for malignancy, operative laparoscopic removal is usually not appropriate, and laparotomy should be performed without delay. Dermoids, endometriomas, hemorrhagic cysts, cystadenomas, and persistent functional cysts often have a characteristic appearance on ultrasound. Along with the clinical picture and other laboratory data, the ultrasound may help select patients that can be approached by operative laparoscopy.

Functional cysts are usually unilocular, and in premenopausal women, the majority of purely cystic masses < 7 cm will resolve spontaneously. Hemorrhagic cysts contain internal echoes, usually change over time, and often regress spontaneously. Dermoids have a variable appearance on an ultrasound and may appear as a cystic mass with a thickened wall, echogenic material in a nondependent area, or highly echogenic areas representing bone or teeth. Endometriomas usually have regular but slightly thickened borders with low level and diffuse internal echoes.

CA125, a tumor-associated antigen, has been studied to determine its value in preoperative differentiation of benign and malignant pelvic masses. Vasilev found that 128 of 132 patients (97%) with pelvic masses who had a CA125 < 35 U/mL had benign masses.[22] However, in patients < 50 years old who had an elevated CA125 value, 34 of 40 patients (85%) had a benign mass. Endometriosis, leiomyomata, adenomyosis, dermoid cysts, pregnancy, and acute or chronic salpingitis may all be associated with elevated CA125 levels. Values may also be elevated with inflammatory bowel disease, colon cancer, lung cancer, breast cancer, cirrhosis, liver disease, pancreatitis, and pancreatic carcinoma.

The combination of clinical examination, sonogram, and (in postmenopausal women) CA125 values is presently used to determine the appropriateness of laparoscopic surgery for patients with an ovarian mass.[23] Intravenous pyelograms are rarely necessary preoperatively, but are ordered postoperatively if abdominal pain persists on or near the ureter following surgery. Presently, there is no indication for CT scan or MRI prior to laparoscopic ovarian surgery.

Surgical Considerations

All patients scheduled for operative laparoscopy should also consent to a possible laparotomy, and most surgeons should be prepared to proceed with staging laparotomy without delay if malignancy is found. Under general endotracheal anesthesia, surgery is performed in the lithotomy position. Foley catheters are used in most patients to avoid bladder injury and prevent overdistension during prolonged surgery. A 10-mm laparoscope is used for its excellent optical acuity. Five- and 11-mm trocars are inserted via suprapubic incisions as needed.

Initially, the upper abdomen and pelvis are inspected for obvious carcinoma, excrescences, and ascites. Pelvic and abdominal washings are done for staging, in the event that carcinoma is found. If excrescences are found, they are biopsied and sent for frozen section. If obvious carcinoma, ascites, or a positive frozen section is found, most surgeons proceed to immediate staging laparotomy through a midline incision.

Procedures

Both laparoscopic and laparotomy surgery can be time-consuming and technically difficult and are best performed by an expert surgeon. However, despite lengthy laparoscopic procedures (two to four hours), most women are discharged on the day of the procedure, avoid major abdominal incisions, experience minimal complications, and return to full activity within one week of surgery. This portion of the chapter will describe laparoscopic ovarian surgery in detail.

Ovariolysis

Ovarian adhesions to the pelvic sidewall can be filmy or fused. The object of ovarian adhesiolysis is to preserve as much peritoneum and intact ovarian cortex as possible, while freeing the ovary. If the adhesions are not obvious, dissection begins by using the aquadissector to develop potential spaces among the adhesions. Thereafter, laparoscopic scissors are used to divide the adhesions, usually taking very small bites and using blunt scissor dissection to help elevate the ovarian cortex. Dissection continues until the ovary is free to its hilum. On occasion, CO_2 laser is used to aid in the dissection of fused adhesions, especially if ureteral location is in doubt, as this laser causes minimal thermal damage deep to the operative site. Endometriomas usually drain spontaneously as the ovary is separated from the pelvic sidewall or uterosacral ligament.

Oophorectomy (Figures 30.4.1–30.4.13)

Laparoscopic oophorectomy was first reported by Semm and Mettler using a loop ligature and a tissue punch morcellator, and Reich who used bipolar electrosurgical desiccation and culdotomy.[24–27] The indications for laparoscopic oophorectomy (or salpingo-oophorectomy) include: pelvic pain secondary to ovarian adhesions from previous hysterectomy; pain from ovarian adhesions unresponsive to laparoscopic lysis; pelvic mass secondary to hydrosalpinx from PID or previous surgery; and perimenopausal and postmenopausal ovarian cysts. In women not desiring future fertility, oophorectomy should be considered for pain or mass arising from ovarian endometrioma, hemorrhagic corpus luteum cyst, or dermoid cyst when the contralateral ovary is normal, especially if the cyst is on the left as this ovary frequently heals adhered to the rectosigmoid. Postmenopausal cystic ovaries can be removed intact through a culdotomy. Women in families with two or more first degree relatives (mother

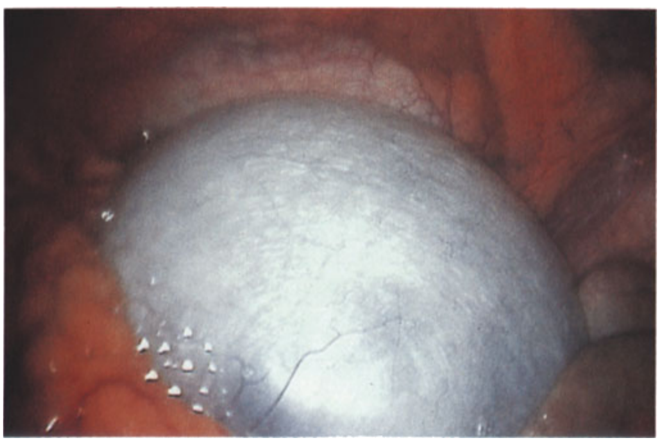

FIGURE 30.4.1. Large 12-cm cystic ovary fills lower abdomen.

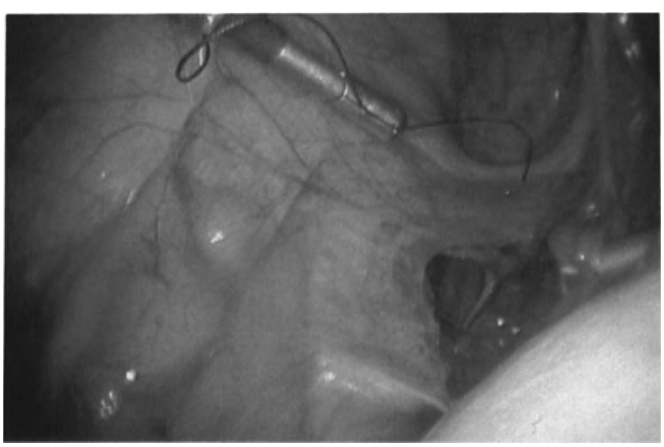

FIGURE 30.4.2. Left pelvic sidewall is mobilized and a suture without needle introduced for large vessel ligation.

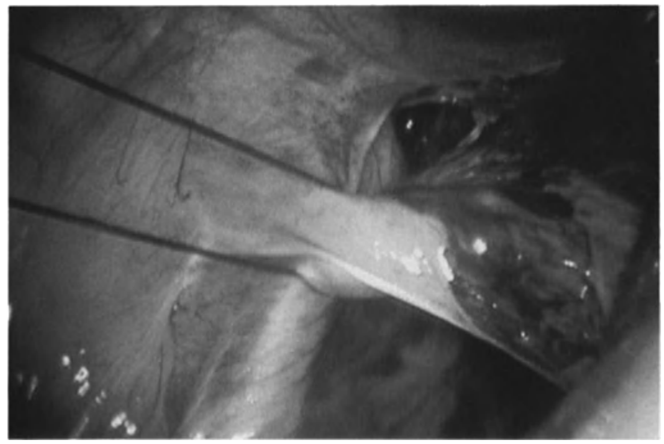

FIGURE 30.4.3. The suture is placed around the left ovarian vessels after they have been skeletonized.

FIGURE 30.4.4. Similarly, a suture is placed around the left utero-ovarian ligament and fallopian tube pedicle.

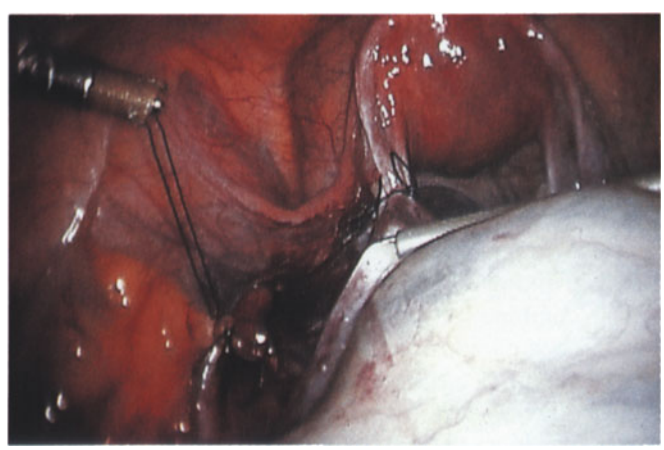

FIGURE 30.4.5. Both infundibulopelvic ligament and utero-ovarian ligament have been tied.

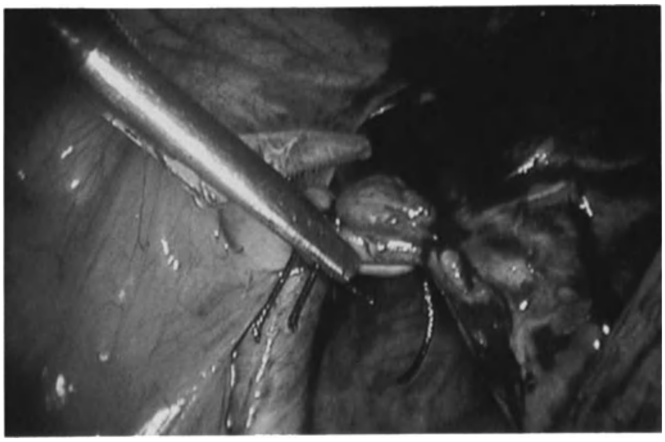

FIGURE 30.4.6. Left ovarian vessels are divided with scissors between ligatures.

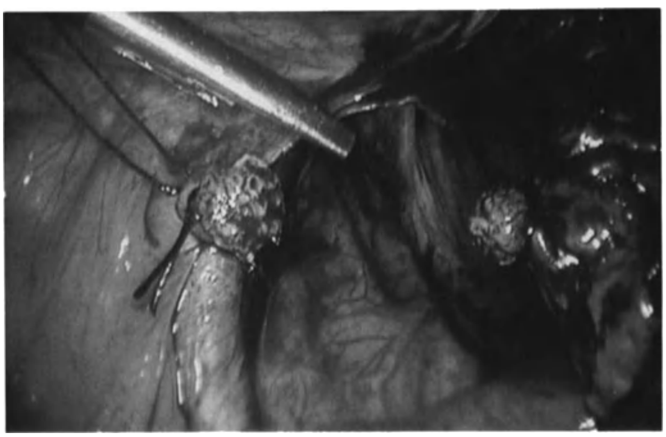

FIGURE 30.4.7. The left broad ligament is divided lateral to the left tube and ovary.

FIGURE 30.4.8. Spoon electrode at 150 W cutting current is used to divide the proximal pedicle (utero-ovarian ligament and fallopian tube).

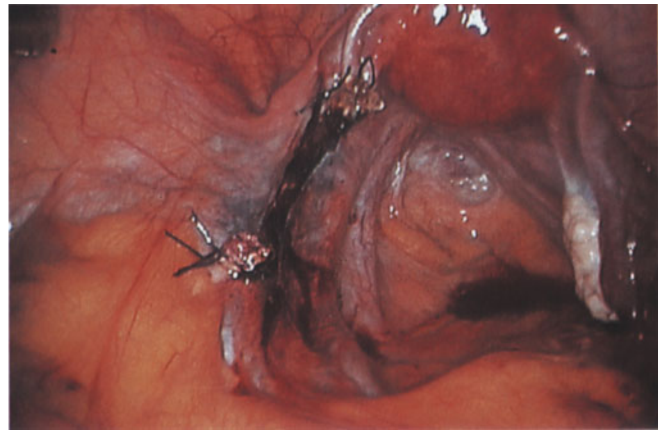

FIGURE 30.4.9. After division of pedicles but before removal of ovary, pelvis is inspected. Hemostasis is complete.

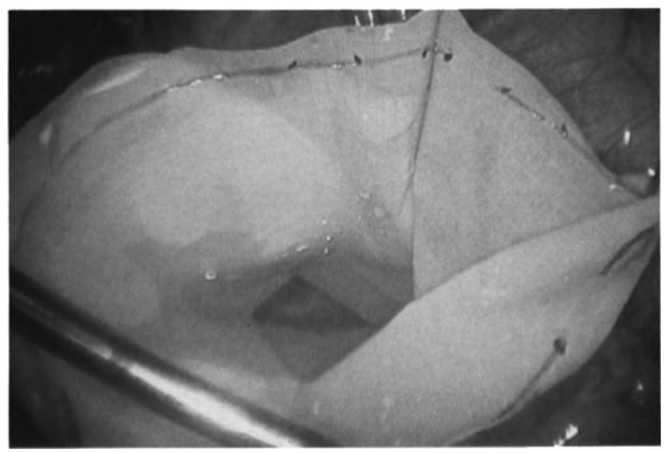

FIGURE 30.4.10. Large LapSac (5 × 8 in.) is pulled into the peritoneal cavity through a culdotomy incision and opened.

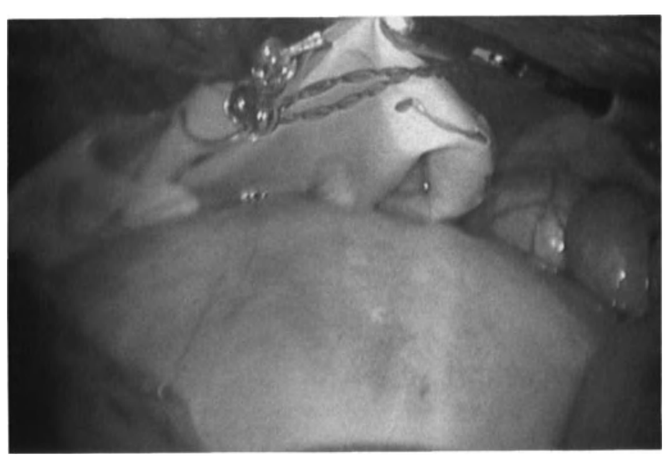

FIGURE 30.4.11. In this case, the mass was too large to fit into the sac.

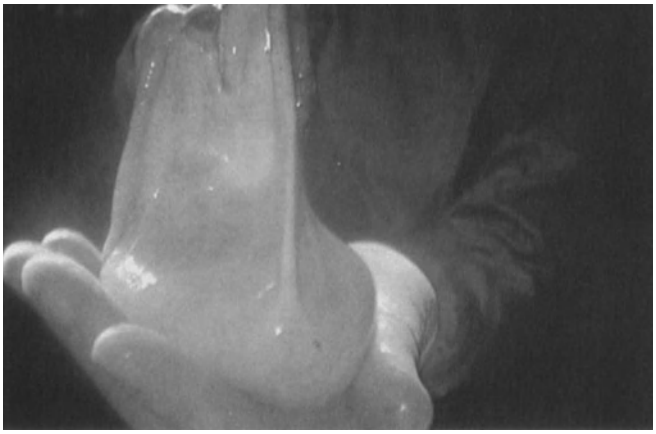

FIGURE 30.4.12. The mass was removed by pushing it into the deep pelvis and aspirating some of its fluid vaginally. The large mass is held down in the deep pelvis during aspiration, through the vagina, so as to prevent leakage into the peritoneal cavity. The intact mass is seen in the surgeon's hand following this procedure.

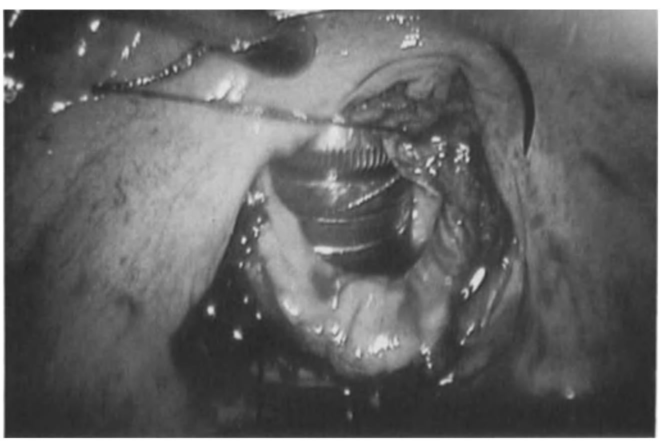

FIGURE 30.4.13. The laparoscopically made culdotomy incision is closed with a Vicryl suture.

or sister) with ovarian cancer can consider early prophylactic oophorectomy after age 35 if childbearing has been completed.

Prior to starting oophorectomy, it is imperative that the surgeon visualize the course of the ureter. It crosses the external iliac artery near the bifurcation of the common iliac artery at the pelvic brim and is usually lower on the left, where its entrance into the pelvis is covered by the inverted V-shaped root of the sigmoid mesocolon. The peritoneum above the ureter is opened with sharp scissors. Smooth grasping forceps are then opened parallel and perpendicular to the retroperitoneal structures until the ureter is identified. Scissors can be used to further dissect the ureter throughout its course along the pelvic sidewall.

Prior to removal, the ovary is released from all pelvic sidewall and bowel adhesions. The fallopian tube is grasped and pulled medially to stretch out the infundibulopelvic ligament containing the ovarian vessels. Kleppinger bipolar forceps are used to compress and desiccate the infundibulopelvic ligament, the broad ligament, the fallopian tube isthmus, and the utero-ovarian ligament with bipolar *cutting* current. In most cases, three contiguous areas are desiccated. Laparoscopic scissors divide the pedicle. Alternatively, 2–0 or 0 Vicryl sutures are applied to the skeletonized ovarian vessels with a curved needle or a stick tie (Figures 30.4.1–30.4.13). The free ovary is removed through the umbilicus or cul-de-sac.

When the ovary or ovarian remnant is fused to or within the pelvic sidewall peritoneum, a retroperitoneal approach for oophorectomy is considered. Scissors or CO_2 laser is used to incise the peritoneum lateral to the infundibulopelvic ligament, progressing parallel to the tube and ovary up to the uterine end of the round ligament. With traction on the tube, ovary, or peritoneum, the retroperitoneal space is entered and its loose areolar tissue dissected with scissors until the ureter is identified. Then, the ovarian vessels are desiccated or ligated just caudad to where they cross over the iliac vessels. After division of the infundibulopelvic ligament, it is placed on traction and the procedure continues caudad with division of the peritoneum just below its ovarian attachments and lateral to its rectosigmoid attachments. Finally, the utero-ovarian ligament and proximal fallopian tube are desiccated or ligated and divided, freeing the specimen. The peritoneal sidewall defect is not closed.

Ovarian Cyst Aspiration

Aspiration, as an isolated procedure, is not recommended because it does not allow inspection of the cyst wall or removal of tissue for pathologic analysis. Cytologic analysis of cyst fluid is associated with a high false-negative rate, and aspiration may be associated with a recurrence rate approaching 30%.[28] In most cases of simple cysts, we favor cystectomy since this allows microscopic analysis of the cyst wall.

If a dermoid is encountered during syringe aspiration, cyst excision should be accomplished with as little spill as possible, often by placing a large impermeable sac around the ovary during cyst dissection. Shelling out a dermoid from inside an ovary following drainage is usually much easier than endometrioma cyst wall excision. Vigorous peritoneal cavity irrigation with at least 10 L of Ringer's lactate and underwater examination with direct suctioning of fatty and epidermal elements is recommended to prevent a chronic granulomatous reaction.[29]

Cystectomy

Ovarian cysts are discovered during pelvic examination or vaginal ultrasonography. If persistent, these cysts are surgically evaluated because of the small risk of malignancy. Laparotomy for benign cyst excision is inappropriate because of the increased risk of ovarian adhesions.[30]

Laparoscopic inspection of a suspected ovarian cyst often reveals a parovarian cyst, hydrosalpinx, or inflammatory peritoneal pseudocyst. Parovarian cysts are excised if large enough to disrupt ovum pickup, and pseudocysts require excision of pelvic adhesions. Cysts with a translucent thin wall are usually functional. Most organic cysts have thick walls. The ovaries are evaluated for visual evidence of malignancy. All cysts should be smooth walled and without excrescence. All but the most benign-appearing cysts are removed intact through the cul-de-sac, or in an impermeable sac, to avoid the potential risk of metastasis to the anterior abdominal wall. All cysts opened during laparoscopic surgery, either intentionally or during mobilization of the ovary, require a careful examination of their inner walls. Cystectomy is preferable to puncture with biopsy in order to avoid recurrence of organic cysts.

Ovarian cystectomy for functional cysts (simple cysts, follicle cysts, or corpus luteum cysts) is not a common laparoscopic procedure, and laparoscopic excision should be considered only when persistence of the cyst or pain is documented. Even an actively bleeding hemorrhagic corpus luteum cyst can be totally excised laparoscopically with minimal bleeding. Hemostasis without excision of a bleeding corpus luteum can be obtained using electrosurgical fulguration with an electrode or the argon-beam coagulator. Suture repair is sometimes indicated.

Simple cysts may be excised intact, drained with electrosurgery, or aspirated with a needle attached to a syringe after cul-de-sac washings have been obtained. It must be emphasized that drainage with a needle does not prevent spill and is performed for only the most benign-appearing cysts. After documentation of clear- or hemosiderin-filled fluid, the ovarian cortex is opened at its most dependent portion, with a knife electrode at 70 W cutting current, and the cyst excised.

Enlarged ovaries containing cysts are either free in the peritoneal cavity or attached to the pelvic sidewall, uterosacral ligament, or cul-de-sac. When attached to the sidewall, the cyst frequently proves to be an endometrioma. During mobilization of the cyst from the pelvic sidewall, chocolate-like hemosiderin-filled fluid will spill from the ovary (Figure 30.4.14). When this occurs, the ovary is completely mobilized to its hilum, using aquadissection and careful blunt dissection, to avoid unnecessary pelvic sidewall peritoneal damage. The endometrioma cyst wall is then excised (Figures 30.4.15 and 30.4.16). The cyst wall is usually fused to the ovarian cortex in the area of rupture during dissection or avulsion, that is, on the portion that was adherent to the pelvic sidewall or uterosacral ligament. A knife electrode at 70 W cutting current is

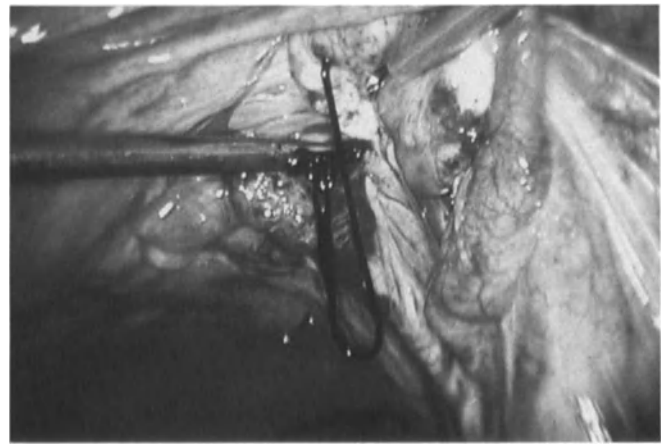

FIGURE 30.4.14. Small right ovarian endometrioma noted during mobilization of right ovary from right pelvic sidewall.

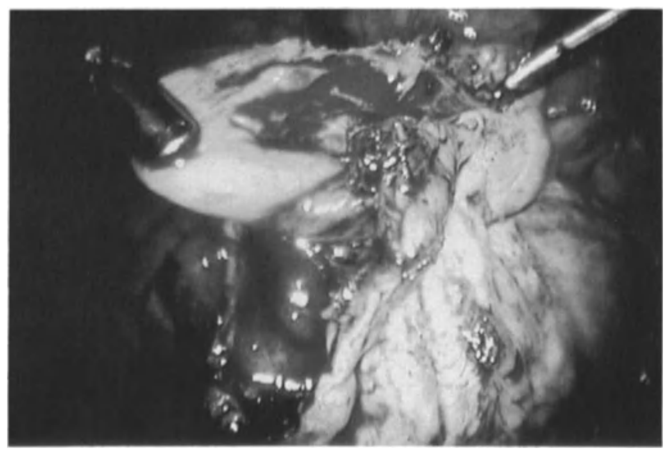

FIGURE 30.4.15. Endometrioma cyst wall excised from inside right ovary using two grasping forceps, one to stabilize the ovary and the other to pull the endometrioma out.

FIGURE 30.4.16. Endometrioma cyst wall evident near end of its excision from inside ovary.

used at the juncture of ovarian cortex and endometrioma cyst wall to develop a dissection plane in this firmly attached area. If visible and accessible, this incision is extended through the 360° opening. The cutting current will destroy endometriosis at the ovarian cortex-endometrioma junction while making a divot of separation between the two structures. Thereafter, biopsy forceps are placed on the ovarian cortex and endometrioma cyst wall and traction exerted to peel the endometrioma cyst wall from the ovary.[11] During dissection of cyst from cortex, much repositioning of the traction forceps is necessary, close to the cleavage plane. Either cyst or ovarian cortex is stripped, depending on which is easier. Minimal bleeding accompanies this type of procedure and usually stops spontaneously. Hemostasis is checked by underwater examination inside the ovary, and individual bleeders are identified using irrigation, and coagulated with microbipolar forceps. When the defect is large, the ovary is suture repaired to appose the edges of the ovary, usually with one purse-string suture, applied close to the utero-ovarian ligament in one direction, and the infundibulopelvic ligament in the other, or with one or two interrupted sutures.

If the ovary is free of the pelvic sidewall and viscera, a dermoid cyst or other benign neoplasm may be present. When a dermoid cyst is suspected, puncture drainage is avoided and an attempt is made to excise the cyst without spill. A superficial incision is made in the cortex with CO_2 laser. The incision is extended with scissors and undermined with a combination of scissors and aquadissection. If it is a functional cyst (follicle cyst or corpus luteum), its thin wall will usually rupture spontaneously. If the cyst is neoplastic, it will rarely rupture, and cystectomy without spillage can be accomplished. After locating the cleavage plane between the cyst wall and the ovarian cortex, the cortex is held with a toothed forceps and an aquadissector is inserted to instill pressurized fluid to separate the dermoid cyst from surrounding ovarian tissue. Laser and scissors are used to separate fibrous adherences, and a well-defined vascular bundle is coagulated with microbipolar forceps. Caution is constantly exercised to prevent puncturing the cyst wall. After excision of the intact cyst from inside the ovary, individual bleeders are identified using irrigation, and coagulated with microbipolar forceps or electrosurgical fulguration to obtain complete hemostasis. The ovarian edges usually reappose, and suturing is not required; large ovarian defects are suture repaired. The cyst is removed through the cul-de-sac using a laparoscopic culdotomy incision, made with electrosurgery or the CO_2 laser at high power to obtain at-large spot size (3 to 4 mm) for hemostatic cutting.[31]

The intact cyst is pushed out through the cul-de-sac or, if too large, it is aspirated vaginally using a 14-G needle on a needle extender attached to a 50-cc syringe, until it is small enough to pop out of the culdotomy incision. Thereafter, the culdotomy incision is closed with 2–0 Vicryl on a curved needle, vaginally or laparoscopically.

Alternatively, after laparoscopic culdotomy, an impermeable sack (LapSac; Cook Ob/Gyn) is inserted into the peritoneal cavity through the vagina. This 5 × 8-in. nylon bag has a polyurethane inner coating and a nylon drawstring. It is impermeable to water and dye. The free, intact specimen is placed in the bag, which is closed by pulling the drawstring. The drawstring is delivered through the vagina; the bag opened; and the intact specimen visually identified, decompressed, and removed[10] (Figure 30.4.10).

Dermoid cysts involve both ovaries in 10 to 15% of women. In most cases bilateral involvement, if present, will be evident on clinical examination. A normal opposite ovary with no identifiable tumor may be either left alone or cystic areas drained with the knife electrode.[32] Synchronous covert bilaterality of mature teratomas is not common and a visually normal contralateral ovary should not be routinely bivalved or wedge resected.

Acute Adnexal Torsion

Adnexal torsion is a rare cause of acute pelvic pain. Though torsion occurs most frequently if there is an adnexal lesion, healthy organs can twist.[33] The event can occur in the gravid or nongravid woman. Classically, management has been by laparotomy with excision of the afflicted organ without untwisting the pedicle. The rationale for this approach is to avoid the risk of embolization from the occluded ovarian venous plexus.[34]

Recently, it has been suggested that ovarian preservation can be achieved if early diagnosis is made before irreparable adnexal ischemia, and the pedicle is simply untwisted.[35,13] The torsed adnexa are untwisted using a blunt probe or aquadissector and grasping forceps. After complete unraveling of the tube and ovary, often involving multiple turns, the affected adnexa is observed to ensure viability of the involved structures, usually while additional surgical procedures are done. No special precautions are taken in pregnant patients other than avoiding the placement of an intrauterine manipulator. Early recourse to laparoscopy permits accurate diagnosis, and effective, safe ovarian conservation while limiting hospital stay and, hence, cost.

Tubo-Ovarian Abscess

The goals of managing acute tubo-ovarian abscess are prevention of infertility and the chronic sequela of infection including pelvic adhesions, hydrosalpinx, and pain, each of which may lead to further surgical intervention. The combination of laparoscopic treatment and effective intravenous antibiotics is a reasonable approach to the treatment of the total spectrum of PID, from acute salpingitis to ruptured tubo-ovarian abscess. Laparoscopic treatment is effective and economical. It offers the surgeon 100% accuracy of diagnosis, including the extent of tubo-ovarian involvement, while simultaneously accomplishing definitive treatment with a low complication rate. This approach allows tubo-ovarian conservation with subsequent fertility potential.

A woman presenting with lower abdominal pain and a palpable or possible pelvic mass should be examined with a laparoscope to determine the true diagnosis. The diagnosis of tubo-ovarian abscess is suspected in a woman with a recent or prior history of PID who has persistent pain and pelvic tenderness on examination. Fever and leukocytosis may not be present. Ultrasound examination frequently documents a tubo-ovarian complex or abscess. The importance of laparoscopy cannot be overstated: Even "obvious abscesses" may prove to be endometriomas, hemorrhagic corpus luteum cysts, or the result of a ruptured appendix. After presumptive diagnosis, hospitalization is arranged, either on the day of diagnosis or the following morning, with laparoscopy soon thereafter.

Intravenous antibiotics are initiated on admission, usually a few hours prior to laparoscopy, in order to gain adequate blood levels to combat transperitoneal absorption during the procedure. Cefoxitin 2 g IV q4h is frequently used from admission until discharge. Oral doxycycline is started on the first postoperative day and continued for 10 days following hospital discharge, usually on postoperative day 1 or 2. A single 1-g oral dose of azithromycin is given postoperatively, resulting in significant levels that are active against chlamydia infection persisting for a week or more in most tissues, including the endometrium and fallopian tubes.

At laparoscopy, either a blunt probe or an aquadissector is used to mobilize omentum, small bowel, rectosigmoid, and tubo-ovarian adhesions until the abscess cavity is entered. Purulent fluid is aspirated and inflammatory exudate excised with biopsy forceps. Afterward, aquadissection is performed by placing the tip of the aquadissector against the adhesive interface between bowel-adnexa, tube-ovary, or adnexa-pelvic sidewall, to develop a dissection plane that can be extended either bluntly or with more fluid pressure. When the dissection is completed, the abscess cavity (necrotic inflammatory exudate) is excised in pieces using a 5-mm biopsy forceps.[36–38]

The importance of peritoneal lavage cannot be overemphasized. The peritoneal cavity is extensively irrigated with Ringer's lactate solution until the effluent is clear per underwater exam. The total volume of irrigant often exceeds 20 L. At the close of each procedure, at least 2 L of Ringer's lactate is left in the peritoneal cavity.

Polycystic Ovaries

Surgical treatment of polycystic ovarian disease by laparotomy (ovarian wedge resection) is no longer done; a high incidence of ovarian adhesions resulted from these procedures as documented by second-look laparoscopy.[30,39] Recently, polycystic ovaries have been drilled laparoscopically using electrosurgery or laser.[40,41]

Polycystic/sclerocystic ovaries are usually enlarged with a smooth, thickened capsule, and without evidence of ovulatory stigma. Numerous 2- to 6-mm subcapsular follicular cysts are present with surrounding hyperplasia of the theca interna (stromal hyperthecosis). Following diagnosis by endocrine studies and vaginal ultrasound, women desiring present fertility should be treated with clomiphene citrate (CC), alone or in combination with dexamethasone, and if resistant, CC-hCG (human chorionic gonadotropin). When CC does not work, the patient is given the option of treatment with menotropins (Pergonal) or laparoscopic multiple cyst puncture.

At laparoscopy, multiple symmetrically placed holes are drilled over subcapsular follicle cysts and into the stroma. Small polycystic ovarian cysts do not bleed after incision like physiologic follicle cysts. Though studies have not been performed to determine the actual depth of penetration into the stroma using the various energy sources, cutting current electrosurgery at 30 to 60 W makes a precise focal incision extending into the stroma. Over 30 such incisions can be placed in each ovary. When using CO_2 or contact tip lasers, the surface puncture is much larger, limiting the number of cysts that can be drained, and increasing the surface thermal necrosis that may result in later adhesion formation. Depth of penetration may be important in this procedure to destroy functioning theca surrounding the small ovarian follicles. Cutting current electrosurgery penetrates deeply on its way back to the large return electrode. CO_2 laser energy vaporizes very superficially and may not destroy much stroma.

Laparoscopic drilling of polycystic ovaries is, at best, a temporary solution. Normal ovulatory cycles may result for a short time. Concern remains regarding the possibility of ovarian adhesions or premature menopause from thermal damage. Care should be taken to avoid ovarian disruption close to the tubo-ovarian ligament to preserve tubal fimbrial freedom.

De novo adhesion formation following this procedure has been described. The reported relative incidence ranges from 3 to 85%.[42,43] The degree of adhesion formation is significantly less than that following laparotomy ovarian wedge resection. Regardless, it is of concern that some degree of adhesion formation has been documented. These recent studies, though limited in terms of sample size, serve as an important reminder that surgical intervention of any kind can create, as well as correct, gynecologic pathology.

Conclusion

Most ovarian surgery can be performed using a laparoscopic approach. Continued advances in technique, instrumentation, and video magnification and definition will further expand surgical possibilities. No longer can the surgeon or the consumer ignore the benefits of minimally invasive surgery. While these techniques and procedures are not without risk, to deny their inherent advantages is impossible. In 1995, the onus should be on the gynecologic surgeon to prove that laparotomy results in better outcome than laparoscopy, not vice versa. Minimally invasive surgery is the future, and astute clinicians will work together to discern the most appropriate uses of this therapy.

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30.5
Ectopic Pregnancy

Harry Reich and Nicholas Kadar

Introduction

One in 66 pregnancies in the United States is an ectopic pregnancy. The success of laparoscopic management of ectopic pregnancy has been well documented (Table 30.5.1).[1–19] An ectopic pregnancy can be tubal (ampullary, isthmic, or infundibular), interstitial, angular, ovarian, cervical, or abdominal and can be present in more than one location or with an associated intrauterine pregnancy. It is usually located within the lumen of the ampullary tube (67%) or in its extraluminal space between serosa and muscularis-mucosa.[20] The ectopic pregnancy may be leaking small or large amounts of blood through the distal tubal ostium, may be in the process of rupturing, or frankly ruptured with varying degrees of intravascular volume compromise. Distal tubal abortion may be in progress or completed. The ectopic pregnancy may be viable, with fetal heartbeat noted on ultrasound, or dead with surrounding blood clot in various states of organization. The American Fertility Society has provided a classification scheme for tubal pregnancies (Figure 30.5.1.).

Various laparoscopic techniques can now be used to treat tubal ectopic pregnancy. With the use of sensitive radioimmunoassays for the β-subunit of human chorionic gonadotropin (β-hCG) and high-resolution ultrasonography, most tubal gestations are unruptured at diagnosis. Laparotomy with salpingectomy was the standard treatment of tubal pregnancy during this century, and may remain so for a few practitioners. Such laparotomy approaches are not addressed in this chapter. The relative merits of a conservative approach (salpingostomy or partial salpingectomy) versus radical treatment (salpingectomy or salpingo-oophorectomy) are discussed. Nonsurgical management is evaluated because of its potential as both an adjunct to laparoscopic surgery and as definitive therapy by itself.

Major advantages of the laparoscopic approach include reduced hospital stay, return to full activity within one week of surgery, and a reasonable subsequent intrauterine pregnancy rate. Average hospital stay for laparotomy management is 5.2 days, whereas a laparoscopic approach frequently results in hospitalization of less than 24 hours.[21] In addition, laparoscopy prevents drying of both the parietal and visceral peritoneum and limits the risk of infection, both of which may result in the reduction of postoperative adhesions commonly associated with laparotomy. Blood loss and cutaneous scarring associated with an abdominal incision are also avoided.

The term *salpingotomy* is used throughout this chapter to mean conservative removal of products of conception through an incision in the tube, whether the tube is later left open or reapproximated. Salpingotomy implies opening a fallopian tube by an incision, whereas salpingostomy, in most cases, infers making a new opening designed to remain open. Some authors use the term salpingostomy to mean that the tubal incision is left open, after evacuating its contents with closure later by secondary intention, and salpingotomy to imply primary surgical closure of the tube.

Following the 1980 report by Budowick and colleagues,[22] there was controversy regarding whether most tubal pregnancies grow inside the tube, or in the extraluminal loose adventitial tissue, between the tubal serosa and muscularis. An extraluminal location has rarely been reported by surgeons performing conservative procedures for tubal pregnancy, and it can be inferred that most tubal pregnancies grow inside the tube. The special problems associated with trophoblast growth in the extraluminal space are addressed.

Historical Review

Report of laparoscopic treatment using salpingectomy and salpingotomy are numerous. Manhes is generally recognized as the first to treat ectopic pregnancy using laparoscopy in 1970. By 1975, both Shapiro and Adler, and

TABLE 30.5.1. Reported success of laparoscopic salpingostomy for unruptured ectopic pregnancy and subsequent fertility, 1980 to 1992.

Study	Year	No. treated	No. of successful treatments	Tubal patency		Subsequent fertility		
				HSG*	Patent	No. included**	Pregnancy	Ectopic pregnancy
+Bruhat et al.[1]	1980	60	57	12	9	28	21	3
Daniell and Herbert[2]	1984	22	22	21	17	21	5	1
Pouly et al.[3]	1986	321	306			118	102	26
+Johns and Hardie[4]	1986	15	15	9	9			
DeCherney and Diamond[5]	1987	79	77			69	43	7
Bornstein et al.[6]	1987	16	16			4	3	2
Reich et al.[7]	1988	65	65	26	26	38	19	6
Brumsted et al.[8]	1988	10	9					
Silva[9]	1988	8	7			6	4	0
Vermesh et al.[10]	1989	30	26	20	16	18	10	1
Henderson[11]	1989	17	14					
Huber et al.[12]	1989	9	9	9	9			
Karsten and Seifert[13]	1990	12	12	6	6	12	3	1
Keckstein et al.[14]	1990	22	21	16	14			
Mecke et al.[15]	1991	251	236			143	83	23
Chapron et al.[16]	1991	63	55					
Verco[17]	1991	10	10					
Chapron et al.[18]	1992	26	25			11	8	1
Mottla et al.[19]	1992	5	5					
Total no. (%)		966	915 (94.7)	98	88 (89.8)	440	280 (63.6)	68 (24.3)

*HSG denotes hysterosalpingography, a method of documenting tubal patency.
**The number of women seeking to become pregnant.
+Excluded from totals as included in a subsequent cumulative report.

Soderstrom had described laparoscopic partial salpingectomy using electrocoagulation.[23,24] The credit for pioneering the laparoscopic treatment of ectopic pregnancy belongs to Professor Bruhat and his colleagues in France, who were the first to perform laparoscopic salpingotomy and fimbrial expression. During the 10-year period 1974 to 1984, they treated 321 cases of tubal pregnancy in 295 women endoscopically, and currently treat over 90% of tubal gestations this way. There were 15 failures (5%), that is, incomplete removal of trophoblast; seven were treated with a second laparoscopic procedure, and eight by laparotomy. Of 118 patients desiring pregnancy and followed for more than 12 months, 76 (64%) had an intrauterine pregnancy—five after laparoscopic treatment of a second ectopic pregnancy. Twenty-six (22%) had a subsequent ectopic pregnancy. More importantly, 53 of 62 women (86%) without a history of infertility and 23 of 56 (41%) with a history of infertility had an intrauterine pregnancy. Eleven of 24 women (46%) had an intrauterine pregnancy after removal of an ectopic gestation from their sole remaining tube, but seven (29%) in this group had a second ectopic pregnancy.[3]

One hundred cases of salpingectomy were reported by Dubuisson in 1987, using thermocoagulation and transection of the isthmus, mesosalpinx, and tubo-ovarian ligament. This included hemoperitoneum of more than 100 mL (12 cases), tubal rupture (32 cases), and an ampullary pregnancy > 3 cm in diameter (42 cases). Two laparotomies, one for severe adhesions and the other for a large retrouterine hematocele, were necessary. The average operating time was 37 minutes, with more recent procedures taking 15 to 40 minutes. Average postoperative stay was two days, and no immediate or delayed postoperative hemorrhage or fever occurred.[25]

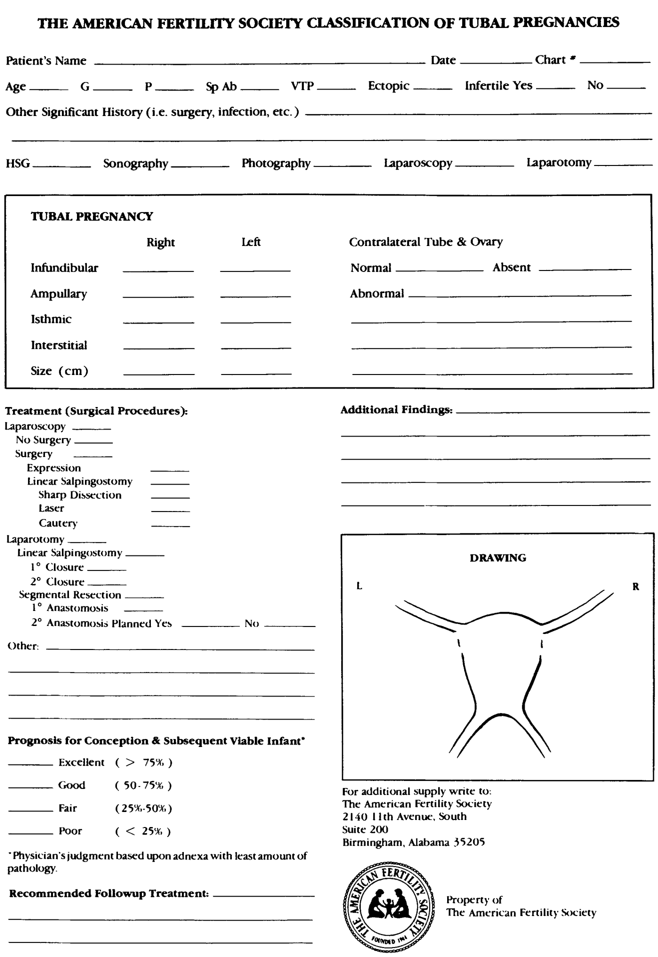
In the author's experience (Reich), 64 tubal pregnancies were managed laparoscopically, including 6 with rupture, 3 interstitial, and 1 ovarian pregnancy. Since 1983 laparoscopic procedures have been the author's only method of managing tubal pregnancy (last 61 cases).[7,21]

Diagnosis

Use of the hCG β-subunit assay to diagnose an ectopic pregnancy was first reported in the literature by Kosasa and colleagues in 1973. Utilizing a discrimination zone, the levels of hCG in every ectopic pregnancy were found to be lower than an intrauterine pregnancy of comparable gestation. A subsequent publication by Kosasa and coworkers showed that a small percentage of ectopic pregnancies could have hCG levels consistent with an intrauterine gestation, but that the rate of rise in every case was markedly slower than a normal pregnancy.[26,27]

A nonsurgical approach using serial β-hCG titers, combined with ultrasound, for the diagnosis of ectopic pregnancy was first described by Kadar in 1981.[28,29] Many minor variations of the original algorithm have been devised, but all involve the combined use of ultrasound and a sensitive hCG assay, and serial hCG testing in some patients. The value of serial hCG testing as originally described, although questioned by some, has been repeatedly validated,[30–32] and extended to cases with falling hCG values.[33]

Valid estimates and fiducial limits for the discriminatory zone have also been made for vaginal sonography.[34] The discriminatory hCG zone was described by Kadar and colleagues to aid in sonographic evaluation for ectopic pregnancy. The discriminatory zone is the hCG value above which the gestational sac of an intrauterine pregnancy can be imaged with ultrasound (6500 for abdominal and 3000 for vaginal). The diagnostic work-up that remains valid to this day is summarized (Figures 30.5.2 and 30.5.3). The underlying concept was that in normal pregnancies there must be an hCG concentration below which the gestational sac can never be imaged sonographically, a concentration above which it can always be identified, and an intervening zone when it can be imaged in some patients but not in others. In other words, the serum hCG concentration is used to determine whether the gestational sac of an intrauterine pregnancy should be detectable sonographically. Because the date of the last menstrual period is frequently uncertain or unreliable, the serum hCG provides a more reliable yardstick by which to interpret the ultrasonographic findings than gestational age. If the hCG concentration is above



THE AMERICAN FERTILITY SOCIETY CLASSIFICATION OF TUBAL PREGNANCIES

Patient's Name ______ Date ______ Chart * ______

Age ____ G ____ P ____ Sp Ab ____ VTP ____ Ectopic ____ Infertile Yes ____ No ____

Other Significant History (i.e. surgery, infection, etc.) ______

HSG ____ Sonography ____ Photography ____ Laparoscopy ____ Laparotomy ____

TUBAL PREGNANCY

	Right	Left	Contralateral Tube & Ovary
Infundibular	____	____	Normal ____ Absent ____
Ampullary	____	____	Abnormal ____
Isthmic	____	____	____
Interstitial	____	____	____
Size (cm)	____	____	____

Treatment (Surgical Procedures):
Laparoscopy ____
No Surgery ____
Surgery ____
Expression ____
Linear Salpingostomy ____
Sharp Dissection ____
Laser ____
Cautery ____
Laparotomy ____
Linear Salpingostomy ____
1° Closure ____
2° Closure ____
Segmental Resection ____
1° Anastomosis ____
2° Anastomosis Planned Yes ____ No ____
Other: ______

Additional Findings: ______

DRAWING
L R

Prognosis for Conception & Subsequent Viable Infant*
____ Excellent (> 75%)
____ Good (50-75%)
____ Fair (25%-50%)
____ Poor (< 25%)

*Physician's judgment based upon adnexa with least amount of pathology.

Recommended Followup Treatment: ______

For additional supply write to:
The American Fertility Society
2140 11th Avenue, South
Suite 200
Birmingham, Alabama 35205

Property of
The American Fertility Society

FIGURE 30.5.1. The American Fertility Society classification of tubal pregnancies. (From The American Fertility Society. The American Fertility Society classifications of adnexal adhesions, distal tubal occlusion, tubal occlusion secondary to tubal ligation, tubal pregnancies, Müllerian anomalies and intrauterine adhesions. *Fertil Steril* 1988;49:944–955. Reproduced with permission of the publisher, The American Fertility Society.)

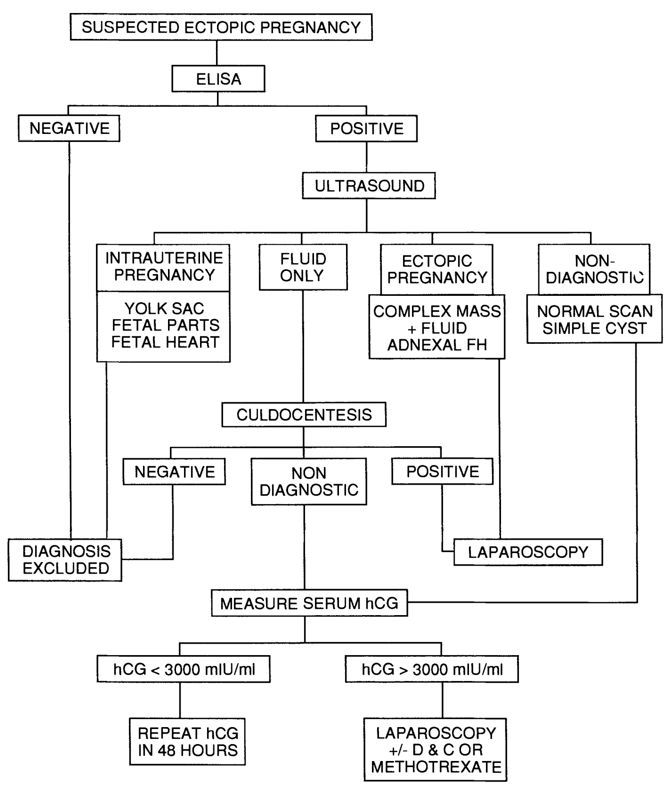


FIGURE 30.5.2. Diagnosis of ectopic pregnancy.

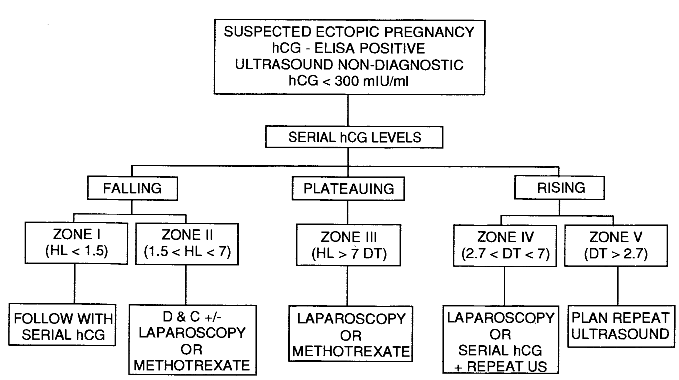


FIGURE 30.5.3. Serial hCG patterns in suspected ectopic pregnancy.

the discriminatory zone and a gestational sac cannot be imaged, this provides presumptive evidence for an ectopic pregnancy. However, if the serum hCG is below the discriminatory zone, failure to image a gestational sac is a nondiagnostic finding that may mean nothing more than that the intrauterine pregnancy is too early to be imaged sonographically. If an intrauterine pregnancy is imaged, this is taken to exclude an ectopic pregnancy because combined intrauterine and ectopic (heterotopic) pregnancies are very uncommon (except when ovulation induction with Pergonal has been used).[28]

Briefly, women of childbearing age complaining of abdominal pain or abnormal vaginal bleeding are examined and a urinary pregnancy test is performed. Urinary (ELISA) pregnancy tests are now sensitive enough for a negative result to exclude the diagnosis for practical purposes. If the pregnancy test is positive, a vaginal ultrasound is performed that will afford a definitive diagnosis of ectopic or intrauterine pregnancy in 50 to 70% of cases. If the ultrasound findings are nondiagnostic, and the patient clinically stable, the serum hCG concentration is measured by radioimmunoassay, and if the concentration is $> 3{,}000$ mIU/mL, a presumptive diagnosis of ectopic pregnancy is made. If the serum hCG concentration is $< 3{,}000$ mIU/mL, the serum hCG concentration is measured 48 hours later, and the doubling time or half-life of hCG calculated.

Fortunately, there is now only one hCG standard available, and all hCG assays are standardized against it. The standard, formerly called the International Reference Preparation (IRP or 1st-IRP) has been renamed the 3rd International Standard (3rd IS) by the World Health Organization.

Some have advocated algorithms based on a serum progesterone measurement instead.[35] The use of serum progesterone measurements had its origins in the observation by Radwanska and colleagues that the serum progesterone increased little during the first trimester of normal pregnancy, and that serum progesterone concentrations were lower in ectopic and aborting pregnancies than in normal intrauterine ones.[36] Thus, it appeared that an age-independent measurement was available in the first trimester that might be useful in differentiating normal and abnormal pregnancies. Rather implausibly, Mathews and colleagues[37] and Yeko and colleagues[38] subsequently suggested that ectopic and nonectopic gestations could be differentiated with 100% reliability on the basis of a single serum progesterone determination, an observation that has not withstood the test of time.[39–41] Although Stovall and colleagues still favor a diagnostic algorithm centered on a serum progesterone concentration, we have not found this to be useful in practice.[36,41,42]

Although it is true that normal intrauterine pregnancies have progesterone concentrations > 5 ng/mL, and ectopic pregnancies are rarely associated with serum progesterone concentrations > 25 ng/mL, most women with suspected ectopic pregnancies will have values between these extremes, and the progesterone level will add nothing but cost to the diagnostic work-up. Moreover, if the serum progesterone concentration is > 25 ng/mL, the serum hCG is almost always $> 3{,}000$ mIU/mL and vaginal ultrasound will be diagnostic of either an intrauterine or an ectopic pregnancy, and the progesterone concentration measurement adds nothing. Finally, although a serum progesterone concentration < 5 ng/mL establishes that a pregnancy is nonviable, failure to detect villi in a curettage specimen from these cases does not necessarily mean that an ectopic pregnancy is present, as has been suggested by the Tennessee group, nor do falling hCG levels necessarily signify an aborting intrauterine rather than a tubal pregnancy.[30] Thus, only a very small proportion of women with suspected ectopic pregnancies and nondiagnostic sonar findings will in fact have missed abortions associated with progesterone levels below 5 ng/mL and positive curettage specimens, and a correct diagnosis can be made in these patients without the serum progesterone value.

Selection of Therapy

The optimal surgical management of tubal pregnancies has been a matter for debate since the turn of this century, and remains so today. The debate originally centered on whether to save or remove the affected tube, and subsequently on what type of operation to perform, both if the tube was to be removed or conserved. The advent of laparoscopic surgery did little to resolve these questions because each type of operation can be performed laparoscopically just as well as by laparotomy. Rather, it increased controversy because added questions were raised about the safety and the efficacy of laparoscopic operations. Even before published data clearly established the advantages of laparoscopic surgery, however, the debate moved on to where it is today, focused on nonsurgical therapy.

Compounding the plethora of treatment options available has been the inability to interpret the results obtained with different operations, because pregnancy rates after surgery (both tubal and intrauterine) have rarely been adjusted for the many other factors besides treatment that affect outcome following the treatment of a tubal pregnancy. It is, therefore, hardly surprising that identical operations yielded statistics as disparate as, for example, live birth rates of 100 and 50%, and recurrent ectopic pregnancy rates of 0 and 20%.[43,44]

Despite these uncertainties, a number of procedures were, with justification, consigned to the dustbin of surgical history. They include resection of the ampulla, cornual resection at the time of salpingectomy, salpingo-oophorectomy, and, under most circumstances, "milking" of the tube. It also became apparent, doubtless to the silent relief of laparoscopists, that salpingotomy incisions did not require closure, and that salpingotomy yielded results comparable to segmental tubal resection, except perhaps in the case of isthmic pregnancies. Thus, one was essentially left with a choice between salpingectomy and salpingotomy, a choice that simply took one back to the original debate over the relative merits of conservative and ablative operations.

Salpingotomy Versus Salpingectomy

Despite little conclusive support from published data, it is now widely accepted that a conservative operation is almost always to be preferred over an ablative one for women who are desirous of future childbearing. It is not our intention to try to resolve this controversy, which has been with us for almost a century, because it is impossible to settle it dispassionately with the evidence at hand. Suffice it to say that despite incontrovertible evidence that salpingotomy can restore the reproductive function of an oviduct after a tubal pregnancy, and that repeat ectopic pregnancies are distributed with equal frequency between the conserved tubes and the contralateral ones, it does not follow that preservation of the tube, when the patient has another functional one, will increase her chance of bearing a living child without increasing her risk of having another ectopic pregnancy.[45] In fact, most case series show no indication that tubal conservation increases subsequent live birth rates,[46–49] and many show it to be associated with a trend towards higher recurrent ectopic pregnancy rates. It is also incontestible that complications (hemorrhage, persistent trophoblast), however few, are more frequent after salpingotomy than after salpingectomy, which makes salpingotomy contraindicated in women who do not wish to bear more children. Despite these uncertainties, however, solid indications for salpingotomy can be identified, as discussed more fully elsewhere.[45]

Tubal conservation is clearly indicated if the pregnancy is located in a woman's only remaining tube, or if the contralateral tube is blocked. The procedure is about three times more likely to result in a live birth than *in vitro* fertilization, and if conception occurs, a term pregnancy is at least twice as likely as an ectopic pregnancy. Tubal conservation is contraindicated if the contralateral tube and ovary appear to be normal and patent on intraoperative chromotubation but the gravid tube shows evidence of pre-existing disease, or has been operated on before, either for a previous ectopic pregnancy or blockage. When both tubes show evidence of prior disease, the decision to conserve the gravid tube when it has been operated upon previously, or when it appears to have been damaged much more than the opposite one, is not an easy one, and has to be made on an individual basis, using as a guide the extent to which the gravid tube has been damaged, both in absolute terms (amount of scarring, mobility, and length), and relative to the other side.

If the contralateral adnexa appears to be completely normal and patent at intraoperative chromotubation, the case for tubal conservation is not very compelling. Those who favor salpingotomy argue that if a salpingectomy is performed and an ectopic pregnancy recurs, the opportunity to save what is then the only remaining tube may not present itself. This is the strongest argument justifying salpingotomy under these circumstances, but it is a weak one, since this eventuality is likely to occur in $< 5\%$ of cases after salpingectomy. It has also been argued that intraoperative chromotubation is unreliable and that a normal-appearing tube may nonetheless be diseased. However, the problem with chromotubation is that a patent tube may appear blocked (usually because blood or decidua occlude the cornua), and patency on intraoperative chromotubation is clearly a valid finding. The case against salpingotomy is that when the contralateral tube and ovary are normal, even the most favorable results obtained show no increase in the subsequent live birth rate, but tubal conservation probably does increase the recurrent tubal pregnancy rate even if only by about 5%. The risk of early and late postoperative hemorrhage is also greater.

Based on the available information, one can legitimately adopt either a conservative or an ablative operation in the presence of a normal contralateral adnexa. For example, if the pregnancy in the tube is small and unruptured and shells out easily at salpingotomy without bleeding, the tube should almost certainly be conserved. However, if there is a large ruptured tubal pregnancy present, or after attempting a salpingotomy there is persistent bleeding from the tube, one should have a much lower "threshold" for removing the gravid tube, if the contralateral adnexa are normal, than if the affected tube is the patient's only oviduct or if the contralateral adnexa is severely diseased.

Salpingotomy Versus Segmental Resection

Segmental tubal resection or partial salpingectomy is the procedure of choice whenever a gravid oviduct is to be conserved, but its wall is ruptured or there is persistent or uncontrollable bleeding from the tube, following salpingotomy. Although segmental resection with primary or delayed anastomosis has been advocated for the treatment of all tubal pregnancies on the grounds that salpingotomy conserves what is an abnormal implantation site, there is no evidence that better results are obtained by resecting the implantation site than by salpingotomy. Salpingotomy, therefore, remains the conservative operation of choice for tubal pregnancies.

There is persuasive evidence that the reproductive performance of women following conservative surgery for a tubal pregnancy is worse if the pregnancy is located in the isthmus rather than the ampulla. Hallatt stated, without giving figures, that the intrauterine-to-ectopic pregnancy ratio after conservative surgery was about four times higher when the pregnancy was located in the ampulla as opposed to the isthmus.[50]

Ectopic pregnancy in the isthmic portion of the fallopian tube is uncommon. Twenty-two isthmic tubal pregnancies were treated by laparoscopic salpingotomy in Pouly and colleagues' 1986 report of 118 women with a tubal pregnancy who desired future fertility; 12 of these women later had intrauterine pregnancies (54.5%), and 8 had a repeat ectopic pregnancy (36.4%). Their intrauterine pregnancy rates following laparoscopic salpingotomy were 64 out of 96 (67%) for ampullary pregnancies, and 12 out of 22 (55%) for isthmic pregnancies. The recurrent tubal pregnancy rates were 18 out of 96 (19%) and 8 out of 22 (36%), respectively.

Whether the reproductive performance of women with isthmic pregnancies is any better following segmental tubal resection than after salpingotomy remains, however, far from clear. DeCherney and Boyers have argued strongly that it is, but their argument is based on rather meager evidence. In a retrospective audit, they found that three of four women with unruptured isthmic pregnancies who were treated by salpingotomy had tubal occlusion on hysterosalpingography and none conceived, whereas three of six women who were treated by segmental resection and delayed anastomosis delivered live infants. One of six women so treated had a recurrent tubal pregnancy.[51] However, these authors' dismal experience with salpingotomy in isthmic pregnancies was not reflected in the results obtained by Pouly and colleagues[3] with laparoscopic salpingotomy or in a subsequent, randomized, prospective clinical study reported by Smith and colleagues.[52]

Smith and coworkers reported one year's experience at Grady Memorial Hospital, Atlanta, GA, with 20 isthmic ectopic pregnancies. These authors randomly allocated the treatment of women with unruptured isthmic pregnancies to segmental resection and anastomosis (four cases) or to salpingotomy (nine cases). [Some patients randomized to segmental resection in fact had a salpingotomy if a tubal surgeon was not available, and women with ruptured isthmic pregnancies were treated by segmental tubal resection alone (seven cases)]. All four tubes that were primarily anastomosed following segmental resection were patent on subsequent HSG, and one of the two women who were actively trying to conceive had an intrauterine pregnancy. Four of the nine women treated with salpingotomy, including one women with contralateral tubal occlusion, subsequently had intrauterine pregnancies (two having delivered at the time of the report), while five were using contraception. Patency of the involved fallopian tube was demonstrated in five of the six patients who had postoperative hysterosalpingography; the sixth had isthmic patency but a hydrosalpinx.[52]

Because the number of patients studied was so small, no meaning can be attached to the lack of statistical significance between the differences in outcome in the different treatment groups. Nonetheless, in as much as all women who tried to become pregnant after salpingotomy conceived intrauterine pregnancies, the results provide a striking contrast to those reported by DeCherney and Boyers.[51]

In the series of 109 consecutive tubal pregnancies compiled by Reich and colleagues, there were 9 isthmic tubal pregnancies; 6 were treated by partial salpingectomy and 3 by salpingotomy. No subsequent pregnancy has occurred in either group. A future laparotomy for microsurgical tubal anastomosis is always necessary following laparoscopic partial tubal resection, if a solitary tube is present.[7] This procedure may possibly be avoided by a salpingotomy. The optimal treatment of unruptured isthmic pregnancies must, therefore, be considered subjective because the available data do not provide compelling evidence for treating women with isthmic and ampullary pregnancies differently. Because salpingotomy is a much simpler operation, it should still be regarded as the operation of choice.

Laparoscopic Versus Abdominal Salpingotomy

Despite early skepticism, abundant data, including some from randomized trials, demonstrates that compared with the open operation, laparoscopic salpingotomy is associated with shorter hospital stay, a shorter postoperative convalescence, and a reduced requirement for analgesia after surgery, as well as less postoperative adhesion formation.[8,10,53,54] Live birth rates are similar, but the recurrent ectopic pregnancy rate, surprisingly enough, tends to be lower for reasons that are unclear.[10,45]

The only absolute contraindication to laparoscopy is a hemodynamically unstable patient. Initially, the procedure was considered applicable to a very select group of patients (unruptured ampullary pregnancies < 3 cm in size, an otherwise normal pelvis and contralateral tube) but Reich and colleagues[7] were among the first to show that virtually all tubal pregnancies could be managed endoscopically unless the patient was hemodynamically unstable.

Laparoscopic Versus Nonsurgical Therapy

Although the nonsurgical management of ectopic pregnancies is feasible and safe, the selection criteria used for medical management have been ill-defined and variable. Two aspects of nonsurgical therapy have become fairly well established: (1) conservative therapy is ill-advised if a heartbeat is detected ultrasonographically; and (2) intratubal injection of chemotherapeutic agents is associated with an unacceptably high failure rate. It has been known for a long time that some tubal pregnancies resorb spontaneously without treatment, and observation alone, with no active intervention can be an appropriate way to manage women with ectopic pregnancies who have minimal symptoms, hCG concentrations $< 1,000$ mIU/mL, and falling hCG levels (half-life < 1.5 days).[55] The type of patient who goes on to have a chronic ectopic pregnancy needs to be better defined, however.

Women have relatively small (< 3 cm) unruptured pregnancies can also be managed with a single, intramuscular dose of methotrexate 50 mg/m^2, provided a heartbeat cannot be detected on ultrasound, a hemoperitoneum (fluid) is not present, and serum hCG levels are increasing subnormally (doubling time > 2.7 days), and preferably plateauing.[55] Carson and Buster recently compiled published statistics pertaining to the medical management of tubal pregnancies, and found that the tubal patency rate among those tested (about a third of the total treated) was 81%, the live birth rate was 71%, and 11% had recurrent ectopic pregnancies.[35] In as much as women treated nonsurgically are highly selected, the temptation to compare these figures with those obtained by surgery should be resisted.

Equipment

Laparoscopic electrosurgical techniques are ideally suited for tubal pregnancy surgery. Bipolar forceps, that permit high-frequency low-voltage current (25 to 50 W) to be passed through its jaws, are used for desiccation of the proximal tube, its mesosalpinx, and in rare cases, both the infundibulopelvic ligament with enclosed ovarian vessels and the utero-ovarian ligament.[56]

A knife electrode is an excellent instrument for opening a fallopian tube with a salpingotomy incision. The tips of laparoscopic scissors can be used in a similar fashion, as can the CO_2 laser. The knife electrode is connected to a low-voltage electrosurgical generator, and unipolar cutting current (40 to 80 W) is used. Pure cutting current is critical, both for precision and to minimize the low-grade thermal coagulation zone in surrounding tissue. Coagulation current is used only for fulgurating specific blood vessels or hemorrhagic ovarian cysts.

Throughout most laparoscopic procedures, a suction-irrigator-dissector is essential to evacuate smoke, remove clots, retract, atraumatically elevate the tube or ovary, irrigate the tube and cul-de-sac, and develop surgical planes (aquadissection). The Aquapurator with a solid distal tip made by WISAP (Sauerlach, Germany) fits this requirement. Viable products of conception, without surrounding organized blood clots, can often be evacuated completely from a fallopian tube using a suction-irrigator; trophoblastic tissue with surrounding blood clots can be irrigated out of the tubal lumen using the hydraulic pressure of the fluid irrigant.

A laser beam can be used to open the tube and perform a laparoscopic culdotomy. However, the laser is often not practical for nonscheduled (emergency) surgery in most hospitals. The insurance policies of many hospitals mandate that a separate "laser nurse" be present for laser surgery, in addition to the necessary scrub and circulating nurses, often an impossibility in the middle of the night.

Basic Techniques

All operations are performed under general anesthesia with endotracheal intubation. Steep Trendelenburg position (30°) is helpful as is a high-flow CO_2 insufflator capable of delivering CO_2 at 10 L/min. Hysteroscopy using CO_2 is usually performed at the same time as peritoneal insufflation, when the diagnosis is not in doubt, followed by insertion of a Valtchev manipulator into the uterus for tubal lavage and uterine manipulation. A 10-mm laparoscope is inserted through a vertical intraumbilical incision, and lower quadrant 5-mm puncture sites are made just below the pubic hairline and lateral to the inferior epigastric vessels. The aquadissector, the "workhorse instrument" in most cases is placed on a sterile table behind the surgeon and connected by tubing to wall suction and to a pressurized source of Ringer's lactate irrigant. The tubing of the aquadissector, which is manipulated with the surgeon's left hand, would frequently kink when stretched across the abdomen to a right-sided abdominal puncture site. It is important for the operator to be consistent with incisions, regardless of the pathology involved. Consistency results in a reproducible procedure with resultant reduction in intraoperative decision making.

A video camera with or without beam splitter attached to the laparoscope permits much of the procedure to be performed with the surgeon watching a video monitor. Devices can be used to stabilize the laparoscopic trocar sleeve, allowing the surgeon to operate with two hands, each on a lower-quadrant instrument.

Any adhesions on the contralateral tube are usually treated during the same laparoscopic procedure. At the close of each procedure, excess CO_2 is expelled and 2 L of Ringer's lactate left in the peritoneal cavity to separate visceral surfaces during early healing. Postoperatively, Rh immunoglobulin (RhIg) is administered to unsensitized Rh-negative patients with an ectopic pregnancy (50 μg RhIg is usually adequate to prevent sensitization). To document successful treatment, quantitative β-hCG titers are obtained weekly until negative.

Evacuation of Hemoperitoneum

Usually the suction-irrigator is sufficient to evacuate the hemoperitoneum, including large clots that may require much manipulation and clearing of the instrument. In cases of tubal rupture, the patient may be unstable and hemoperitoneum and clots may be excessive. For these cases, it is best to insert an 11-mm left lower quadrant trocar (similar to the umbilical trocar) and thread the wall suction tubing directly through it (seamless surgical connecting tubing with an internal diameter of 0.25 in.). Wells Johnson Co. (Tucson, AZ) aspiration tubing, with an internal diameter of 0.281 in., can also be attached just above the trumpet valve of an 11-mm trumpet-valved trocar sleeve. By aspirating the larger clots directly, one can avoid obstructing the suction-irrigation device. Visualization of the site of rupture or active bleeding can thus be rapidly obtained and treatment initiated. If prompt control is unattainable, immediate laparotomy should be considered.

Laparoscopic Salpingectomy

Laparoscopic salpingectomy is the method of choice when future fertility is not desired or in cases of rupture. Tubal pregnancy after sterilization failure, in a blind ending distal tubal segment after partial salpingectomy, in a previously reconstructed tube, requested sterilization, hemorrhage following salpingotomy, and chronic tubal pregnancy all may fall into this category.

Following evacuation of hemoperitoneum, Kleppinger bipolar forceps and laparoscopic hook scissors are introduced successively to desiccate and cut the tube and its mesosalpinx. Bipolar continuous sinusoidal wave current (cutting) at 25 W should be used. An end point monitor is essential to indicate the completion of desiccation and avoid char sticking to the forceps as carbonization occurs thereafter. An Endoloop ligature (Ethicon, Somerville, NJ) can also be used around the distended tube to perform salpingectomy safely.

The segment of tube with its enclosed ectopic pregnancy is then removed from the peritoneal cavity through the 11-mm umbilical trocar sleeve, using forceps placed through the operating port of a right angle operating laparoscope. The laparoscope, forceps, sleeve, and the portion of the tube within the trocar sleeve are removed in one motion, resulting in either complete removal of the tube or removal of a portion of tube, which can then be grasped with a hemostat and teased out through the umbilical incision. The laparoscope and sleeve are reinserted and final inspection performed. Removal of a tube in this manner may result in a "milking" process, leaving products of conception extruded from the tube as it is being pulled through the trocar sleeve in the peritoneal cavity; there they can be removed with the aquadissector or biopsy forceps. Salpingotomy (ampullotomy), with aspiration of the products of conception, reduces its volume before extraction of the tube through the umbilical trocar sleeve, and thus prevents a "milking" effect.

The umbilical extension technique developed by the author is a better method for removal of tubes containing products of conception from the peritoneal cavity. The umbilical incision is always made inside the umbilicus, overlying the area where skin, deep fascia, and parietal peritoneum of the anterior abdominal wall meet. This incision can be enlarged using the operating laparoscope with scissors in the operating channel. The tip of the laparoscope is placed 1 cm from the tip of the trocar sleeve, which is then gently removed from the peritoneal cavity. The peritoneum is first visualized and can then be incised downward in the midline with the scissors in the operating channel of the operating laparoscope. Next, deep fascia is identified and incised to add another 1 to 2 cm to the incision. Finally, the skin incision inside the umbilicus can be extended upward to incorporate the superior wall of the umbilical fossa.[57]

The products of conception can also be removed through a lower quadrant 5- or 11-mm trocar sleeve. Alternatively, a culdotomy can be made using laparoscopic techniques: a sponge at the end of a ring forceps is placed just behind the cervix to identify the posterior cul-de-sac. A second sponge or probe is placed in the rectum and then removed; this step confirms the anatomic relation of the rectum to the posterior vagina and thus serves to identify any abnormal tenting of the rectum in this area. A 2- to 3-mm spot size CO_2 laser beam with power set at 60 to 100 W continuous is then directed through the laser laparoscope to make a transverse culdotomy incision directly over the posterior fornix sponge. Alternately, a spoon electrode at 150 W cutting current can be employed. Thereafter the usually large tubal pregnancy can be pushed through the incision made from above, or pulled through from below either with laparoscopic biopsy forceps, ring forceps, or the surgeon's fingers, all under direct visualization.

Laparoscopic Partial Salpingectomy (Midtube Resection)

Laparoscopic partial salpingectomy can be performed for salpingotomy failure, ruptured tubal pregnancy, isthmic ectopic pregnancy, distal interstitial ectopic pregnancy, chronic tubal pregnancy, and same-side recurrent tubal pregnancy. Kleppinger bipolar forceps are used to coagulate the tube on each side of the distention made by the tubal pregnancy. The resultant desiccated areas are then divided with laparoscopic hook scissors. The mesosalpinx supplying the involved tubal segment is next coagulated and divided, and the tube segment removed from the peritoneal cavity through the 11-mm umbilical trocar sleeve or by laparoscopic culdotomy.

With another technique, a Roeder loop ligature (Endoloop, Ethicon) can be placed around the tube segment with its enclosed ectopic pregnancy. This loop is inserted into a special applicator and introduced into the pelvis through the 5-mm trocar sleeve. The tube and its mesosalpinx are divided with laparoscopic scissors. Should the Endoloop ligature slip, the pedicle can always be regrasped and either another Endoloop ligature placed or complete hemostasis obtained using bipolar forceps.

Laparoscopic Salpingotomy (Figures 30.5.4–30.5.15)

Tubal preservation should be attempted in all cases of tubal pregnancy surgery where future fertility may be desired, vital signs are stable, and gross rupture is not evident. Salpingotomy is the procedure of choice for tubal preservation and can be performed easily, quickly, and safely. It is faster than partial salpingectomy with imme-

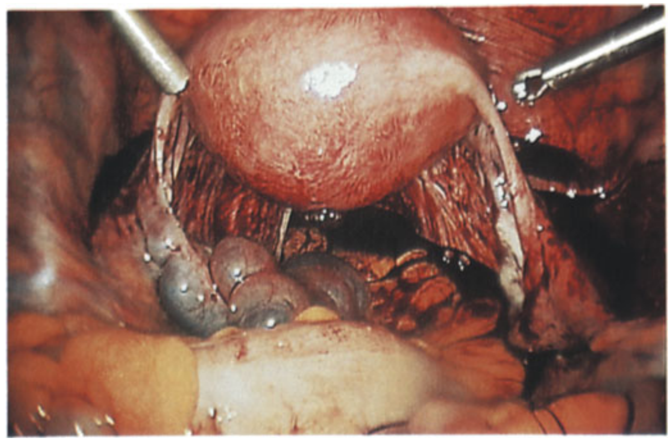


FIGURE 30.5.6. Right-sided 5-mm trocar sleeve has been inserted. Hemoperitoneum is aspirated with aquadissector from the left side.

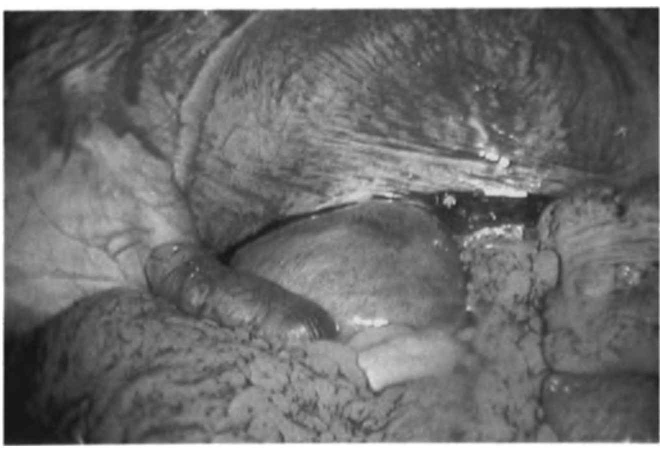


FIGURE 30.5.4. Left tubal pregnancy seen with surrounding hemoperitoneum.

FIGURE 30.5.7. Ectopic pregnancy occupies ampulla of left tube and can be seen distending the tubal serosa, indicating a probable extraluminal location between tube serosa and muscularis.

FIGURE 30.5.5. Trendelenburg position exposes uterus, tubes, and ovaries. Left-sided 5-mm trocar is inserted lateral to the rectus muscle.

FIGURE 30.5.8. Left tube is stabilized and thinnest portion of serosa noted.

FIGURE 30.5.9. Scissors are used to open thinned-out tubal serosa.

FIGURE 30.5.10. Aquadissector is inserted into salpingotomy incision in tubal serosa and used to flush out the ectopic.

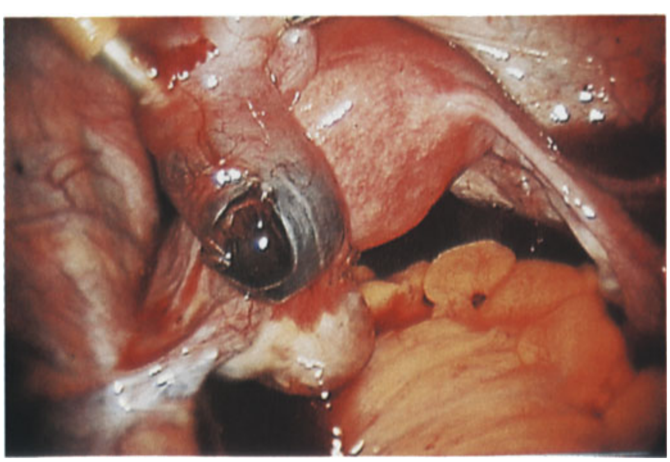


FIGURE 30.5.11. Fluid under pressure creates a second opening in another markedly thinned-out portion of the tube through which the products of conception will be extruded.

FIGURE 30.5.12. Intact products of conception noted after being flushed out of tube.

FIGURE 30.5.13. Microbipolar forceps are used to obtain hemostasis at the original salpingotomy incision.

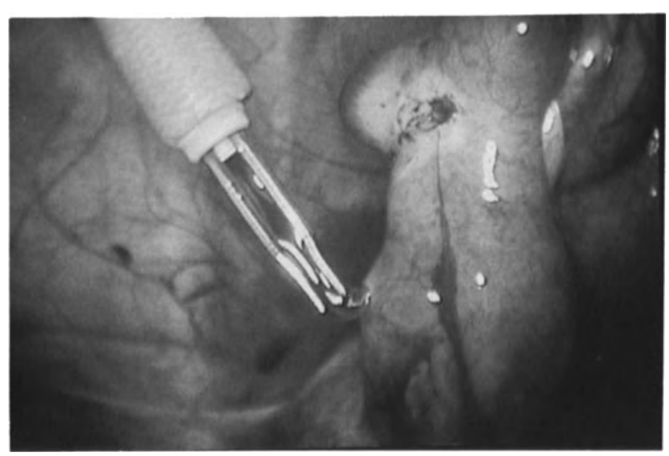


FIGURE 30.5.14. Hemostasis is complete at salpingotomy site.

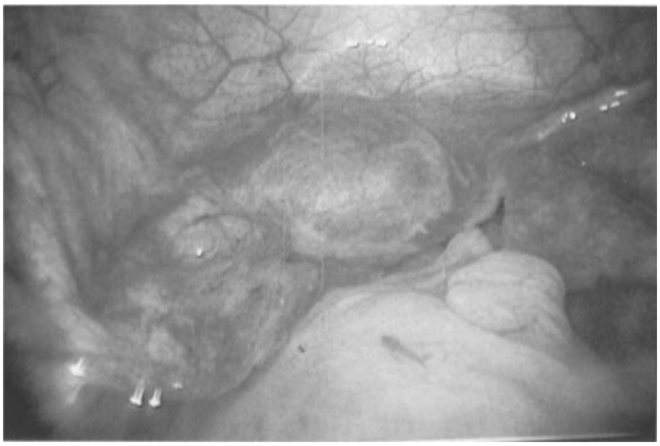


FIGURE 30.5.15. Underwater examination confirms complete hemostasis of the tube that lies free in the pelvis. All blood clot and blood products have been irrigated from the peritoneal cavity until the effluent is clear.

diate anastomosis and more economical than partial salpingectomy with delayed anastomosis, as it saves the patient a future laparotomy. As most tubal pregnancies occur in the ampulla, isthmic tubal pregnancies are addressed separately, as is the rare ampullary tubal pregnancy whose main component is in the extraluminal space.

Following evacuation of the hemoperitoneum, the tubo-ovarian complex is mobilized, usually with the aid of the aquadissector. In many cases a "phlegmon" of tube-ovary exists that should be separated using the aquadissector. The knife electrode is used to make a 1- to 2-cm incision in the antimesenteric border over the point of maximal tubal dilatation using cutting current (50 to 80 W). Alternatively, scissors or the CO_2 laser at 25 to 35 W super-pulse can be used. Tubal layers can often be identified, that is, serosa followed by stretched out muscularis-mucosa, prior to entering the tubal lumen. On occasion, a blood clot can be expressed from the extraluminal space prior to separately opening the muscularis-mucosa.

Often, following salpingotomy incision, products of conception begin to extrude. At this point, the aquadissector is used to suction loose, friable products of conception that may be present with viable ectopic pregnancies. In other cases, where a blood clot has formed firmly around the products of conception, irrigation from the aquadissector can be used to mobilize the clot with its enclosed gestational tissue. On occasion, it is necessary to insert atraumatic grasping forceps into the tube to mobilize the products of conception with a spreading motion prior to using the aquadissector to effect expulsion. These same forceps are also used to check the inside of the tube after evacuation. Finally, toothed biopsy forceps are necessary in some cases to grasp and tease out products of conception closely adherent to the tubal wall. Removal of the products of conception from the peritoneal cavity is accomplished as previously described, using the 11-mm umbilical trocar sleeve and the operating laparoscope with enclosed biopsy forceps. At times, the products of conception can be reduced to smaller pieces, using biopsy forceps and the aquadissector.

The tube is then irrigated both distally with the aquadissector and proximally through a cervical Cohen cannula. The salpingotomy is usually left open. If the defect is large or marked eversion of mucosa occurs, a 4–0 Vicryl or polydioxanone suture (PDS:Ethicon Z-420) can be placed and tied either with instruments inside the peritoneal cavity or outside the peritoneal cavity with half hitches that are pushed to the tube.[58] Should bleeding from the tubal edge or implantation site be present following evacuation of the products of conception, compression with grasping forceps should be attempted prior to resorting to either electrosurgical coagulation, laser, or a suture. Frequently, five minutes of pressure at the salpingotomy edge results in complete hemostasis. In other instances, lifting the adnexa (tube-ovary) above the pelvic brim—in effect kinking the mesosalpingeal vessels—yields a similar result.

If uncontrollable hemorrhage occurs during evacuation of the ampulla, the ampulla can be loosely ligated with an Endoloop as described by Semm.[59] The cul-de-sac and the subphrenic space are irrigated and evacuated. After 5 to 10 minutes, the ligature is released. In most cases the bleeding subsides. If not, selected areas in the mesosalpinx can be suture ligated; or if the contralateral tube appears normal, salpingectomy or partial salpingectomy can be performed as previously described.

The mesosalpinx can be infiltrated with a dilute vasopressin solution before salpingotomy (Pitressin; Parke Davis, Morris Plains, NJ) as first described by Bruhat's group.[1] A mixture of 20 units (one ampule) in 50 mL of normal saline works well, though more dilute or more concentrated solutions may be used. A 5-mm injection and puncture cannula can be used through the lower quadrant trocar sleeves. Alternatively, a 22-gauge spinal needle can be inserted directly through the skin at the pubic hairline level, usually just lateral to the inferior epigastric vessels. Care must be taken at initial insertion into the mesosalpinx to avoid direct injection into the blood vessels by gently puncturing the serosa prior to infiltration of the solution. Thereafter 10 to 20 mL of the solution can be infiltrated, which should cause a grossly visible swelling in the mesosalpinx.

The pharmacologic effect of vasopressin persists for approximately two hours and is probably sufficient to allow physiologic hemostasis to occur. Great care is necessary during penetration of the mesosalpingeal peritoneum to avoid vessel laceration or intravascular injection, which can cause arterial hypertension. Extravascular injection itself can induce a moderate increase in the arterial blood pressure or a moderate bradycardia. Complications from vasopressin have been reported, and both Bruhat's group and this author no longer use it during laparoscopic procedures.

Fimbrial Evacuation of Tubal Pregnancy

Fimbrial evacuation, tubal aspiration without salpingotomy, and tubal abortion without salpingotomy all refer to the technique of removing products of conception at or near the fimbrial end of the tube using either suction or grasping forceps and, on occasion, using grasping forceps to gently push the products of conception toward the fimbrial end. In some cases tubal abortion is already in progress.

Of 15 failures (incomplete removal of trophoblast) among 321 tubal pregnancies treated by Bruhat and colleagues, 4 occurred in the tubal abortion group.[3] In Bruhat and colleagues' 1980 report of 60 tubal pregnancies,[1] 3 failures were noted following 17 cases of tubal aspiration. Nevertheless, the same group in 1986 reported 15 fimbrial tubal pregnancies occurring in 118 patients desiring future fertility: 12 of the women had subsequent intrauterine pregnancies (80%), and three had recurrent ectopic pregnancies (20%).[3]

Concern regarding incomplete removal of trophoblast and increased tubal damage has resulted in the condemnation of fimbrial evacuation of a tubal pregnancy using either laparoscopic or laparotomy techniques, especially following Budowick's study (1980) implying that most tubal pregnancies occur in the extraluminal space.[22] The findings of Sherman and colleagues may encourage the laparoscopic surgeon to reconsider this method. Through a laparotomy series, Sherman's group successfully expressed 31 unruptured tubal gestations through the fimbriated end of the tube. Of 27 women followed for more than three years, 25 later conceived, resulting in 23 term pregnancies, two spontaneous abortions, and no repeat ectopic pregnancies.[60]

If most ampullary tubal pregnancies rapidly invade the tubal wall and grow in the loose connective tissue between mucosa and serosa, milking the ectopic pregnancy out of the fimbria would cause further tubal destruction. We have not seen a high incidence of extraluminal tubal pregnancies and have treated 8 of our last 18 tubal pregnancies by "aqua-expression." With this technique, in selected cases of nonviable intraluminal ampullary ectopic pregnancy, the tip of the aquadissector is inserted through the open end of the affected tube into the ampulla. Fluid under pressure is used to dislodge and expel the intraluminal products of conception with surrounding blood clot (a tubal cast) without a salpingotomy incision. They can be aspirated from the peritoneal cavity. There were no intraoperative or postoperative complications. β-hCG titers were in the nonpregnant range two weeks postsurgery in all cases.[61]

hCG Monitoring Following Conservative Surgery

Several, tacit assumptions underlie the policy of screening for residual trophoblastic activity following conservative surgery for tubal pregnancy. The first assumption is that in the absence of residual functioning trophoblast, the serum hCG will fall unabatedly and in a predictable manner. The second assumption is that a period of renewed trophoblastic growth is required for symptoms to develop. The third assumption is that during this preclinical stage, renewed trophoblastic growth will manifest itself first by a delayed rate of fall in the serum hCG levels, and eventually by rising serum hCG values.

Vermesh and colleagues described the use of serial postoperative hCG and progesterone measurements following the conservative operative treatment of tubal pregnancies. They found that even in patients with persistent trophoblastic activity, hCG levels fell precipitously in the early postoperative period, reaching 13 to 25% of the baseline value by three days after surgery, and 6 to 25% by six days. Thereafter, the serum hCG between the "persistent ectopic" and the "resolved ectopic" groups diverged, there being no overlap at all between the groups by the 12th postoperative day. However, the definition of persistent trophoblastic activity was not made totally clear in the paper in as much as two out of six patients with this diagnosis had continually decreasing hCG values, and were managed by simple observation.[62]

"Normal" limits for the rate of hCG clearance are difficult to define because the dynamics of hCG clearance are rather complex, involving at least two half-lives (an initial half-life of 5 to 6 hours, and a second, slower one of 11 to 38 hours). The between patient variation in the rate of hCG clearance is also large. Part of the reason may be that, unless a pregnancy is terminated by salpingectomy or hysterectomy, some trophoblast is always disseminated into the circulation and will continue to secrete hCG. In tubal pregnancies, the presence or absence of trophoblastic tissue within the tubal wall is an added factor that complicates and increases the variability of hCG clearance rates. Consequently, no hCG pattern invariably presages continued trophoblastic growth or predicts resolution of the pregnancy.

Because the bulk of the trophoblast is always removed during surgery (barring gross technical errors), hCG levels invariably fall precipitously during the first few days after surgery, even in patients destined to develop symptoms for continued trophoblastic growth. There is, therefore, no merit in measuring the hCG concentration earlier than a week after surgery, because hCG levels in women with persistent and resolving trophoblastic activity overlap before this time.[62] Therefore, hCG measurements should commence a week following conservative surgery, but the optimal method of monitoring patients has not been defined, and few studies have been undertaken to identify those at particular risk for developing this problem. Those who have an hCG concentration > 1,000 mIU/mL a week after surgery are probably at greater risk,[63] and hCG titers should be monitored every three days. If the level is < 1,000 mIU/mL a week after surgery, titers can be obtained at weekly intervals until they become negative or at least < 100 mIU/mL.

In the absence of symptoms, intervention is not indicated so long as hCG levels continue to fall, however slowly. Rising values are more ominous but do not by any means invariably presage continued trophoblastic growth. A reasonable compromise between overtreatment and undertreatment is to intervene if the rate of increase is "normal," that is, doubling time < 2.7 days, or to follow subnormally increasing titers for a few days with repeat measurements to ensure that the rising pattern persists (because it often does not) before intervening. We intervene with chemotherapy and have always used methotrexate 50 mg/m^2 intramuscularly, which we know works in uncomplicated trophoblastic disease.

Persistent Trophoblastic Tissue and Persistent Ectopic Pregnancy

Successful conservative treatment of tubal pregnancy is documented by declining quantitative β-hCG levels. Persistent trophoblastic tissue has been described and implies further presence or growth of trophoblastic tissue within the tube or peritoneal cavity following conservative surgery. It should be suspected if serum levels of β-hCG are detectable two weeks postop. Thereafter, titers should be followed, and a tentative diagnosis made if titers plateau or rise. A second laparoscopy should be performed to confirm diagnosis and institute treatment.

In at least 40% of tubal pregnancies the trophoblast penetrates the tubal wall and some trophoblastic tissue is left behind if the implantation site is not removed, as is the case with a salpingotomy. This tissue usually degenerates, but in about 5% of cases, instead of resorbing, the residual trophoblastic tissue persists and resumes growing, until the patient eventually develops symptoms from intraperitoneal hemorrhage or a pelvic mass. The frequency of this complication is ill-defined, probably subject to considerable publication bias and on how "persistence" is defined. It is also slightly more common after laparoscopic salpingotomy than abdominal salpingotomy. Stock attributes the problem to incomplete evacuation of the trophoblastic tissue, and intuitively, the author feels he is probably correct.[64]

Persistent ectopic pregnancy implies the presence of persistent trophoblastic tissue within the fallopian tube following salpingotomy or fimbrial aspiration. Persistent ectopic pregnancy presents with signs of intraperitoneal hemorrhage or pain referable to a pelvic mass usually 10 or more days after the original surgery and occasionally as early as a week later.[65] Serial hCG monitoring after conservative operations has been instituted, in the hope of forestalling this problem, by identifying persistent trophoblastic activity at an asymptomatic stage. At laparoscopy, a second salpingotomy procedure is usually effective. Alternately, a partial salpingectomy procedure can be done using either the endoloop ligature or bipolar coagulation.

In our series of 109 consecutive tubal pregnancies treated laparoscopically, one persistent ectopic pregnancy occurred and was treated with a second laparoscopic salpingotomy procedure four weeks later. Four other women had persistent β-hCG titers. Laparoscopy four weeks later revealed ectopic trophoblastic tissue on the pelvic sidewall and cul-de-sac peritoneum. Treatment consisted of excision with laparoscopic biopsy forceps or laser vaporization.[7,66]

Persistent trophoblastic tissue has been successfully treated with methotrexate, without a laparoscopic procedure. However, laparoscopy has the advantage of documenting the location of the persistent trophoblastic tissue. Should the trophoblastic tissue be in the form of peritoneal implants, patency can be confirmed in the salpingotomized tube. Conversely, should methotrexate therapy be instituted without laparoscopic diagnosis, future hysterosalpingography revealing patent tubes should not be misconstrued as evidence supporting the benefits of methotrexate therapy.

Special Situations

Cornual (Interstitial) Ectopic Pregnancy

Cornual ectopic pregnancies are rare, and few reports exist of treatment via laparoscopy. Both Johns and this author have noted isthmic tubal pregnancies bordering on cornual pregnancies, that is, the proximal portion of the tubal dilatation caused by the ectopic pregnancy was actually in the uterine wall. These three cases were treated laparoscopically by segmental resection, resulting in preservation of most of the distal portion of the tube, but destruction of much interstitium, making the success of a future anastomosis unlikely.[7,67] However, tubal implantation would still be possible.

The diagnosis of interstitial ectopic pregnancy may be missed at laparoscopy. It is suspected when the endometrial cavity is empty and both fallopian tubes look normal, despite a β-hCG value indicating an existing pregnancy. Bulging or nodularity in the cornual area is usually present.

Methotrexate may be considered for treatment of cornual ectopic pregnancy, and there are two reports documenting its successful use. Tanaka and colleagues (1982) reported a case where an interstitial ectopic pregnancy was diagnosed at laparotomy. The abdomen was closed and the patient treated with methotrexate.[68] The decision to use methotrexate was based to a large extent on the patient's desire to maintain subsequent fertility potential. Hysterosalpingography, following completion of therapy, revealed bilateral tubal patency. Similarly, Brandes and colleagues reported a woman with suspected gestational trophoblastic disease treated with an eight-day course of methotrexate plus citrovorum factor rescue; repeat ultrasound and later diagnostic laparoscopy revealed a right cornual pregnancy. Hysterosalpingography subsequently documented blockage of this tube.[69]

Extraluminal Tubal Pregnancy

In 1980, Budowick and colleagues, from a series of 20 dissections of tubal pregnancies, concluded that the growing gestation rapidly penetrates the wall of the tube, and most of this subsequent growth occurs in an extratubal location between the tubal serosa and its muscularis.[22] In 1985, Stock reviewed the histopathology of 110 cases of tubal gestation and concluded that the developing tubal pregnancy was intraluminal, within the muscularis of the tube, in all but one case.[70] Pauerstein and colleagues concluded, after a systematic gross and histopathologic study of 25 consecutive ectopic pregnancies, that an intraluminal location was present in 67%.[20] This evolving understanding of the pathophysiology of ectopic tubal pregnancy has significant clinical implications regarding management decisions.

In most cases of extraluminal ectopic pregnancy, upon opening the tubal serosa over the most distended portion of the tube, products of conception will be evident and may extrude themselves. If spontaneous extrusion does not occur, as there is no surrounding muscularis, trophoblastic tissue must be removed in pieces, with special care taken not to avulse the normal tube. Thereafter, irrigation with the aquadissector produces distention of the tube without any flow of irrigant out of the fimbrial end. The operator can err by trying to open the tube further if bleeding is present.

In my experience with these cases, rarely will the surgeon enter the tubal lumen. Occasionally the blood clot or products of conception will encircle the space between serosa and muscularis. After removal of the bulk of the products of conception, and obtaining hemostasis with pressure or electrosurgical fulguration with an electrode or an argon-beam coagulator, the surgeon should end the procedure and follow the patient carefully with β-hCG titers. Adjuvant therapy with methotrexate may be considered.

Ruptured Tubal Pregnancy

In the series of 109 consecutive tubal pregnancies compiled by Reich and colleagues, there were 16 cases of ruptured tubal pregnancy. Salpingectomy or partial salpingectomy was performed in 13 of these cases, and salpingotomy in 3. Subsequently, two women had intrauterine pregnancies. Another woman who underwent salpingectomy has since had two pregnancies in her remaining tube, both treated by laparoscopic salpingotomy.[7]

In Bruhat's series of 118 women who had tubal pregnancies treated by laparoscopic salpingotomy while still desiring fertility, a ruptured tube was present in 47. Intrauterine pregnancies were later recorded in 27 of these women (57.4%) and recurrent ectopic pregnancy in 9 (19%).[1] A ruptured tube was present in 32 of the 100 cases of laparoscopic salpingectomy reported by Dubuisson and colleagues.[25]

Although many clinicians believe that laparoscopy may cause treatment delay in the patient with a ruptured tubal pregnancy who is in shock, the expert laparoscopist can control bleeding as quickly as most gynecologists can with laparotomy, regardless of the extent of hemoperitoneum. Although only one of four women with ruptured tubal pregnancy treated by this author was in shock, all had at least 500 mL of hemoperitoneum. The woman in shock was admitted from the emergency room to the operating room. After induction of anesthesia, active bleeding was controlled within five minutes using Kleppinger bipolar forceps to coagulate the 13-week gestation tube and its mesosalpinx. After receiving 2 units of packed cells, the patient was discharged on her first postoperative day. The Kleppinger bipolar forceps is a potent bipolar coagulator-desiccator that can effectively coagulate the tube and mesosalpinx despite active arterial or venous bleeding. We have used this instrument to coagulate the ovarian vessels in more than 300 laparoscopic salpingo-oophorectomy procedures.[71,72]

A ruptured tubal pregnancy is almost an absolute contraindication for a conservative approach. When the contralateral tube is absent, segmental resection or evacuation of products of conception after establishment of complete hemostasis can be considered—but only by the most expert laparoscopist. In most cases it is better to consider *in vitro* fertilization as the only hope for an intrauterine pregnancy in these women.

Ovarian Pregnancy

Ovarian ectopic pregnancy, when recognized, can be treated much like any other ovarian cyst of unknown etiology, that is, shelled out, often intact, through a superficial ovarian cortex incision. Ovarian pregnancy should be suspected in women with hCG titers above 3,000, an empty uterus by ultrasound, and no evidence of a tubal pregnancy at laparoscopy. The CO_2 laser or a knife electrode at 20 W cutting current is used to bivalve the ovary perpendicular to its long axis, starting at its most dependent part where cystic area meets solid tissue. Thereafter, the cortex over the cystic area can be lifted with grasping forceps and the aquadissector inserted to gently aquadissect the gestational sac from surrounding ovarian tissue. Often, an intact sac can be removed from inside the ovary with little ovarian bleeding. The ovary usually falls together thereafter, without a suture.

Chronic Ectopic Pregnancy

Fifty cases of chronic ectopic pregnancy among 882 ectopic pregnancies (5.7%) over a 3.5-year period were reported in 1982 by Cole and Corlett. This condition is usually the direct result of a tubal abortion or ruptured ectopic pregnancy in which the hemodynamic insult is subclinical and self-limiting. It causes an inflammatory response to surrounding structures, with resultant dense adhesions and occasional abscess formation involving tube, ovary, small and large bowel, and omentum. The β-hCG level is frequently low owing to nonviable trophoblastic tissue. In the Cole and Corlett series, 86% of the women had pain, 80% a mass, and 68% bleeding. Operative procedures included salpingectomy (20 cases), salpingo-oophorectomy (17 cases), and salpingo-oophorectomy with abdominal hysterectomy (13 cases). Twelve women had an infection as part of the chronic ectopic process, four with abscess formation.[73]

We have treated two chronic ectopic pregnancies laparoscopically, one by partial salpingectomy and the other by salpingectomy.[7] The surgical techniques involved are similar to those described for laparoscopic treatment of pelvic abscess.[74,75] Acute and subacute adhesions, that is, adhesions of relatively recent onset, are amenable to laparoscopic lysis. The key is careful blunt dissection using the aquadissector until all structures are separated. Thereafter, salpingectomy can be performed using bipolar forceps to coagulate the fallopian tube and its mesosalpinx. Intravenous antibiotics should be administered if any sign of purulent material is present, and the patient is discharged on an antibiotic effective against *Chlamydia.*

Conclusion

Ectopic pregnancy, a complex yet increasingly common condition that can occur in a variety of locations, and under a diverse set of circumstances, can be appropriately managed using minimally invasive techniques with emphasis on tubal preservation. Advantages of laparoscopic treatment over conventional surgical management include minimal cosmetically placed incisions, short hospital stay, and a significant reduction in recuperation time. Laparoscopic advantages over medical management include accurate assessment of pregnancy status and location, ability to lyse tubo-ovarian adhesions and evaluate the contralateral tube, confirmation by direct visualization of adequate treatment and complete hemostasis, and evacuation of all blood clots at the close of the procedure, usually "underwater" following the replacement of CO_2 peritoneum by Ringer's lactate solution.

Considering the diversity and complexity of the problem, it is not surprising that controversy exists regarding whether primary laparoscopic surgical treatment of an early unruptured tubal pregnancy offers any advantages for tubal preservation over expectant management, medical treatment with methotrexate, or transvaginal injection of the ectopic pregnancy under sonographic guidance with hypertonic glucose, KCl, or methotrexate. To answer this question, multiple studies with long-term follow-up are necessary to determine tubal patency, fertility outcome, and subsequent recurrence of ectopic pregnancies following each of these treatment modalities. These studies must include better documentation of the ectopic pregnancy location, including whether it has penetrated the muscularis-mucosa, an accurate description of its viability, and whether surrounding blood or clot are present. This documentation may not be obtainable using medical treatment that is also unlikely to improve the underlying tubal compromise. Intensely sclerosing agents like methotrexate may actually increase tubal adhesions when injected into the tubal lumen. Is there a place for adjuvant medical therapy following a surgical procedure? Viable extraluminal ectopic pregnancy, interstitial pregnancy, and cervical pregnancy may prove to be the ultimate testing ground for the use of methotrexate or transvaginal injection.

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30.6
Laparoscopic Treatment of Tubo-Ovarian and Pelvic Abscess

Harry Reich

Introduction

In recent years, therapy for the spectrum of pelvic inflammatory disease (PID) from early salpingitis to an unruptured tubo-ovarian abscess has been antibiotics, with surgical intervention reserved for those who did not respond to medical therapy.[1] Although this approach avoids immediate operation when successful, prolonged contact between necrotic and inflamed tissue often results in dense fibrous adhesions that diminish reproductive potential and cause chronic pelvic pain from organ entrapment.

This accepted therapy for PID is administered as an outpatient, with hospitalization and intravenous antibiotics reserved for situations when the diagnosis is uncertain, surgical emergencies cannot be excluded, suspected pelvic abscess, pregnancy, adolescence, inability to follow or failure to respond to outpatient management, or when clinical follow-up cannot be obtained otherwise.[2] Sexually transmitted diseases treatment guidelines are listed in Table 30.6.1.[3] Similarly, an unruptured adnexal abscess is treated with intravenous antibiotics with surgical intervention considered only when the patient does not respond to antibiotics.

Antibiotic success implies the resolution of symptoms and, often at a much later date, resolution of the pelvic mass, as judged by clinical or ultrasound examination; it in no way implies the resolution of pelvic adhesions that could result in future infertility. The literature cited below confirms that when long-term resolution of the symptoms and infertility is considered, medical treatment usually fails even with modern antibiotics.

It is much easier to operate on acute adhesions than it is to deal with dense adherences between structures that obliterate normal anatomic relationships and have, by their chronicity, developed neovascularization. For example, second-look laparoscopic adhesiolysis soon after a surgical procedure for infertility is much easier than the original operation.[4]

Electrosurgery, laser surgery, and sharp scissor dissection are all useful for chronic pelvic inflammatory adhesive disease, but have no place in the treatment of acute adhesions. The laparoscopic treatment of acute adhesions with or without abscess does not require the high level of technical skill necessary to excise an endometrioma, open a hydrosalpinx, or remove an ectopic pregnancy under laparoscopic control.[4–6] It is an exercise in careful blunt dissection, using a probe, or aquadissection with an aquadissector, and can be performed by gynecologists experienced in operative laparoscopy, using equipment available in most hospitals.[7–9]

Definition

Pelvic inflammatory disease is defined as an infection of the uterus, fallopian tubes, and pelvic peritoneum. Pelvic abscess, the most severe manifestation of this disease, is a localized collection of a large number of organisms, inflammatory exudate, and necrotic debris separated from surrounding tissue by a fibrous capsule. An adnexal abscess that lacks a classic abscess wall and contains an agglutination of tube and ovary to adjacent pelvic and abdominal structures is termed a tubo-ovarian complex. True pelvic abscess with a classic abscess wall can occur in the ovary and after rupture of a diverticulum. Whatever the terminology, purulent material exists in a collection within the pelvis. The terms adnexal abscess, tubo-ovarian abscess (TOA), tubo-ovarian complex, and pelvic abscess are used interchangeably, with pelvic abscess implying extension of the adnexal abscess to involve most of the true pelvis.

Approximately one million women in the United States are diagnosed with PID annually.[10] Risk factors include adolescence, multiple sexual partners (especially a new partner within the last two months), failure to use a barrier method, use of an intrauterine device (increased risk the first months after insertion), immunosuppression,

TABLE 30.6.1. Regimens for the treatment of pelvic inflammatory disease recommended by the CDC.*

Type of treatment	Comment
Inpatient	
Regimen 1	
Cefoxitin, 2 g intravenously every 6 h, or cefotetan, 2 g intravenously every 12 h Doxycycline, 100 mg intravenously or orally every 12 h	The regimen is continued for at least 48 h after the occurrence of substantial clinical improvement after which doxycycline, 100 mg orally 2 times a day, should be given until day 14 of treatment
Regimen 2	
Clindamycin, 900 mg intravenously every 8 h Gentamicin, 2 mg/kg of body weight intravenously or intramuscularly (loading dose) followed by 1.5 mg/kg intravenously or intramuscularly every 8 h (maintenance dose)	The regimen is continued for at least 48 h after the occurrence of substantial clinical improvement, after which doxycycline, 100 mg orally 2 times a day, or clindamycin, 450 mg orally 4 times a day, should be given until day 14 of treatment.
Outpatient	
Regimen 1	
Cefoxitin, 2 g intramuscularly in a single dose, plus concomitant probenecid, 1 g orally, or ceftriaxone, 250 mg intramuscularly, or another third-generation cephalosporin (e.g., ceftizoxime of cefotaxime) Doxycycline, 100 mg orally 2 times a day for 14 days	
Regimen 2	
Ofloxacin, 400 mg orally 2 times a day for 14 days Clindamycin, 450 mg orally 4 times a day for 14 days, or metronidazole, 500 mg orally 2 times a day for 14 days	

*1993 Sexually transmitted diseases treatment guidelines. *MMWR* 1993; 42(RR-14):75–81.

and frequent douching. Recently, bacterial vaginosis has been implicated as a risk factor.

Pathophysiology

PID is usually an ascending infection. It is estimated that *Chlamydia trachomatis* or *Neisseria gonorrhoeae* are the causative organisms in more than half of all cases. Enteric and bacterial vaginosis-associated organisms have also been isolated.[11]

Abscess is the end result of an acute or subacute infection beginning with an initial peritonitis stage where aerobic bacteria predominate, followed by the development of an intra-abdominal abscess with emergence of anaerobic bacteria as the predominant flora. Abscesses contain a large number of organisms in high concentration, but not in a rapid growth phase, making them less susceptible to antimicrobial agents requiring actively growing organisms for efficacy. The fibrinous capsule may inhibit adequate levels of antimicrobial agents from entering the abscess.[12] The anaerobic milieu may hinder host defense mechanisms, reducing the ability of neutrophils to phagocytize and kill bacteria. Thus, therapy for abscesses must include some technique of adequate drainage along with appropriate antimicrobial agents.

Diagnosis

Women with acute or subacute onset of lower abdominal pain and a palpable or ultrasound suggestive pelvic mass require early laparoscopy for diagnosis and treatment, as even an "obvious TOA" may prove to be an endometrioma, hemorrhagic corpus luteum cyst, or an abscess surrounding a ruptured appendix. The routine use of laparoscopy to diagnose acute PID has become widespread in Europe and is accepted by every gynecology department in Sweden.[13,14] The worldwide average rate of misdiagnosis of PID is 35% when laparoscopy has been used for confirmation. Conversely, PID can be an unanticipated finding at laparoscopy for pelvic pain.

The diagnosis of an adnexal infection or abscess is suspected in women who have persistent pain and abdominal, adnexal, or cervical motion tenderness on examination. "Because of the potential for serious long-term sequelae, even from mild disease, clinicians should have a high index of suspicion and a low threshold for making the diagnosis and initiating treatment."[10]

Temperature, leukocytes, or sedimentation rate may be elevated. Endocervical cultures for gonorrhea and chlamydia may be positive. A recent study indicates that endometrial biopsy has a diagnostic sensitivity of 89%, and specificity of 67% with laparoscopically confirmed disease.[15] Serum or urine human chorionic gonadotropin (hCG) must be obtained and a negative result documented. Ultrasound may demonstrate a large hydrosalpinx filled with dense fluid or an adherent adnexal mass; septations, air fluid levels, internal echoes, and abscess cavity may be identified. HIV testing should be considered, especially in women with pelvic abscess.[16]

More sophisticated diagnostic testing, including gallium 67- and indium 111-labeled white blood cell scans and computed tomographic scans, are rarely necessary, as laparoscopy can determine the diagnosis. After a presumptive diagnosis of PID/TOA is made, laparoscopic diagnosis and treatment should be initiated within 24 to 48 hours. The procedure is explained to the patient and family, including the risks and benefits, and other treatment alternatives. Informed consent is obtained and documented.

Review of Literature

The commonly accepted belief that surgical intervention during acute pelvic infection would result in greater injury than waiting for the infection to subside dates back 80 years to a New York City report (1909) suggesting that early surgery is associated with increased technical difficulty.[17] This opinion prevailed until recently, even though the risks associated with surgical intervention have changed drastically since the early part of this century.

Medical Treatment

In 1973, Franklin and colleagues reported a series of 137 consecutive cases of acute pelvic abscess. Of these women, 120 underwent conservative management including 35 posterior colpotomies (nine-day average hospital stay); 10 underwent laparotomy for definitive diagnosis; and 7 underwent immediate surgery because of a presumed ruptured pelvic abscess. Of the 120 cases treated conservatively, 103 were followed for 2.5 to 8.0 years. The total failure rate was 26% (31). Twelve women (10%) required definitive surgery, usually hysterectomy and adnexectomy for "early failure" to respond to conservative management during their initial hospitalization, and 19 (16%) required subsequent definitive surgery for persistent mass, pain, or hypermenorrhea. Among the 120 women, 10 subsequently conceived (8%).[18]

Ginsburg and colleagues reviewed 160 patients with TOA (1969 to 1979). Of these women, 76 responded to medical therapy with no subsequent surgery, and 84 (53%) required subsequent surgery. Surgery during the acute phase was done in 50 women because of failure to respond to the medical regimen (40 TAH/BSO, 4 unilateral adnexectomies, and 6 abscess drainage procedures), and 34 had later surgery for persisting symptomatology related to the abscess. Eighty percent of the women who responded to medical therapy and had no subsequent surgery continued to experience persistent or recurrent disease. Of 120 women in whom reproductive function was preserved, 9 conceived (7.5%); no women with a bilateral TOA conceived.[19]

Hager (1970 to 1974) also documented poor success with medical therapy alone. Of 50 women with the original diagnosis of TOA, only 5 had successful medical treatment. Hager reported that response to antimicrobial therapy may be the most reliable way to distinguish women with salpingitis only, from those with salpingitis plus a TOA, as the latter group did not respond well to antibiotic treatment alone.[20]

In 1983, Landers and Sweet reported that 175 of 232 women with TOAs were treated with antibiotics alone. Laparoscopic confirmation was performed in only 15 of these women. Twenty-five percent required surgery as part of their original therapy, including 8 of 71 women initially treated with regimens including clindamycin. Long-term follow-up information was available for 58 women treated with antibiotics alone: 31% required subsequent surgery.[21]

Seventeen of the 71 patients with salpingitis, treated with single agent B-lactam, also demonstrated *C. trachomatis* on endometrial tissue biopsy. Most women (16 of 17) had resolution of symptoms. Twelve continued to have positive chlamydia cultures, a well-recognized risk factor for future episodes of PID and its sequela.[22]

Hemsell and associates reported 41 women with pelvic abscesses treated with cefotaxime during 1980 and 1981. Chronic pelvic pain and recurrent infection were infrequent during a 31- to 43-month follow-up period, but five women (12%) subsequently required TAH/BSO for a persistent adnexal mass, and a sixth underwent unilateral salpingo-oophorectomy for an asymptomatic adnexal mass (hydrosalpinx). A pregnancy rate of 20% (6 of 30) was observed.[23]

Diagnosis in the above and other studies was based on clinical and sonographic findings, without laparoscopy for diagnosis or later evaluation.[24] These studies document that antimicrobial treatment of a formed TOA rarely results in complete resolution without adhesion formation. In addition, medical treatment resulted in prolonged initial hospitalization, in most cases, with a high rate of readmission. Medical treatment has not been beneficial in ensuring fertility and can be justified only because ovarian preservation results in the possibility of a future *in vitro* fertilization procedure.

Alternative Surgical Treatment

Primary surgical treatment (laparotomy) for an unruptured TOA within a few days of admission has always been controversial. Early TAH/BSO was advocated by Kaplan and associates who, during 1964 to 1966, treated 71 women with a presumptive diagnosis of pelvic abscess in this manner. Five patients received more than 2 units of blood. Postoperatively, there were seven superficial wound infections, one subfascial wound, and one evisceration. Cuff abscess occurred in three women.[25]

Colpotomy drainage can be performed for those pelvic abscesses dissecting into the upper portion of the rectovaginal septum. Rubenstein and colleagues reported the results of 38 colpotomy procedures for pelvic abscess: 14 (37%) required additional surgery. Mean duration of hospitalization was 12.4 days (7.7 days after drainage).[26]

Rivlin reviewed the results of 59 colpotomy drainage procedures. Further surgery during the same admission was performed in 13 cases and additional surgery at a later admission in 11 patients. Five of 40 potentially fertile women (12.5) had successful pregnancies.[27] Rivlin and colleagues also reviewed the results of 348 colpotomy drainage procedures at two medical centers. There were 23 instances of diffuse peritoneal sepsis (6.5%) with six deaths attributable to this condition.[28]

Percutaneous Drainage

Van Sonnenberg and colleagues reported a 78% success rate with percutaneous drainage of 50 pelvic abscesses.[29] Gerzof and colleagues successfully treated six of nine pelvic abscesses (67%) via percutaneous drainage.[30] Worthen and Gunning reported percutaneous drainage of 35 pelvic abscesses, secondary to pelvic inflammatory salpingitis. Nine patients with 11 abscesses were treated by percutaneous catheter placement, with a success rate of 77%; two required surgical procedures. Nineteen women underwent percutaneous aspiration. Among them, there were 23 abscess cavities, 18 (94%) of which were successfully aspirated; 1 required surgical drainage. Seven women had abscess cavities that could not be drained or aspirated. Four of these seven recovered on antibiotic therapy alone, and three required surgical drainage. Long-term follow-up was not part of any of these studies.[31]

Why Laparoscopic Treatment Works

Important peritoneal defense mechanisms protecting the host from invading bacteria include absorption of the microbes from the peritoneal cavity via translymphatic absorption through specialized structures of the diaphragm for distribution to systemic defense systems, phagocytosis by macrophages and polymorphonuclear leukocytes, complement effects, and fibrin trapping.[32] Fibrin trapping and sequestration of the bacterial inoculum by the omentum and intestinal distention and the tubo-ovarian complex act to contain the infection initially, although abscesses may eventually form. Although fibrin traps bacteria, thereby decreasing the incidence of septicemic death, thick fibrin deposits represent a barrier to *in situ* destruction by neutrophils, with resultant abscess formation. Once formed, the abscess walls inhibit the effectiveness of antibiotics and the ability of the host to resolve the infection naturally.

Ahrenholz and Simmons[12] studied the role of purified fibrin in the pathogenesis of intraperitoneal infection. Implantation of 0.5% bovine fibrin clots containing 2×10^8 *Escherichia coli* into the rat peritoneal cavity reduced the 24-hour mortality rate from 100 to 0% (compared to that seen after implantation of *E. coli* in a similar volume of saline solution). However, the 10-day mortality rate with fibrin was 90%; 100% of rats developed intraperitoneal abscesses. A control group of animals receiving sterile clots lysed them over one to two weeks without abscess formation. As few as 10^2 *E. coli* per fibrin clot produced abscesses, but 10^7 or more were required to produce death; without fibrin fewer than 10^7 *E. coli* neither killed nor produced intraperitoneal infections. Both late death and abscess size with 2×10^8 *E. coli* were directly proportional to the fibrin clot size but not the concentration of fibrin in the clot. Operative debridement of the fibrin at 4 or 24 hours completely eliminated abscess formation in surviving animals. Ahrenholz and Simmons concluded that fibrin delays systemic sepsis, but the trapped bacteria cannot be eliminated easily by normal intraperitoneal bactericidal mechanisms and, as a result, abscess formation occurs. They also concluded that radical peritoneal debridement or anticoagulation may reduce the septic complications of peritonitis, that is, procedures that decrease fibrin deposition or facilitate fibrin removal, either enzymatically or surgically, probably further decrease the incidence of intraperitoneal abscess formation and peritonitis.

Hudspeth[33] successfully treated 92 patients with advanced generalized bacterial peritonitis by radical surgical debridement, after the source of contamination had been eliminated. The ages of these patients varied from 3 to 69 years. All were critically ill, and more than 90% had mechanical intestinal obstruction. Although the operations were tedious and often prolonged (average operating time three hours), all patients survived, and postoperative complications were minimal. Hudspeth believed that treatment success resulted from preventing further contamination and restoring the peritoneum to a state that allows normal host defense mechanisms to clear any residual infection. He further emphasized that the obvious way of preventing residual abscess formation and allowing the peritoneum to clear intra-abdominal infection is to break down all inflammatory adhesions, remove all necrotic tissue, eliminate any possible anaerobic condition, and reduce the bacterial count to a practical minimum.

Success with laparoscopic treatment further substantiates the laboratory findings of Ahrenholz and Simmons.[12] Laparoscopic drainage of a pelvic abscess followed by lysis of all peritoneal cavity adhesions and excision of necrotic inflammatory exudate allows host defenses to effectively control the infection. In addition, extensive direct peritoneal cavity irrigation helps debride peritoneal surfaces, debulks the peritoneal cavity of bacteria, and facilitates bacterial absorption into the bloodstream where antibiotics are more effective. Hudspeth's[33] and this author's results confirm that there is no substitute for hard work. Meticulous dissection and attention to detail, when separating adhesions and debriding necrotic purulent exudate, produce results that are advantageous to the patient and rewarding for the surgeon.[34]

Laparoscopic Surgical Technique

Laparoscopic treatment of pelvic abscess was first proposed by Dellenbach in 1972.[35] The largest series of laparoscopic treatment of TOA (50 cases) was reported by Henry-Suchet in 1984, using a technique of lysing recent friable adhesions with a rod, despite the presence of acute infection.[8] Laparoscopic drainage of a pelvic abscess, followed by lysis of peritoneal cavity adhesions and excision of necrotic inflammatory exudate, allows host defenses to effectively control the infection.[7,8]

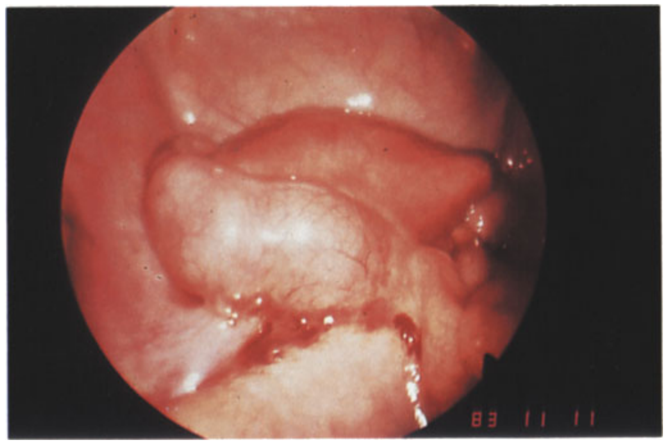

FIGURE 30.6.1. Large tubo-ovarian abscess with left hydrosalpinx stuck to bowel.

Preoperative Care

Intravenous antibiotics are initiated on admission to the hospital, usually 2 to 24 hours prior to laparoscopy. Adequate and sustained blood levels of antibiotics are required to combat transperitoneal absorption of aerobic and anaerobic organisms during the operative procedure. This author prefers cefoxitin, 2 g intravenously, every four hours from admission until discharge, usually on postoperative day 2 or 3. Oral doxycycline is started on the first postoperative day and continued for 10 days. Although clindamycin and metronidazole both have demonstrated greater ability to enter abscess cavities and reduce bacterial counts therein, cefoxitin is used to simplify therapy to a single intravenous agent and assess further the efficacy of the laparoscopic surgical procedure; that is, the intravenous antibiotic alone cannot be considered the reason for successful therapy. Azithromycin is the treatment of choice for *C. trachomatis* when cost permits.

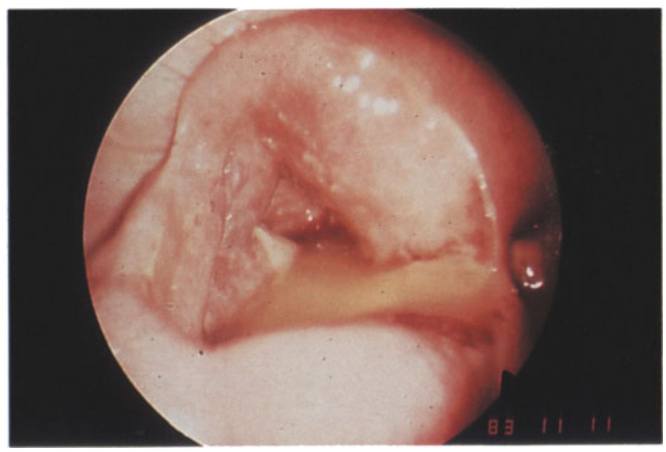

FIGURE 30.6.2. Following separation of tube from top of uterus, purulent drainage is observed and immediately aspirated.

Operative Technique (Figures 30.6.1–30.6.12)

Hysteroscopy is done during peritoneal insufflation to inspect the endometrial cavity. Tissue is obtained for histology and chlamydia, gonorrhea, anaerobic, and aerobic bacterial cultures. A uterine manipulator is inserted. A 10-mm laparoscope is used through a vertical intraumbilical incision. Lower quadrant puncture sites are made above the pubic hairline and lateral to the deep epigastric vessels.

The upper abdomen is examined and the patient is placed in 20° Trendelenburg position before focusing attention on the pelvis. A Foley catheter is inserted if the bladder is distended. Through the right-sided trocar sleeve, either a blunt probe or a grasping forceps is inserted and used for traction and retraction. Through the left-sided trocar sleeve, a suction-irrigator-dissector (aquadissector) or a suction probe attached to a 50-cc

FIGURE 30.6.3. Following drainage of the abscess, all pelvic adhesions are divided, freeing both tubes and ovaries from their respective pelvic sidewalls and posterior uterus.

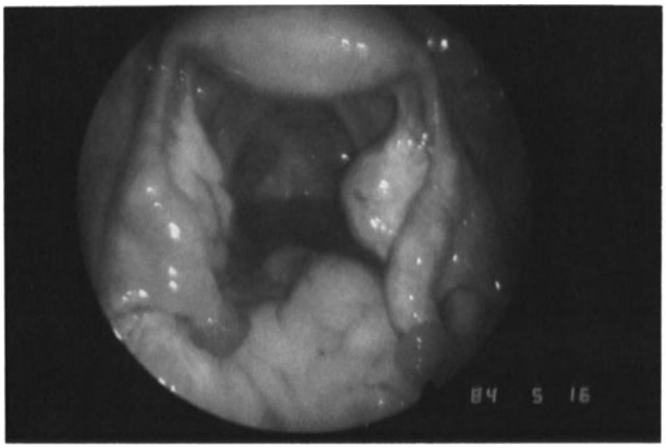

FIGURE 30.6.4. Second-look procedure in this patient reveals relatively normal tubes and ovaries with minimal pelvic adhesions.

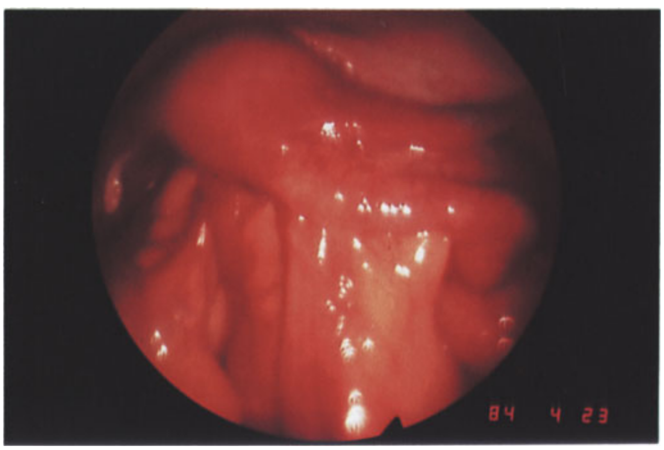

FIGURE 30.6.5. A 64-year old woman with a diverticular abscess. Note the small bowel adhesions to the right tube.

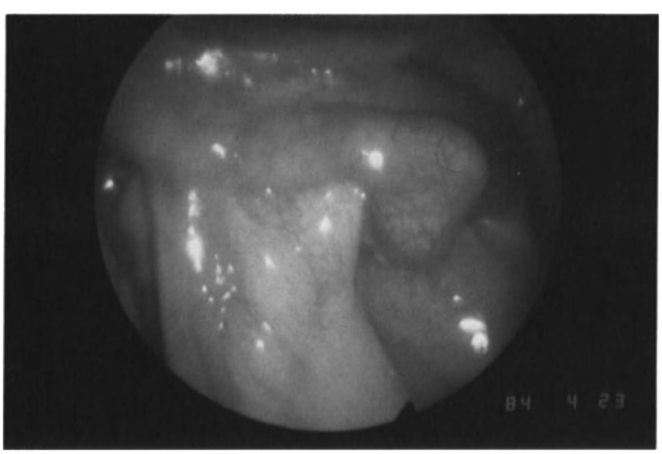

FIGURE 30.6.6. Close-up of small bowel stuck to right tube.

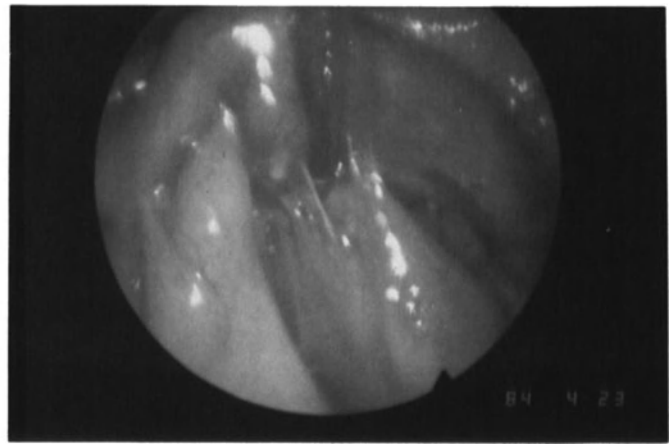

FIGURE 30.6.7. Using aquadissection, small bowel is separated from posterior uterus.

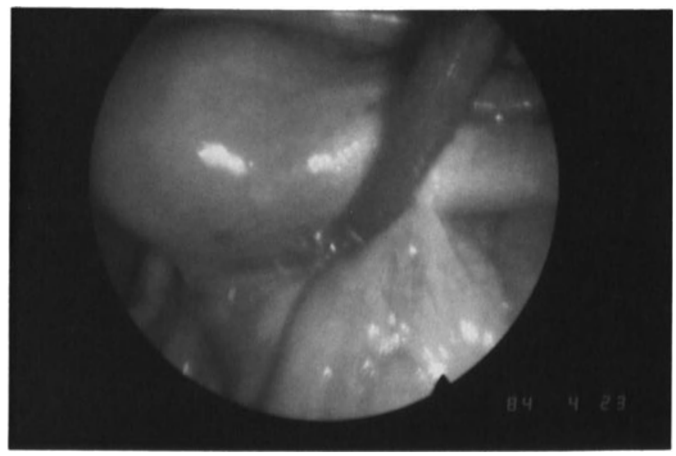

FIGURE 30.6.8. Division of adhesions continues with careful blunt dissection freeing small bowel until abscess cavity is entered.

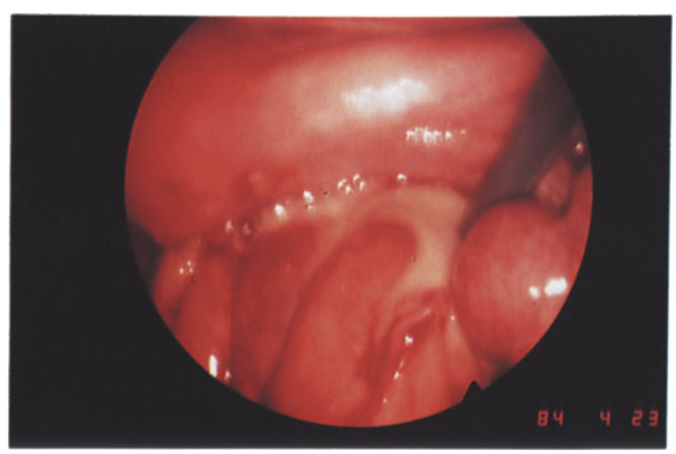

FIGURE 30.6.9. Purulent fluid in abscess cavity is drained with minimal pelvic cavity contamination.

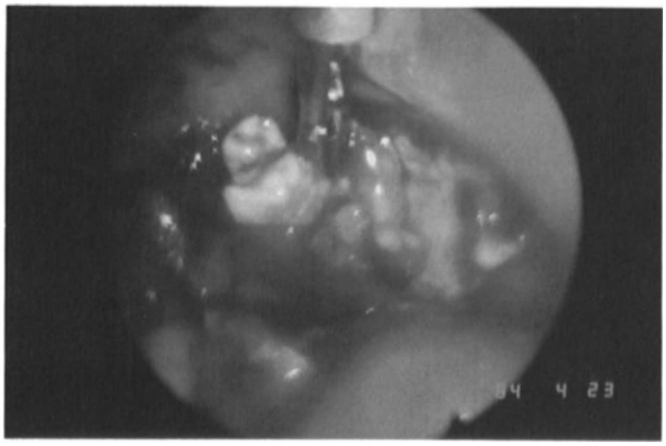

FIGURE 30.6.10. Fibrinous exudate making up abscess cavity is excised from peritoneal cavity.

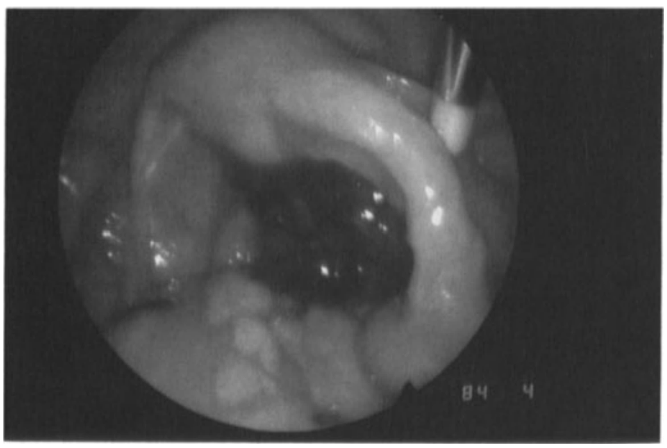

FIGURE 30.6.11. The deep cul-de-sac, which was previously occupied by the abscess cavity, is now clean and all pelvic organs separated. No leakage of bowel contents from the rectosigmoid can be visualized.

syringe is inserted and used to mobilize omentum, small bowel, rectosigmoid, and tubo-ovarian adhesions until the abscess cavity is entered. Purulent fluid is aspirated while the operating table is returned to a 10° Trendelenburg position. Cultures should be taken from the aspirated fluid, and inflammatory exudate excised with biopsy forceps, especially exudate near the tubal ostium.

After the abscess cavity is aspirated, the aquadissector is used to separate the bowel and omentum completely from the reproductive organs and to lyse tubo-ovarian adhesions (aquadissection). Aquadissection is performed by placing the tip of the aquadissector against the adhesive interface between bowel-adnexa, tube-ovary, or adnexa-pelvic sidewall and by using both the tip and the pressurized fluid gushing from it to develop a dissection plane that is extended either bluntly or with more fluid pressure. The grasping forceps place the tissue to be dis-

FIGURE 30.6.12. This woman underwent a second laparoscopic procedure one year later to evaluate the extent of her diverticular disease. Minimal adhesions formed following the laparoscopic treatment of a diverticular abscess.

sected on tension so that the surgeon can identify the distorted tissue plane accurately prior to aquadissection. When the dissection is completed, the abscess cavity (necrotic inflammatory exudate) is excised in pieces using a 5-mm biopsy forceps.

It is important to remember that after ovulation, purulent material from acute salpingitis may gain entrance into the ovary by inoculation of the corpus luteum, which may then become part of the abscess wall. Thus, after draining the abscess cavity and mobilizing the entire ovary, a gaping hole of varying size may be noted in the ovary that was intimately involved in the abscess cavity. This area should be well irrigated; it will heal spontaneously. Significant bleeding is rarely encountered.

The next step is to insert grasping forceps into the fimbrial ostia and spread them in order to free agglutinating fimbriae. Retrograde irrigation of the tube is performed with the aquadissector to remove infected debris and diminish the chance of recurrence. The fimbrial endosalpinx is assessed for future prognosis.

Tubal lavage with indigo-carmine dye through a Cohen cannula is attempted. With early acute abscess, the tubes are rarely patent due to interstitial edema. However, when the abscess process has been present for more than one week or the patient was previously treated with an antibiotic, lavage frequently documents tubal patency, and inspissated necrotic material may be pushed from the tube.

The peritoneal cavity is irrigated thoroughly with Ringer's lactate solution until the effluent is clear. The total volume of irrigant may exceed 20 L. As part of this procedure, 2 L of Ringer's lactate solution are flushed into the upper abdomen, one on each side of the falciform ligament, to dilute any purulent material that may have gained access to these areas during the 20° Trendelenburg positioning. Reverse Trendelenburg position is then used for the "underwater" exam. The laparoscope and the aquadissector are manipulated into the deep cul-de-sac beneath floating bowel and omentum, and this area is alternatively irrigated and suctioned until the effluent is clear. An underwater examination is then performed to observe the completely separated tubes and ovaries and to document complete hemostasis. At the close of each procedure, at least 3 L of Ringer's lactate is left in the peritoneal cavity to prevent fibrin adherences from forming between operated upon surfaces during the early healing phase and to dilute the bacteria present.[36] Blood loss is rarely greater than 100 cc. No drains, antibiotic solutions, or heparin are used. Second-look laparoscopy is encouraged.

Postoperative Care

Postoperatively, the patient is ambulatory and on "diet as tolerated" after recovery from anesthesia. Leukocytosis and fever rarely persist past the first postoperative day. Discharge is determined by resolution of pain and fever. Intravenous cefoxitin is continued until discharge, usually on the second postoperative day. Oral doxycycline is continued for 10 outpatient days. The patient is examined one week after discharge, and all restrictions are removed.

It is critically important to have the sexual partner undergo medical evaluation and sexually transmitted disease screening. Although frequently asymptomatic, the partner is treated according to the CDC outpatient antibiotic regimen for PID.[37]

Clinical Results

In the author's experience, from 1976 until 1993, 46 of 48 women with TOA and pelvic abscess were treated with intravenous antibiotics and a laparoscopic surgical procedure. One 37-year-old gravida 4, para 4 patient, early in the study, had laparoscopy for diagnosis alone and underwent total abdominal hysterectomy after showing no response to antibiotic therapy. One 29-year-old gravida 1, para 1 patient, who underwent laparotomy for presumed ruptured appendix, was treated for bilateral TOA with preservation of all reproductive organs when the author was consulted during the operative procedure. (She has had two subsequent intrauterine pregnancies.) Of 46 laparoscopically managed cases, there were 25 unilateral TOAs, 14 bilateral TOAs, 4 diverticular abscesses, 1 vaginal cuff abscess, 1 postappendectomy abscess, and rectal abscess secondary to a delayed bowel perforation. The average age was 28 years (range 10 to 61 years) with a medium of 25 years.

Of 46 women treated for abscess, 45 (98%) had complete clinical resolution of the abscess. No laparoscopic complications occurred during the 10 years of the study. Average operating time was 90 minutes, and average length of hospital stay postlaparoscopy was 4.1 days. Minimal adhesions were found in the eight women who later underwent second-look laparoscopy.

Complications

In the treatment of PID and abscess, the most serious complications are inaccurate or delayed diagnosis, and inadequate management. The result for the patient is a lifetime of the sequela of pelvic adhesive disease. Tubal factor infertility occurs in 8% of women after one episode of PID, 20% after two episodes, and 40% after three or more.[38]

Complications of laparotomy treatment of pelvic abscess include superficial wound infection, wound dehiscence, bowel injury including delayed perforation of bowel secondary to unrecognized injury, bowel obstruction, persistent undrained collections, thrombophlebitis, pulmonary embolism, septic shock, and subdiaphragmatic collections with pleural effusion.

At laparoscopy, the subphrenic region can be well visualized and irrigated directly. Delayed bowel perforation secondary to an unrecognized injury is a rare complication of laparoscopy, especially as laser and electrosurgery are infrequently used. Bowel injury, the most common serious operative complication of abscess surgery via laparotomy, occurs only when the bowel is the primary source for abscess formation.

Discussion

> Treatment of infertility is glamorous gynecology. Treatment of pelvic inflammatory disease (PID), the most important preventable cause of infertility, afflicting an estimated 1 million American women yearly, is not glamorous gynecology ... [and] must be one of the most neglected areas of American medicine.[30]

The goals in management of acute TOA are prevention of the chronic sequelae of infection, including infertility and pelvic pain, both of which often lead to further surgical intervention. Laparoscopic treatment in addition to intravenous antibiotics is effective and economical. It offers the gynecologist 100% accuracy in diagnosis while simultaneously accomplishing definitive treatment with a low complication rate.

It is encouraging that at least one healthcare plan emphasizes the importance of expedient management of PID. The Oregon healthcare plan, based on the concept of care-by-priority created 17 ranked categories of healthcare services. The first nine were deemed "essential," the next four are classed as "very important," and the last four, "valuable to certain individuals." The first category, "acute fatal; treatment prevents death and allows full recovery" recognizes that medical and surgical treatment of PID (and ectopic pregnancy) is critically important. We salute the 11 members of the Health Services Commission for their difficult task, but specifically for recognizing that early treatment of PID can prevent significant morbidity and mortality.[40]

Presently, many physicians are reluctant to advocate the routine use of laparoscopy for diagnosis and treatment of acute pelvic adhesions and pelvic abscess. However, continued experience with laparoscopic treatment of pelvic abscess, combined with intravenous antibiotic therapy, indicates better results than early surgery or medical treatment alone, with less risk to the patient.

Antibiotic success implies symptom resolution and, perhaps at a much later date, resolution of the pelvic mass, determined by clinical or ultrasound examination. It in no way ensures fertility and can be justified only because ovarian preservation affords the possibility of future candidacy for IVF. To be accurate, efficacy of antibiotic therapy must include long-term complications (ectopic, infertility, surgery for pelvic pain) in addition to microbiologic response and symptomatic relief.[41]

Laparoscopy allows for conservation of the tube and ovary with subsequent fertility potential. Additionally, laparoscopy has a high degree of patient acceptance due to minimal incision size, shorter hospital stay, and early return to full activity. The combination of laparoscopic treatment and effective intravenous antibiotics is a reasonable approach to the spectrum of PID from acute salpingitis to ruptured TOA.

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30.7 Hysteroscopic Surgery

Ray Garry

Prerequisites for Hysteroscopic Surgery

The first requirement for successful surgery is to ensure adequate exposure of the operative field. This is particularly important in hysteroscopic surgery. The surgeon must have the necessary skills and equipment to ensure clear vision throughout the procedure. The uterine cavity, like most other body spaces, is only a potential and completely dark space. Invasive intrauterine surgery should only be attempted when the surgeon is confident that he or she can ensure optimum operating conditions throughout the procedure.

The uterine cavity can be distended with either gas or fluid media. Carbon dioxide is the preferred medium for diagnostic gynecology. It is the most soluble of the commonly available gases used in medicine and it can be safely infused into the uterine cavity in reasonable volumes. Infusion must be done slowly because the body can deal with only about 150 mL of CO_2 per minute. Quantities in excess of 150 mL may produce venous gas embolism with consequent death or neurological disturbance. It is, therefore, essential to ensure that CO_2 is infused into the uterine cavity only with insufflation equipment designed specifically for hysteroscopy. Such insufflation equipment can now be electronically controlled, permitting the measurement of gas flow and intrauterine pressure, and the careful control of these parameters, to ensure the effective and safe distension of the uterine cavity. Gaseous media that are ideal for office diagnostic hysteroscopy are less suitable for operative hysteroscopy in which circumstance fluid distension media are preferred.

A good quality, rigid hysteroscope with a Hopkins rod-lens system gives the best quality image for hysteroscopic surgery, and is preferred by most gynecologists, although a few, including Professor Cornier from Paris, favor a flexible fiberoptic hysteroscope. To ensure adequate operating conditions, it must be used in conjunction with a high-power, cold-light source, a compact CCD video camera, and a high-resolution monitor. Even with a high-grade visualization system, other factors can impair a clear view of the cavity during operative hysteroscopy.

Almost all operative hysteroscopy is associated with the production of streams of bubbles from electrical or laser vaporization and the concomitant release of solid particles of endometrium. These bubbles and particles will rapidly obscure vision in a stagnant pool of distension medium. They can easily be removed, however, by constantly flushing the cavity with fresh distension medium. A continuous flow should be established in a closed circuit system. This requires using a hysteroscope with an operating and two discrete fluid channels, such as the one illustrated in Figure 30.7.1 and described by Baggish[1] and Garry,[6] or those described by Donnez[3] and Wamstecker.[14]

The most important cause of visual impairment during hysteroscopic surgery is, however, bleeding into the distention medium. The endometrium receives its blood supply from a series of radial arteries that penetrate the myometrium and then branch into a rich subendometrial plexus (Figure 30.7.2). This capillary plexus is vulnerable and is almost invariably damaged during hysteroscopic surgery (Figure 30.7.3). Bleeding from these vessels can

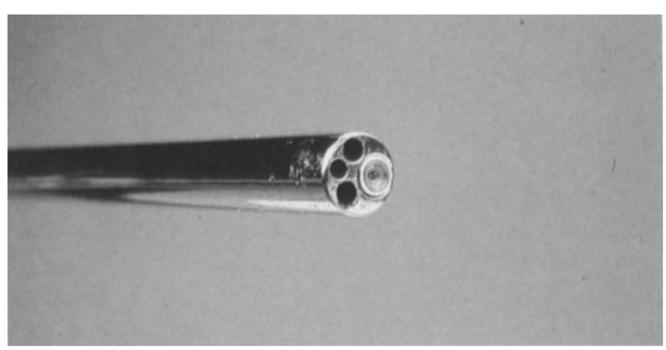


FIGURE 30.7.1. Weck Baggish Hysteroscope with three discrete channels for a continuous flow system.

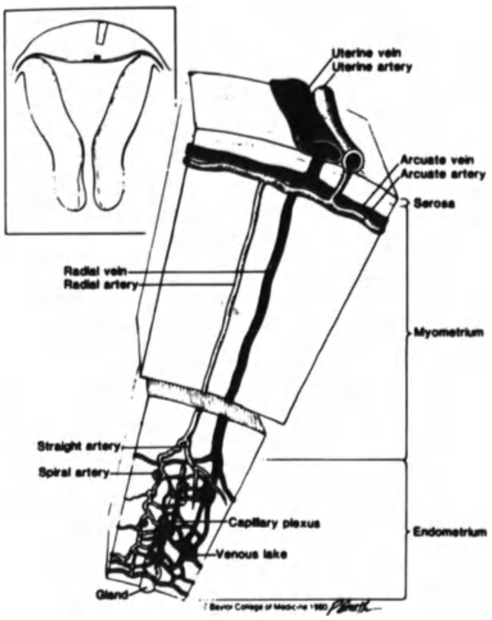


FIGURE 30.7.2. Vascular supply of the endometrium.

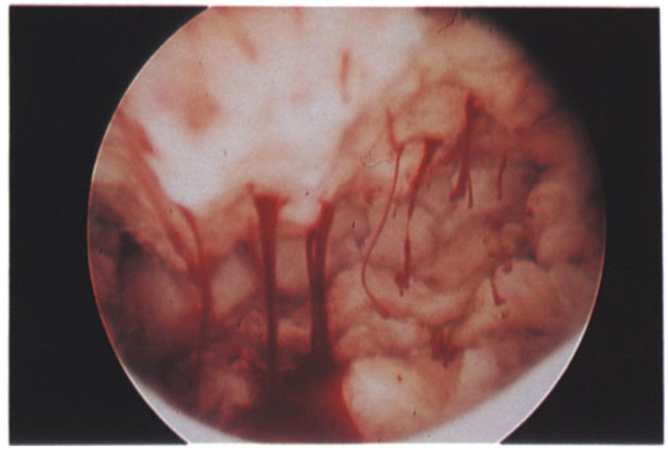


FIGURE 30.7.3. Bleeding from damaged subendometrial blood vessels seen at the end of endometrial resection. (Courtesy of J Hamou.)

readily be stopped and even prevented by raising the intrauterine pressure to produce a tamponade effect. The myometrium is fairly thick and rigid and if the cervix is closed around the hysteroscope, raising the cavity pressure will compress the vessels and prevent bleeding.

Unfortunately, if the pressure in the uterine cavity is increased too much, the flow of fluid will be reversed, and instead of blood leaking into the cavity, distension fluid will be forced into the patient's circulation (Figure 30.7.4). This phenomenon can be demonstrated by hysterograms taken at different known intrauterine pressures. Below a critical level, which appears to approximate the patient's mean arterial blood pressure,[7] distension fluid remains confined inside the cavity. Above this intrauterine pressure level, fluid will be forced into the extensive uterine capillary and venous collecting systems (Figures 30.7.5 and 30.7.6). This may present as a clinical problem in that excess fluid absorption has frequently been described following endometrial ablation.[2,5,8,10] These experimental observations indicate that it is important to be continually aware of the level of intrauterine pressure and to monitor the amount of fluid infused and recovered. This can be done automatically with an instrument called a Hysteromat (K Storz, Tüttlingen, Germany). It consists of a roller pump connected to a pressure transducer. The maximum intrauterine pressure can be preset to any level. As the intrauterine pressure rises, the roller pump slows, and when the predetermined pressure is reached, the pump will stop completely until the obstruction is cleared and the pressure

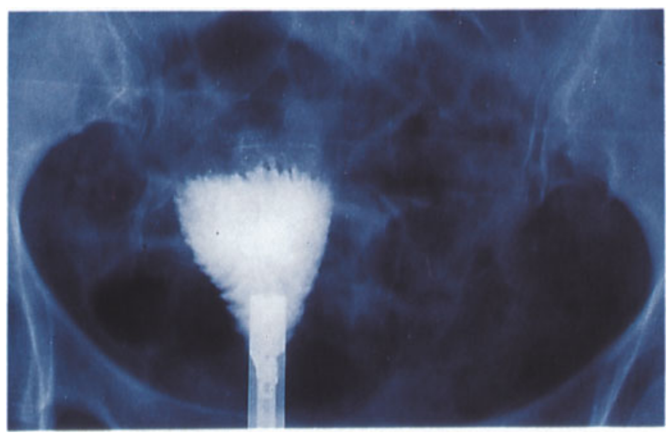


FIGURE 30.7.4. Hysterogram taken at 75 mm Hg pressure. Radio-opaque medium confined to the uterine cavity.

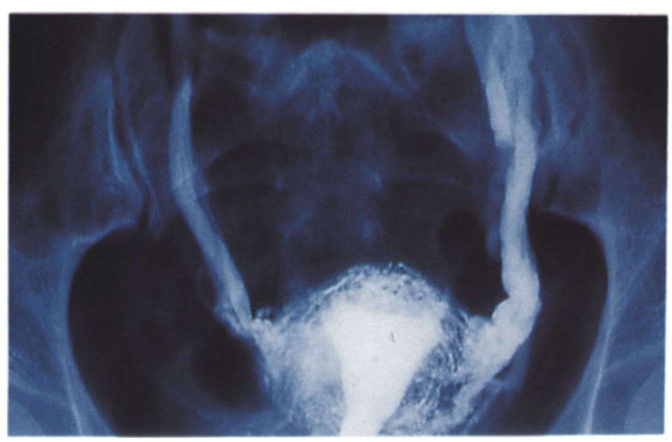


FIGURE 30.7.5. Hysterogram taken at 150 mm Hg pressure. Radio-opaque medium forced into the extensive uterine and pelvic capillary and venous systems.

falls (Figure 30.7.7). In an otherwise closed system, any discrepancy between these volumes would indicate loss of fluid into the patient's circulation. This method of fluid loss has been termed "high pressure" fluid absorption that, in practice, is usually caused by complete or partial blockage of the outflow channel of the hysteroscope by debris and can be corrected by clearing this channel with reverse flushing.

A second mechanism for loss of fluid into the circulation has now been identified.[6] If the laser fiber or the resectoscope loop cuts too deeply into the myometrium, it may enter a large radial vessel. In such circumstances, the fluid inside the cavity at a pressure of 50 mm Hg or more, is in direct communication with the major venous system at a pressure of 5 to 10 mm Hg. Rapid and perhaps massive fluid shift will occur down this pressure gradient. Figure 30.7.8 illustrates the development of such a fistulous communication between the cavity and the pelvic venous system. This mechanism is characterized by a loss of intrauterine pressure, a partial collapse of the cavity, and a loss of vision because of bleeding from the no longer tamponaded vessels, and can be termed "low pressure." Preliminary work suggests that fluid absorption from this type of mechanism may be slowed by attempting to compress the uterine veins by increasing the uterine muscle tone with intravenous oxytocin.[6]

In conclusion, the essential prerequisites for hysteroscopic surgery include a continuous flow hysteroscope, connected in closed circuit, with a system enabling intrauterine pressure to be controlled. Such careful control of the intrauterine environment must be combined with careful surgical technique to ensure that the laser or the electrosurgical device remains in the superficial layers of the myometrium and thereby avoids the risk of penetration into the deeper large vessels.

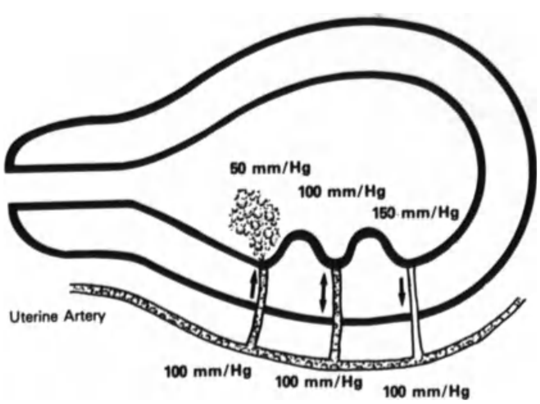


FIGURE 30.7.6. Effect of variations in intrauterine pressure on the direction of flow in the uterine circulation.

Endometrial Ablation

Excessive uterine bleeding is a very common cause of morbidity in women. The most important operative hysteroscopic procedure performed is endometrial ablation for the treatment of this condition. The endometrium has phenomenal powers of regeneration, repairing itself physiologically after every menstruation. To permanently remove the endometrium and prevent its regrowth, it is necessary to remove all the basal glands that are situated deep in the endometrium, immediately above the myometrium.

Milton Goldrath was the first to report the use of an effective hysteroscopic technique for the treatment of excessive uterine bleeding when he described photovaporization of the endometrium with Nd-YAG laser in 1981.[8] The following procedures are currently being investigated:

FIGURE 30.7.7. Hamou Hysteromat automatic pressure-controlled infusion pump.

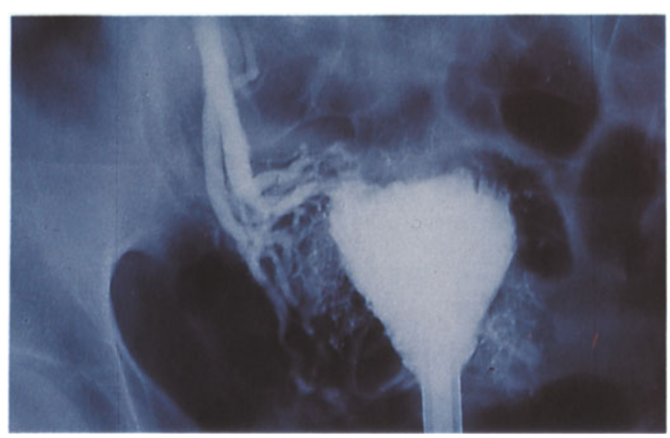


FIGURE 30.7.8. Hysterogram of a fistulous communication between the uterine cavity and a major vein.

1. Nd-YAG laser ablation.
   a. Dragging
   b. Blanching
2. Electrosurgery
   a. Transcervical resection of the endometrium (TCRE)
   b. Rollerball
3. Radiofrequency ablation

Nd-YAG Laser Ablation

The Nd-YAG laser wavelength possesses three properties that make it particularly suitable for endometrial ablation (Figure 30.7.9).

1. The wavelength of 1,068μm permits it to be transmitted down fine flexible quartz fibers, and the energy can thereby be transmitted to almost any site in the body (Figure 30.7.10).
2. Nd-YAG wavelength is not absorbed by water, either in tissues or in distension fluids (Figure 30.7.11). It can, therefore, be used with ease in the fluid-filled uterine cavity, without loss of energy, and can readily be directed at the endometrium via a standard operating hysteroscope.
3. When placed on the surface of a body tissue such as the endometrium, the Nd-YAG energy penetrates deeply, with a zone of tissue destruction of 4 to 6 mm (Figure 30.7.12).

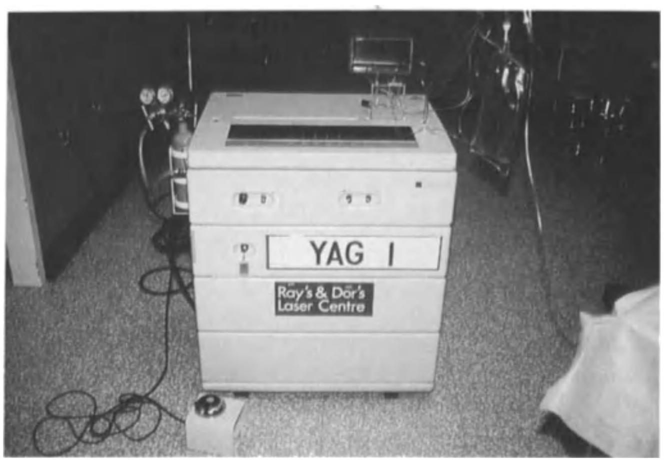


FIGURE 30.7.9. An SLT 100-W Nd-YAG laser.

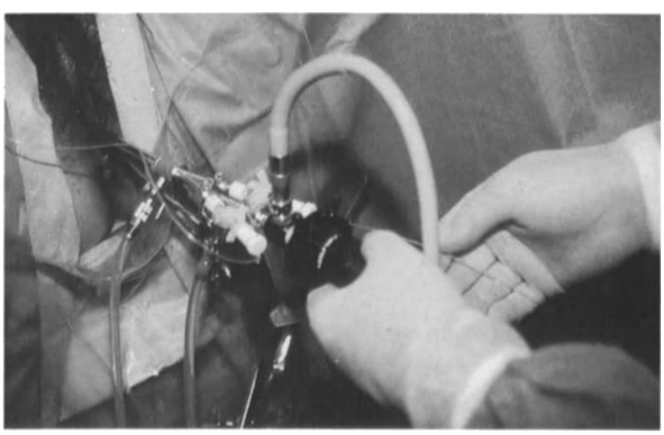


FIGURE 30.7.10. A flexible quartz fiber inserted down an operating hysteroscope.

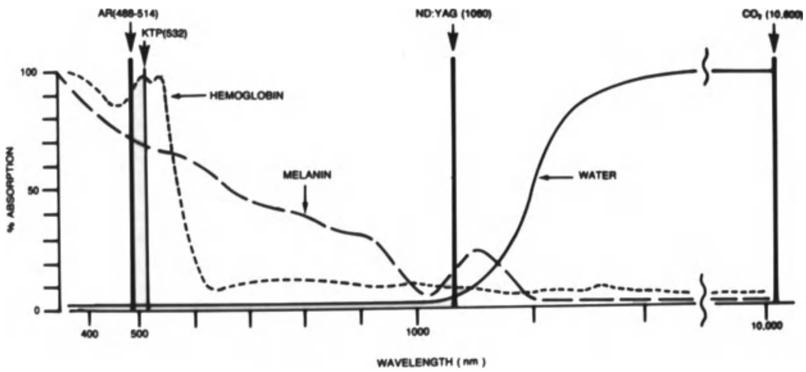
The original method of endometrial laser ablation, as described by Goldrath, involves a dragging technique whereby the laser fiber is placed on the surface of the endometrium and fired as it is pulled toward the operator (Figure 30.7.13). This process is repeated until a series of parallel furrows are created that completely cover the endometrium, in the manner of ploughing a field (Figure 30.7.14). The important points of this technique are that the laser should only be fired when: the tip of the fiber illuminated with a He-Ne laser is clearly seen; and when the fiber is being drawn toward the operator. A second method of Nd-YAG laser ablation has been described by Lomano[9] in which the fiber is held a short distance away from the surface of the endometrium and a true photocoagulation effect produced. This technique is difficult to perform in some areas of the uterus. Treated tissue is less clearly differentiated from nontreated areas and, perhaps, because of these points, the technique appears to be less successful. The author recommends the dragging method. This technique is effective because the Nd-YAG laser energy penetrates 5 mm below and around the fiber. To ensure good results, it is necessary to pretreat the patient with Danazol or a Gn-RH analogue to ensure a thin "resting phase" endometrium.

Electrosurgical Resection

Transcervical Resection of the Endometrium (TCRE)

An endometrial resectoscope is a modification of the instrument used for many years by urologists. It consists of an active cutting loop contained in an outer sheath of 8 to 9 mm in diameter (Figure 30.7.15). The cutting effect of an electrosurgical loop is produced by microarcing from the electrode to the tissue. To obtain the optimum cutting effect, it is important to activate the electrode slightly before pushing it into the tissue to be excised. Various size electrodes can be used and it is important to select the size with care. If the loop is 8 mm in diameter, the maximum depth of cut obtained in one pass should be the radius, that is, 4 mm. As with the laser fiber, the electrode should only be activated when pulling the loop toward the cervix, never when pushing it away toward the fundus. Two techniques are used for removing chips.

FIGURE 30.7.11. Absorption of various laser wavelengths by water, blood, and hemosiderin.



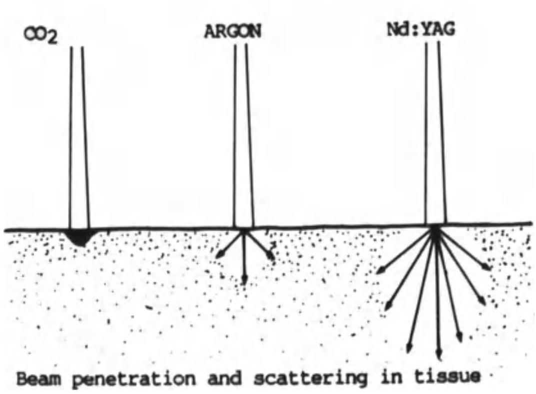


FIGURE 30.7.12. Relative tissue penetration of various lasers.

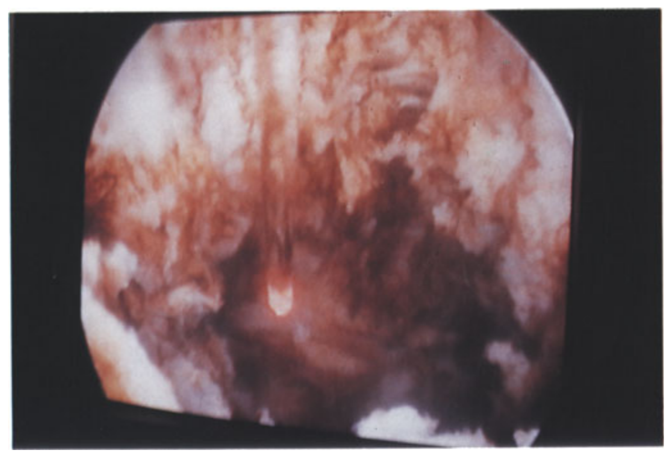


FIGURE 30.7.14. Completed endometrial laser ablation as seen on a video monitor.

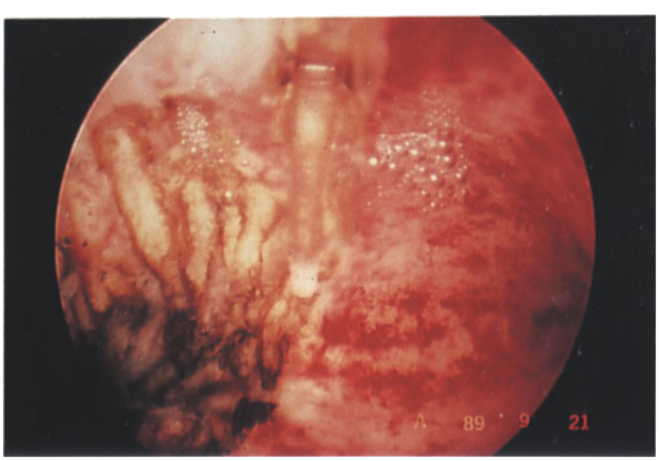


FIGURE 30.7.13. "Dragging" technique with a series of parallel furrows in the endometrium.

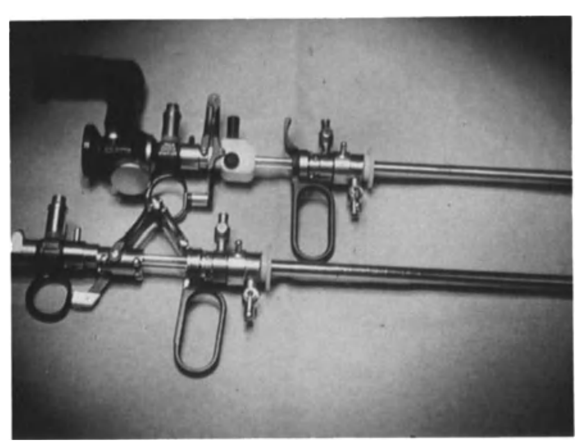


FIGURE 30.7.15. Two Storz resectoscopes.

Some authorities prefer to remove the chips strip by strip and concentrate on producing strips the length of the cavity. This method requires the loop to be held still in relation to the body of the hysteroscope, and the whole resectoscope to be moved. The main advantage of this technique is that the chips are removed as they are produced and so do not obscure vision. The disadvantages are that there is fluid leak every time the resectoscope is removed, with consequent loss of pressure, and increased risk of bleeding, thereby obscuring vision. The alternative technique is to select an appropriate position in the cavity and to then keep the resectoscope fixed at this level until all endometrium in that area has been removed. Chips are removed by closing the handles and pulling the loop into the barrel of the resectoscope, relying on the travel of the cutting loop.[11] As the chips produced in this manner are smaller, they can more conveniently be "parked" in a treated area so that the procedure can be completed without interruption.

A resection should begin in the cornual areas where the myometrium is thinnest and access most restricted, then extend across the fundus, and next to the posterior wall. This will avoid chippings subsequently falling in this area and obscuring the view. It is completed by treating the anterior wall at each level. The resection should remove all the endometrium and 2 to 3 mm of myometrium. It should remove all endometrial downgrowths but avoid the larger vessels. The cut should continue until the circular muscle fibers are reached (Figure 30.7.16). In the United Kingdom, almost all procedures are continued down to the level of the internal os (total resection), but in many parts of Europe, the final 1 cm of endometrium just above the internal os is resected and not removed (partial resection). This partial resection is performed to ensure that amenorrhoea does not occur in women wishing to retain a light menstrual flow.

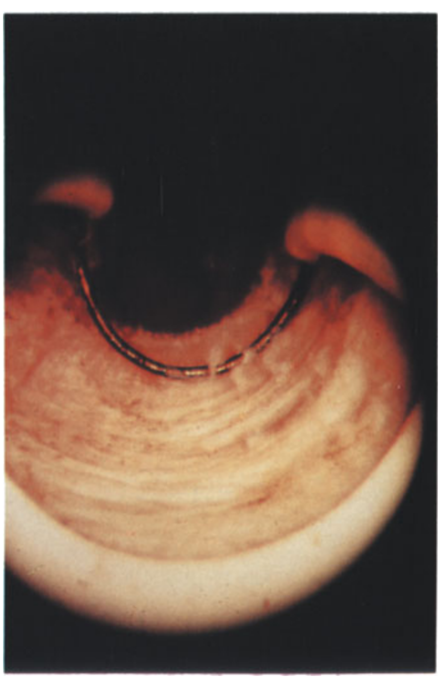


FIGURE 30.7.16. Circular myometrial fibers seen during TCRE.

Rollerball Endometrial Electroablation

The rollerball produces an effect similar to that produced by a Nd-YAG laser, with equipment similar to that used for endometrial resection. The loop electrode of the resectoscope is replaced with a ball- or bar-shaped electrode. When such a large electrode comes into contact with tissue, it produces coagulation and desiccation, rather than arcing and cutting, because the large surface area allows the energy to rapidly escape into the tissues. Vancaillie[12,13] recommends considering the rollerball ablation to occur in two phases. The first or initiation phase requires the operator to press the electrode into contact with the tissue and activate the current. A relatively large volume of tissue will be coagulated and the current flow should be maintained until blanching is observed around the electrode. When this phase has been completed, the second or dynamic phase follows. The operator can move the electrode downward toward the canal. The rate of movement is dependent on the speed at which blanching occurs in front of the electrode when 40 to 60 W of coagulation current is used (Figure 30.7.17). When the electrode has moved beyond the original zone of tissue damage, only the advancing edge contacts uncoagulated tissue. The rest of the ball is passing over already coagulated tissue that now has a high tissue impedence. The most important part of the technique is the surgeon maintaining a slow, steady progression of the ball over the

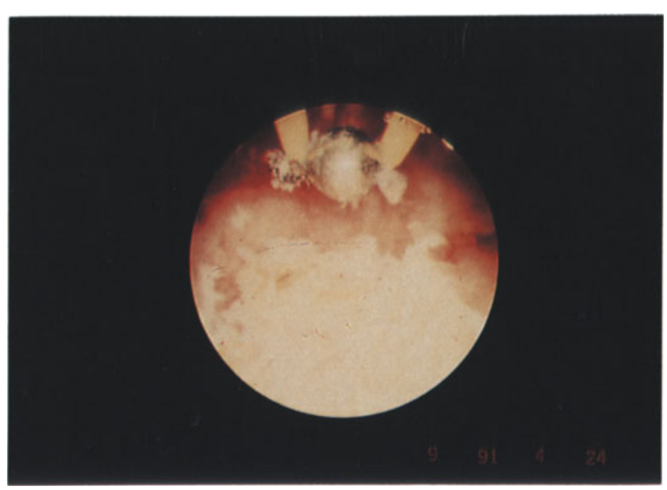


FIGURE 30.7.17. Blanching in front of an advancing rollerball electrode.

endometrium (Figure 30.7.18). As a variable thickness of endometrium would produce variable results, it is important for the success of this method to pretreat the endometrium with danazol or Gn-RH anagonists to produce a predictably thin layer of endometrium.

Results

Each of these methods attempts to achieve the same goal of removing the whole thickness of the endometrium, together with 2 to 3 mm of superficial myometrium. It is not surprising that in skilled hands, the results obtained with each treatment modality should be the same (Table 30.7.1). The complication rate following these interventions, however, appears to be different. TCRE is associated with a greater risk of hemorrhage, perforation, and need for immediate laparotomy than ELA. Rollerball ablation seems to have risks nearer ELA and may turn out to be the optimum procedure when both clinical and financial factors are considered (Table 30.7.2).

Conclusions

It would seem that serious complications are rare with all methods of endometrial ablation. TCRE, however, appears to be associated with a higher morbidity than ELA, and although the data from Australia includes some TCRE cases, and some treated with both rollerball and TCRE, it suggests that the complication rate following rollerball falls somewhere between the other two modalities.

To achieve such good results, however, it is essential to have adequate modern equipment, to understand the principles of the equipment used, and to carefully use the techniques in the appropriate manner. When these principles are respected, endometrial ablation appears to be one of the most effective of all endoscopic procedures.

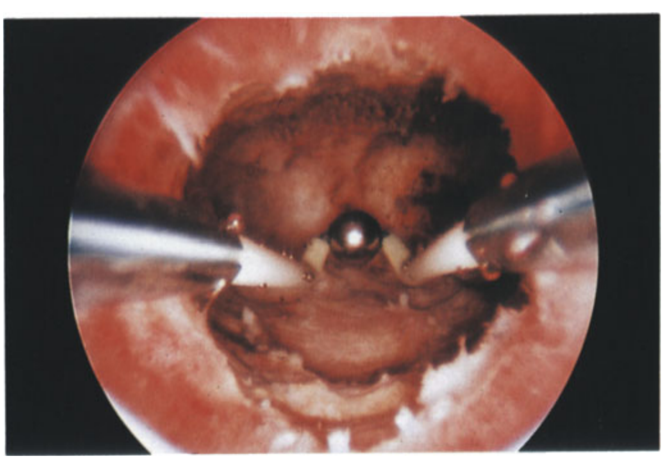


FIGURE 30.7.18. Uterine cavity after rollerball ablation. (Courtesy of J Hamou.)

TABLE 30.7.1. Metanalysis of the results with various methods of ablation.

	ELA	TCRE	Rollerball	RaFE
Number	1,173 (3 units)	1,054 (5 units)	90 (1 unit)	219 (4 units)
Amenorrhea	29–60%	6–59%	20%	42%
Improved	81–97%	92–95%	94%	93%
Failed	3–19%	6–8%	6%	7%

Although the clinical outcome following each of these treatments is virtually identical, the complication rate is not (Table 30.7.2).

TABLE 30.7.2. Metanalysis of complications of various methods of ablation.

	ELA	TCRE	Rollerball*
Number	850	1,054	800
Perforation	0	20 (2%)	8 (1%)
Hemorrhage	0	22 (2%)	9 (1%)
Laparotomy	0	20 (2%)	8 (1%)

References:
ELA Authors unpublished personal series
TCRE Magos et al.[11]
Rollerball Fraser and Pettruco[14]
*Series not exclusive

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30.8
Laparoscopic Hysterectomy

Harry Reich

Introduction

Of the 600,000 hysterectomies performed each year, over 60% are presently accomplished using an abdominal incision.[1] Abdominal hysterectomy will probably become a rarely used procedure, however, because laparoscopy, properly applied, can be effectively used to accomplish a less invasive vaginal hysterectomy. Laparoscopic-assisted vaginal hysterectomy (LAVH) may encourage surgeons to become skilled in vaginal surgery.

Laparoscopic hysterectomy, defined as the laparoscopic ligation of the uterine vessels, is an alternative to abdominal hysterectomy which allows precise attention to ureteral identification.[2–4] First performed in January 1988,[5] laparoscopic hysterectomy (LH) has stimulated a general interest in the laparoscopic approach to hysterectomy that has reached its zenith in the LAVH. LAVH has become an expensive procedure, and skilled vaginal surgeons will not often see sufficient indication for its use. LH remains a reasonable substitute for abdominal hysterectomy.

Most hysterectomies presently requiring an abdominal approach may be performed by laparoscopic dissection of part or all of the abdominal portion, followed by vaginal removal. There are many surgical advantages to laparoscopy, particularly magnification of anatomy and pathology, easy access to the vagina and rectum, and the ability to achieve complete hemostasis and clot evacuation during underwater examination. Patient advantages are many. They include avoidance of a painful abdominal incision, reduced duration of hospitalization and recuperation, and an extremely low rate of infection and ileus. Vaginal surgery by competent surgeons, compared to abdominal surgery, reduces blood loss and respiratory problems and does not require exposure of the bowel.

The goal of vaginal hysterectomy, LAVH, or LH is to safely avoid an abdominal wall incision. The surgeon must remember that if vaginal hysterectomy is possible after ligating the utero-ovarian ligaments, it should be done. Laparoscopic inspection at the end will still allow the surgeon to control any bleeding and evacuate clots. Unnecessary surgery should not be done because of the surgeon's preoccupation with the development of new surgical skills. LH is not indicated when vaginal hysterectomy is possible.

Definitions

There are a variety of procedures for which the laparoscope is useful as an aid to hysterectomy (Table 30.8.1). It is important that these different procedures be clearly delineated. *Diagnostic laparoscopy with vaginal hysterectomy* is the use of the laparoscope for *diagnostic* purposes when indications for a vaginal approach are equivocal, to determine if vaginal hysterectomy is possible.[6] It also ensures that vaginal cuff and pedicle hemostasis are complete and allows clot evacuation.

Laparoscopic-assisted vaginal hysterectomy is a vaginal hysterectomy after laparoscopic adhesiolysis, endometriosis excision, or oophorectomy.[7–9] Unfortunately, this term is also used to refer to staple ligation of the upper uterine blood supply of a relatively normal uterus. It must be emphasized that in most cases the easy part of both

TABLE 30.8.1. Laparoscopic hysterectomy classification.

1. Diagnostic laparoscopy with vaginal hysterectomy
2. Laparoscopic-assisted vaginal hysterectomy (LAVH)
3. Laparoscopic hysterectomy (LH)
4. Total laparoscopic hysterectomy (TLH)
5. Laparoscopic supracervical hysterectomy (LSH)—including CASH (classical abdominal Semm hysterectomy)
6. Vaginal hysterectomy with laparoscopic vault suspension (LVS) or laparoscopic pelvic reconstruction (LPR)
7. Laparoscopic hysterectomy with lymphadenectomy
8. Laparoscopic hysterectomy with lymphadenectomy and omentectomy
9. Laparoscopic radical hysterectomy with lymphadenectomy

abdominal and vaginal hysterectomy is upper pedicle ligation.

Laparoscopic hysterectomy denotes laparoscopic ligation of the uterine arteries either by electrosurgery desiccation, suture ligature, or staples. All maneuvers after uterine vessel ligation can be done vaginally or laparoscopically, including anterior and posterior vaginal entry, cardinal and uterosacral ligaments division, uterine removal intact or by morcellation, and vaginal closure vertically or transversely. Laparoscopic ligation of the uterine vessels is the *sine qua non* for laparoscopic hysterectomy. Ureteral isolation has always been advised.

Total laparoscopic hysterectomy (TLH) is a laparoscopic-assisted abdominal hysterectomy. Laparoscopic dissection continues until the uterus lies free of all attachments in the peritoneal cavity. The uterus is removed through the vagina with morcellation if necessary. The vagina is closed with laparoscopically placed sutures.

Laparoscopic supracervical hysterectomy (LSH) has recently regained advocates after suggestions that total hysterectomy results in a decrease in libido.[10] The uterus is removed by morcellation from above or below. Kurt Semm's version of supracervical hysterectomy, called the CASH procedure (classical abdominal Semm hysterectomy), leaves the cardinal ligaments intact while eliminating the columnar cells of the endocervical canal. After perforating the uterine fundus with a long sound-dilator, a calibrated uterine resection tool (CURT) that fits around this instrument is used to core out the endocervical canal. Thereafter, at laparoscopy, suture techniques are used to ligate the utero-ovarian ligaments. An Endoloop is placed around the uterine fundus to the level of the internal os of the cervix and tied. The uterus is divided at its junction with the cervix and removed by laparoscopic morcellation.

Laparoscopic pelvic reconstruction (LPR) with vaginal hysterectomy is useful when vaginal hysterectomy alone cannot accomplish appropriate repair for prolapse. Ureteral dissection and suture placement before the vaginal hysterectomy aid in high uterosacral ligament identification and plication near the sacrum. Levator muscle plication from below or above is often necessary. Retropubic colposuspension can also be done laparoscopically.

Indications

Indications for laparoscopic hysterectomy include benign pathology such as endometriosis, fibroids, adhesions, and adnexal masses usually requiring the selection of an abdominal approach to hysterectomy. It is also appropriate when vaginal hysterectomy is contraindicated because of a narrow pubic arch, a narrow vagina with no prolapse, or severe arthritis that prohibits placement of the patient in sufficient lithotomy position for vaginal exposure. Laparoscopic procedures in obese women allow the surgeon to make an incision above the panniculus and operate below it. Laparoscopic hysterectomy may also be considered for stage I endometrial, ovarian, and cervical cancer.[11–13] Pelvic reconstruction procedures including cuff suspension, retropubic colposuspension, and rectocele repair may be accomplished through the laparoscope.

The most common indication for laparoscopic hysterectomy is a symptomatic fibroid uterus. Morcellation is often necessary. Fibroids fixed in the pelvis or abdomen without descent are easier to mobilize laparoscopically. Uterine size and weight measurements are important to document the appropriateness of laparoscopic hysterectomy, since most small uteri can be removed vaginally. The normal uterus weighs 70 to 125 g. A 12-week gestational age uterus weighs 280 to 320 g, a 24-week uterus weighs 580 to 620 g, and a term uterus weighs 1,000 to 1,100 g.

Hysterectomy should not be done for stage IV endometriosis with extensive cul-de-sac involvement, unless the surgeon has the capability and the time to resect all deep fibrotic endometriosis from the posterior vagina, uterosacral ligaments, and anterior rectum. Excision of the uterus using an intrafascial technique leaves the deep fibrotic endometriosis behind to cause future problems. It is much more difficult to remove deep fibrotic endometriosis when there is no uterus between the anterior rectum and the bladder; after hysterectomy, the endometriosis left in the anterior rectum and vaginal cuff frequently becomes densely adherent or invades into the bladder and one or both ureters. In many cases of stage IV endometriosis with extensive cul-de-sac obliteration, it is better to preserve the uterus to prevent future vaginal cuff, bladder, and ureteral problems.[14] Obviously, this approach will not be effective when uterine adenomyosis is present. In these cases, after excision of cul-de-sac endometriosis, persistent pain will lead ultimately to hysterectomy. Oophorectomy is not always necessary at hysterectomy; if the endometriosis is carefully removed, it is less likely to recur. Bilateral oophorectomy is rarely indicated in women under age 40 who undergo hysterectomy for endometriosis.

Hysterectomy is performed for abnormal uterine bleeding in women of reproductive age. *Abnormal uterine bleeding* is defined as excessive uterine bleeding or irregular uterine bleeding for more than eight days during more than a single cycle, or as profuse bleeding requiring additional protection (large clots, gushes, or limitations on activity). There should be no history of a bleeding diathesis or use of medication that may cause bleeding. A negative effect on quality of life should be documented. Physical examination, laboratory data, ultrasound, and hysteroscopy are frequently negative. Hormone treatment is attempted before hysterectomy, and its failure, contraindication, or refusal is documented. The presence of anemia is recorded and correction attempted. If hysterectomy is chosen, a vaginal approach is usually appropriate. Laparoscopic hysterectomy is done when vaginal hysterectomy is not possible, including history of previous surgery, lack of prolapse (nulliparous or multiparous), or inexperience of the operator with the vaginal approach. Recognition of vaginal surgery inexperience is important; in many countries vaginal hysterectomy is not done.

Contraindications

Laparoscopic hysterectomy is not advised for the diagnosis and treatment of a pelvic mass that is too large to fit intact into an impermeable sack. The largest available sack for removal of intraperitoneal masses is the LapSac (Cook Ob/Gyn, Spencer, IN), which measures 8 × 5 in. While cyst aspiration is advocated by some investigators,[15] this author feels that postmenopausal cystic ovaries should not be subjected to fluid aspiration before oophorectomy because the inevitable spillage changes the diagnosis from a stage Ia ovarian cancer to a stage Ia with spill. Its effect on survival is unknown, but it may be detrimental. It must be emphasized that small-gauge needles, placement through thickened portions of the ovary, and cyst aspiration devices with surrounding suction and Endoloop placement do not prevent spillage. Ovaries should be removed intact through a culdotomy incision.[16]

The medical status of the patient may prohibit surgery. Anemia, diabetes, lung disorders, cardiac disease, and bleeding diathesis must be evaluated prior to surgery. Age should rarely be a deterrent.

Cesarean hysterectomy is an absolute contraindication. Peripartum hysterectomy for placenta accreta, uterine atony, unspecified uterine bleeding, and uterine rupture are relative contraindications at present. Laparoscopic hysterectomy may be considered for patients needing a postpartum hysterectomy. Another contraindication is stage-III ovarian cancer, which requires a large abdominal incision. Finally, inexperience of the surgeon is a contraindication to the laparoscopic approach.

Equipment

High-flow CO_2 insufflation up to 10 to 15 L/min is necessary to compensate for the rapid loss of CO_2 during suctioning. The ability to maintain a relatively constant intra-abdominal pressure between 10 and 15 mm Hg during laparoscopic hysterectomy is essential. Gasless laparoscopy with abdominal wall retractors is used to minimize abdominal wall subcutaneous emphysema during retroperitoneal surgery, since peritoneal defects resulting in free subcutaneous communication may compromise peritoneal cavity operating space. A useful technique is to insert a Laparolift anterior abdominal wall retractor (Origin Medsystems, Menlo Park, CA), once the vagina is opened, to maintain working space.

Operating room tables capable of a 30° Trendelenburg position are extremely valuable for laparoscopic hysterectomy. Unfortunately these tables are rare, and this author has much difficulty operating when only a limited degree of body tilt can be attained. For the past 16 years, steep Trendelenburg position (20 to 40°), with shoulder braces and the arms at the patient's sides, has been used without adverse effects.

A Valtchev uterine mobilizer (Conkin Surgical Instruments, Toronto, ON) is the best available single instrument to antevert the uterus and delineate the posterior vagina.[17] The uterus can be anteverted to about 120° and moved in an arc about 45° to the left or right by turning the mobilizer around its longitudinal axis. Either the 100-mm long and 10-mm thick or the 80-mm long and 8-mm thick obturator may be used for uterine manipulation during hysterectomy.

If a Valtchev uterine mobilizer is not available, a sponge on a ring forceps is inserted into the posterior vaginal fornix and an 81F rectal probe (Reznik Instruments, Skokie, IL) is placed in the rectum to define the rectum and posterior vagina to excise endometriosis or to open the posterior vagina (culdotomy). In addition, a no. 3 or 4 Sims curette is placed in the endometrial cavity to antevert the uterus markedly and stretch out the cul-de-sac. The rectal probe and intraoperative rectovaginal examinations remain important techniques even when the Valtchev is available. Whenever rectal location is in doubt, it is identified by placing a probe.

Trocar sleeves are available in many sizes and shapes. For most cases, 5.5-mm cannulae are adequate. Newer electrosurgical electrodes that eliminate capacitance and insulation failures (Electroshield from Electroscope, Boulder, CO) require 7- to 8-mm sleeves. Laparoscopic stapling is performed through 12- to 13-mm Surgiports (US Surgical Corporation, Norwalk, CT). However, disposable stapling instruments (US Surgical) are rarely used for large vessel hemostasis during laparoscopic hysterectomy.

Short trapless 5-mm trocar sleeves with a retention screw grid around the external surface (Richard Wolf Medical Instruments, Vernon Hills, IL; Apple Medical, Bolton, MA) are used to facilitate efficient instrument exchanges and evacuation of tissue while allowing unlimited freedom during extracorporeal suture tying.[18] With practice, a good laparoscopic surgical team will be able to make instrument exchanges so fast that little pneumoperitoneum will be lost.

Bipolar forceps use high-frequency low-voltage cutting current (20 to 50 W) to coagulate vessels as large as the ovarian and uterine arteries. The Kleppinger bipolar forceps (Richard Wolf) are excellent for large vessel hemostasis. Specially insulated bipolar forceps are available that allow current to pass through their tips for precise hemostasis. Microbipolar forceps contain a channel for irrigation and a fixed distance between the electrodes. They are used to irrigate bleeding sites for vessel identification before coagulation and to prevent sticking of the electrode to the eschar that is created. Irrigation is used during underwater examination to identify the bleeding vessel before coagulation by removing surrounding blood products. Disposable stapling instruments (US Surgical) are rarely used during laparoscopic hysterectomy because of their expense. Suture and/or bipolar desiccation work better.

Suturing

In 1970, Dr. H. Courtenay Clarke used a knot pusher (Marlow Surgical, Willoughby, OH) for laparoscopic suturing to tie in a manner very similar to the way one would hand-tie suture at open laparotomy.[19] This device is just like an extension of the surgeon's fingers.

To suture with a stick tie, the surgeon applies the suture around the vessel, pulls the loose end outside, and then, while holding both strands, makes a simple half hitch, but not a surgeon's knot, which will not slip as well. The Clarke knot pusher is put on the suture, held firmly across the index finger, and the throw is pushed down to the tissue. A square knot is made by pushing another half hitch down to the knot to secure it, while exerting tension from above.

Suturing with large curved needles requires a special technique to put them into a peritoneal cavity where there is a small incision, that is, through a 5-mm lower quadrant incision.[20] The lower abdominal incisions are placed lateral to the deep epigastric vessels, and thus, lateral to the rectus muscle. The trocar sleeve penetrates skin, external and internal oblique, transversalis, and peritoneum. A tract is obvious upon removing the trocar sleeve and is very easy to re-enter. To suture with a CT-1 needle, the trocar sleeve is taken out of the abdomen and loaded by grasping the end of the suture with a needle holder, pulling it through the trocar sleeve, reinserting the instrument into the sleeve, and grasping the suture about 2 to 3 cm from the needle. The needle driver is inserted into the peritoneal cavity through the original tract, as visualized on the monitor; the needle follows. Even large needles can be pulled into the peritoneal cavity in this manner. At this stage, the Semm straight needle holder (WISAP) is replaced with a Cook oblique curved needle driver (Cook Ob/Gyn, Spencer, IN), and the needle applied to tissue. Afterward, the needle is stored in the anterior abdominal wall parietal peritoneum (like a pin cushion) for later removal after the suture is tied. The needle is cut, the cut end of the suture pulled out of the peritoneal cavity, and the knot tied with the Clarke knot pusher. To retrieve the needle, the trocar sleeve is unscrewed after which the needle holder inside it pulls the needle through the soft tissue after grasping its attached suture remnant. The trocar sleeve is replaced easily with or without another suture.

Preoperative Preparation

The preoperative use of gonadotropin-releasing hormone (GnRH) analogs for at least two months before hysterectomy for large myomas is encouraged. GnRH analogs may reduce the total uterine and leiomyoma volumes, making laparoscopic or vaginal hysterectomy easier.[21,22] During treatment with depoleuprolide (Lupron-Depot) at a dose of 3.75 mg IM once per month for three to six months, anemia secondary to hypermenorrhea will resolve, and autologous blood donation can be considered prior to laparoscopic hysterectomy. Packed red blood cells have a shelf life of 35 days if stored at 1 to 6°C. In addition, Lupron-Depot is often administered after ovulation in the cycle preceding surgery to avoid operating on ovaries containing a corpus luteum.

Patients are encouraged to hydrate and eat lightly for 24 hours before admission on the day of surgery. When extensive cul-de-sac involvement with endometriosis is suspected, a mechanical bowel prep is ordered (Polyethylene glycol-based isosmotic solution: Golytely or Colyte). Lower abdominal, pubic, and perineal hair is *not* shaved. A Foley catheter is inserted during surgery and removed the next morning. Antibiotics (usually cefoxitin) are administered at the two-hour mark in all surgeries lasting over two hours.

Positioning of the Patient

All laparoscopic surgical procedures are done under general anesthesia with endotracheal intubation and an orogastric tube. The routine use of an orogastric tube is recommended to diminish the possibility of a trocar injury to the stomach and to reduce small bowel distension. The patient is flat (0°) until the umbilical trocar sleeve has been inserted and then is placed in steep Trendelenburg position (20 to 30°). Lithotomy position with the hip extended (thigh parallel to abdomen) is obtained with Allan stirrups (Edgewater Medical Systems, Mayfield Heights, OH) or knee braces, that are adjusted to each individual patient before anesthesia. Self-retaining lateral vaginal wall retractors or Vienna retractors (Brisky-Navatril) are used when quick vaginal uterine extraction is anticipated. With large fibroids, the stirrups are replaced with candy-cane stirrups for the vaginal part, in order to obtain better hip flexion so that vaginal sidewall retractors can be used. Examination under anesthesia is always performed prior to prepping the patient.

Laparoscopy was never thought to be a sterile procedure before the incorporation of video, as the surgeon operated with his head in the surgical field, attached to the laparoscopic optic. It is not possible to sterilize skin. Since 1983, this author has maintained a policy of not sterilizing or draping the camera or laser arm. Infection has been rare: less than 1 per 200 cases. The umbilical incision is closed with a single 4–0 Vicryl suture opposing deep fascia and skin dermis, with the knot buried beneath the fascia to prevent the suture from acting like a wick to transmit bacteria into the soft tissue or peritoneal cavity. The lower quadrant incisions are loosely approximated with a Javid vascular clamp (V. Mueller, McGaw Park, IL) and covered with Collodion (AMEND, Irvington, NJ) to allow drainage of excess Ringer's lactate solution.

Total Laparoscopic Hysterectomy Technique

Incisions

Three laparoscopic puncture sites, including the umbilicus, are used: 10- or 12-mm umbilical, 5-mm right, and 5-mm left lower quadrant. The left lower quadrant puncture is the major portal for operative manipulation. The right trocar sleeve is used for retraction with atraumatic grasping forceps. When the Multi-fire Endo GIA 30 was used, it was inserted through the umbilical incision, and the procedure was viewed through a 5-mm laparoscope in one of the 5-mm lower quadrant sites. This is no longer used.

In most cases, a vertical midline incision on the inferior wall of the umbilical fossa extending to and just beyond its lowest point is used. Veress needle insufflation is continued until a pressure of 20 to 25 mm Hg is obtained, usually after 4 to 6 L CO_2. It is not necessary to lift the anterior abdominal wall during trocar insertion after establishment of a 4- to 6-L pneumoperitoneum at 20 to 25 mm Hg, because the parietal peritoneum and skin move as one. The palmed Apple trocar is positioned with moderate pressure in the incision to the peritoneum at a 90° angle and is upturned to approximately 30° in one continuous thrusting motion, with the wrist rotating nearly 90°. The result is a parietal peritoneal puncture directly beneath the umbilicus. The high pressure settings used during initial insertion of the trocar are lowered thereafter to diminish the development of vena caval compression and subcutaneous emphysema. A relatively constant 10 to 15 mm Hg intra-abdominal pressure is maintained during long laparoscopic procedures.

Special entry techniques are necessary in patients who have undergone multiple laparotomies, who have lower abdominal incisions traversing the umbilicus, or who have extensive adhesions either clinically or from a previous surgery. Open laparoscopy or microlaparotomy carry the same risk for bowel laceration if the bowel is fused to the umbilical undersurface. In these cases, Veress needle puncture is done in the left ninth intercostal space, anterior axillary line. Adhesions are rare in this area, and the peritoneum is tethered to the undersurface of the ribs, making subcutaneous insufflation unusual. A disposable Veress needle is grasped near its tip, like a dart, between thumb and forefinger. The needle tip is then inserted at right angles to the skin, but at a 45° angle to the horizontal anterior abdominal wall between the ninth and tenth ribs. A single pop is felt on penetration of the peritoneum. Pneumoperitoneum to a pressure of 20 to 25 mm Hg is obtained. A 5- or 10-mm trocar is then inserted at the left costal margin in the midclavicular line, giving a panoramic view of the entire peritoneal cavity.

Placement of the lower quadrant trocar sleeves under direct laparoscopic vision, just above the pubic hairline, and lateral to the rectus abdominis muscles (and thus, the deep epigastric vessels) is preferred. These vessels, an artery flanked by two veins (venae comitantes), are located lateral to the umbilical ligaments (obliterated umbilical artery). These can be identified by direct laparoscopic inspection of the anterior abdominal wall. The deep epigastric vessels arise near the junction of the external iliac vessels with the femoral vessels and make up the medial border of the internal inguinal ring. The round ligament curls around these vessels to enter the inguinal canal. When the anterior abdominal wall parietal peritoneum is thickened from previous surgery or obesity, the position of these vessels is judged by palpating and depressing the anterior abdominal wall with the back of the scalpel; the wall will appear thicker where rectus muscle is enclosed, and the incision site is made lateral to this area near the anterior superior iliac spine.

Vaginal Preparation

The endocervical canal is dilated to Pratt no. 25, and the Valtchev uterine mobilizer (Conkin Surgical Instruments) is inserted to antevert the uterus and delineate the posterior vagina. When the uterus is in the anteverted position, the cervix sits on a wide pedestal, making the vagina readily visible between the uterosacral ligaments when the cul-de-sac is viewed laparoscopically . Hysteroscopy with CO_2 may be done during insufflation of pneumoperitoneum to identify the location of the fibroids.

Exploration (Figures 30.8.1–30.8.4)

The upper abdomen is inspected, and the appendix is identified. If appendiceal pathology is present, that is, dilatation, adhesions, or endometriosis, appendectomy is

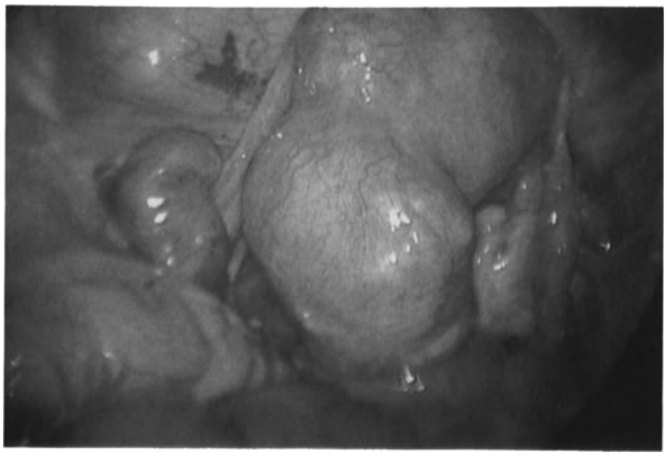

FIGURE 30.8.1. Large fibroid uterus and left hydrosalpinx visualized. In addition, rectum is stuck to back of uterus.

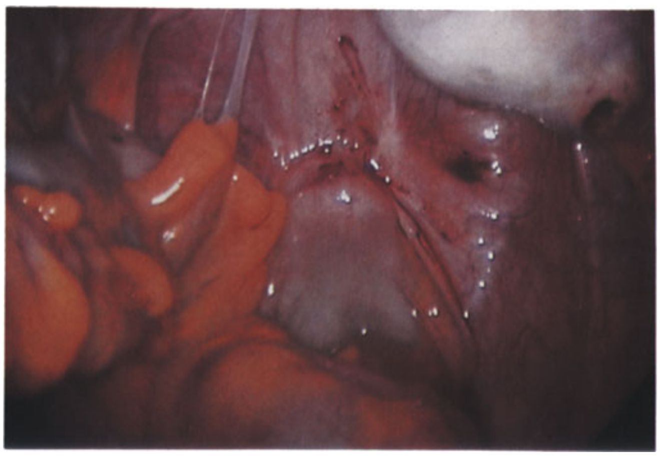

FIGURE 30.8.2. Rectum is noted to be stuck to posterior uterus and cervix by thick fibrotic endometriosis.

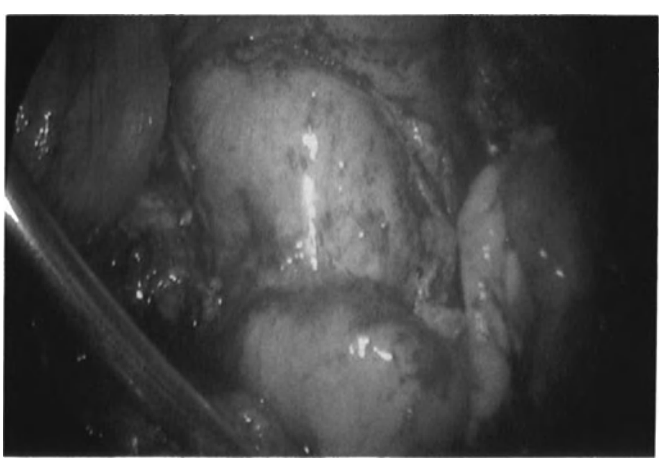

FIGURE 30.8.3. Cicatricial lesion noted across anterior rectum. Initial incision can be seen at top of picture where rectum is to be freed from cervix.

performed after ureteral isolation. This is done by mobilizing the appendix, desiccating its blood supply, and placing three Endoloops [Endoloop (chromic gut ligature), Ethicon, Somerville, NJ] at the appendiceal-cecal junction after desiccating the appendix just above this juncture. The appendix is left attached to the cecum; its stump is divided later in the procedure, after opening the cul-de-sac, so that removal from the peritoneal cavity is accomplished immediately after separation.

Ureteral Dissection (Figure 30.8.5)

Immediately after exploration of the upper abdomen and pelvis, each ureter is isolated deep in the pelvis, if possible. This is done early in the operation, before the pelvic

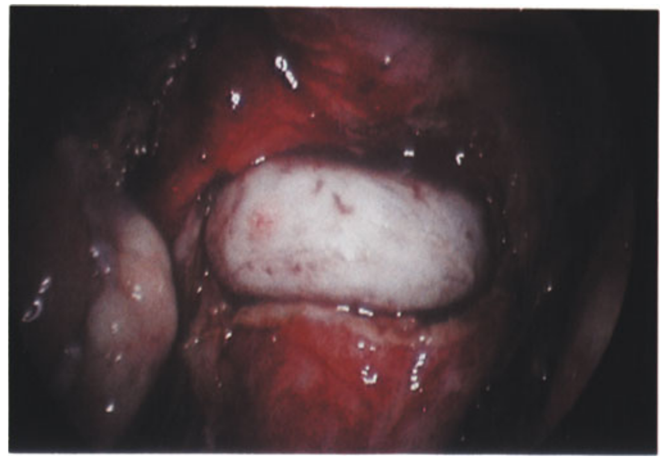

FIGURE 30.8.4. Posterior vagina identified between the uterosacral ligaments after freeing rectum from it and excising the deep fibrotic endometriosis that was between the posterior vagina and anterior rectum. A sponge on a ring forceps placed behind the cervix is used to delineate the top of the posterior vaginal fornix.

FIGURE 30.8.5. Left ureter is isolated. Left uterine artery can be seen crossing it.

sidewall peritoneum becomes edematous or opaque from irritation by the CO_2 pneumoperitoneum or aquadissection, and before ureteral peristalsis is inhibited by surgical stress, pressure, or the Trendelenburg position. The ureter and its overlying peritoneum are grasped deep in the pelvis, on the left, below the lateral rectosigmoid attachments at the pelvic brim. An atraumatic grasping forceps is used from a right-sided cannula to grab the ureter and its overlying peritoneum, on the left pelvic sidewall below and caudad to the left ovary, lateral to the left uterosacral ligament. Scissors are used to divide the peritoneum overlying the ureter, and are inserted into the defect created and spread. Thereafter, one blade of the scissors is placed on top of the ureter, the buried scissors blade is visualized through the peritoneum, and the peritoneum is divided. This is continued into the deep pelvis where the uterine vessels cross the ureter, lateral to the cardinal ligament insertion into the cervix. Connective tissue between the ureter and the vessels is separated with scissors. Bleeding is controlled with microbipolar forceps. Often, the uterine vessel ligation procedure below is accomplished at this time, to diminish backbleeding from the upper pedicles.

Bladder Mobilization

The round ligaments are divided at their midportion using a spoon electrode (Electroscope) at 150 W cutting current with minimal bleeding. Persistent bleeding is controlled with monopolar fulguration at 80 W coagulation current or bipolar desiccation at 30 W cutting current (fulguration is the noncontact application of high-voltage coagulation current). Thereafter, scissors or the same electrode are used to divide the vesicouterine peritoneal fold, starting at the left side and continuing across the midline to the right round ligament. The bladder is mobilized off the uterus and upper vagina, using scissors or the same spoon electrode, until the anterior vagina is identified by elevating it from below with ring forceps.

Upper Uterine Blood Supply

When ovarian preservation is desired, the utero-ovarian ligament and fallopian tube pedicle are suture ligated adjacent to the uterus with 0-Vicryl. When ovarian preservation is not desired, the infundibulopelvic ligaments and broad ligaments are coagulated until desiccated with bipolar forceps at 25 to 35 W cutting current and then divided.

Uterine Vessel Ligation

The broad ligament on each side is skeletonized down to the uterine vessels. Each uterine vessel pedicle is suture ligated with 0-Vicryl on a CT-1 needle (27-in.). The needles are introduced into the peritoneal cavity by pulling them through a 5-mm incision.[20] The curved needle is inserted on top of the unroofed ureter where it turns medially towards the previously mobilized bladder. A short rotary movement of the Cook oblique curved needle holder brings the needle around the uterine vessel pedicle. Sutures are tied extracorporeally using a Clarke knot pusher.[19] A single suture placed in this manner on each side serves as a "sentinel stitch," identifying and watching over the ureter for the rest of the procedure (Figure 30.8.6).

Circumferential Culdotomy (Division of Cervicovaginal Attachments)

The cardinal ligaments on each side are divided, with the CO_2 laser at high power (80 W), or with the spoon electrode at 150 W cutting current. Often, bipolar forceps are necessary to control bleeding. The vagina is entered posteriorly over the Valtchev retractor near the junction of cervix with vagina. A ring forceps inserted into the anterior vagina above the tenaculum on the anterior cervical lip identifies the anterior cervicovaginal junction, which is entered using the laser. Following the ring forceps or the Aquapurator tip, and using them as backstops, the lateral vaginal fornices are divided. The uterus is morcellated if necessary and pulled out of the vagina. Alternately, a 4-cm diameter operative colonoscope (Richard Wolf) is used to outline circumferentially the cervicovaginal junction; it also serves as a backstop for laser work (Figures 30.8.7 and 30.8.8).

Laparoscopic Vaginal Vault Closure and Suspension with McCall Culdoplasty

Vaginal repair is accomplished after packing the vagina and placing a Laparomed (Irvine, CA) portsaver retrac-

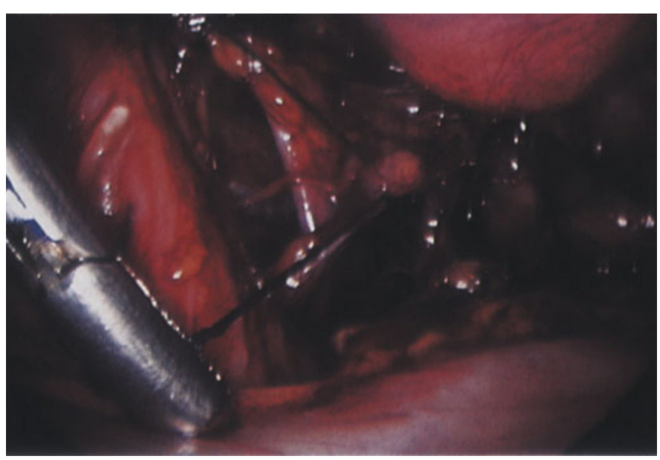

FIGURE 30.8.6. A suture ligature is placed around the left uterine artery near its origin, just before the artery crosses the left ureter.

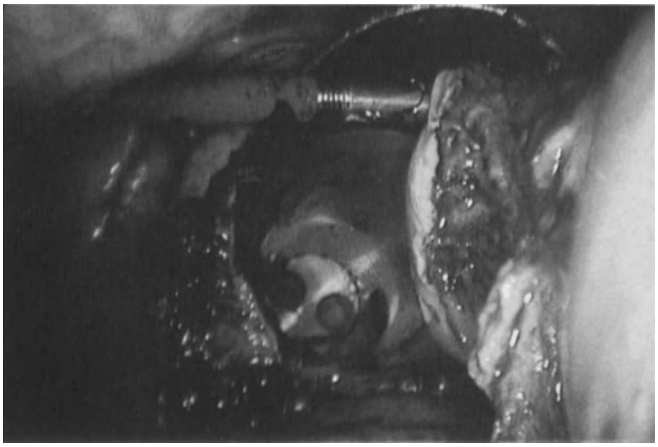

FIGURE 30.8.7. After uterus has been completely freed from vagina, a vaginal delineator similar to the Buess operating sigmoidoscope is used to maintain pneumoperitoneum and a single-tooth tenaculum is inserted through the vaginal delineator to pull out the uterus or at least lodge it into the vagina prior to morcellation by the vaginal route.

FIGURE 30.8.8. Uterus can be seen just inside the vagina. Hemostasis has been obtained around the vaginal cuff.

tion device at the cuff apex (12 o'clock). The left uterosacral ligament and posterolateral vagina are elevated. A suture is placed through this uterosacral ligament into the vagina, exits the vagina including posterior vaginal tissue near the midline on the left, and re-enters just adjacent to this spot on the right. Finally, an opposite-sided oblique Cook needle holder is used to fixate the right posterolateral vagina to the right uterosacral ligament. This suture is tied extracorporeally and gives excellent support to the vaginal cuff apex, elevating it superiorly and posteriorly toward the hollow of the sacrum. The rest of the vagina and the overlying pubocervical fascia are closed vertically with a figure-of-eight suture. In most cases the peritoneum is not closed.

Underwater Examination

At the close of each operation, an underwater examination is used to detect bleeding from vessels and viscera tamponaded during the procedure by the increased intraperitoneal pressure of the CO_2 pneumoperitoneum. The CO_2 pneumoperitoneum is displaced with 2 to 5 L of Ringer's lactate solution, and the peritoneal cavity is vigorously irrigated and suctioned until the effluent is clear of blood products. Any further bleeding is controlled underwater using microbipolar forceps to coagulate through the electrolyte solution, and at least 2 L of lactated Ringer's solution are left in the peritoneal cavity.

Postoperative Considerations

Postoperatively, the vaginal cuff is checked for granulation tissue between 6 and 12 weeks, as sutures are usually absorbed by then. Patients usually experience some fatigue and discomfort for approximately six weeks after the operation, but may perform gentle exercise such as walking and return to routine activities between two and six weeks. Sexual activity may be resumed when the vaginal incision has healed, usually after six weeks.

Complications

Complications of laparoscopic hysterectomy are those of hysterectomy and laparoscopy in general: anesthetic accidents; respiratory compromise; thromboembolic phenomenon; urinary retention; injury to vessels, ureters, bladder, and bowel; and infections, especially of the vaginal cuff.[23,24] Complications unique to laparoscopy include large vessel injury and subcutaneous emphysema. Since the introduction of prophylactic antibiotics, vaginal cuff abscess, pelvic thrombophlebitis, septicemia, pelvic cellulitis, and adnexal abscesses are rare. Abdominal wound infection is rare, but the incidence of incisional hernias after operative laparoscopy is greatly increased if 10-mm or larger trocars are placed at extraumbilical sites. These sites should be closed. If the incision is lateral to the rectus muscle, the deep fascia is elevated with skin hooks and suture repaired. If the incision is through the rectus muscle, the peritoneal defect is closed with a laparoscopically placed suture.

Febrile morbidity with a vaginal approach is about half that of abdominal hysterectomy. Laparoscopic treatment with evacuation of all blood clots and the sealing of all blood vessels after the uterus is out should reduce the infection rate further. Morcellation during laparoscopic or vaginal hysterectomy results in a slightly increased risk of fever, especially if prophylactic antibiotics are not used.

Special Problems Related to Laparoscopic Hysterectomy

Very Large Fibroid Uterus (16 Weeks Size or Above)

The laparoscope is maneuvered into the deep cul-de-sac, and its tip may be used as a lever or retractor to lift the uterus. The ureters are identified and isolated if possible; if this is not possible, the surgeon should go below and use a vaginal access approach early in the procedure. If endometriosis or rectal tenting are present, the peritoneum is opened and the rectum is reflected off the posterior vagina to the loose areolar tissue of the rectovaginal space (see Figures 30.8.2–30.8.4). The vagina is incised between the uterosacral ligaments with a CO_2 laser through the operating laparoscope or with a spatula electrode, and this incision is tamponaded with a sponge or balloon to avoid battling to maintain pneumoperitoneum for the rest of the procedure.

The ovaries are examined. In most cases involving a very large fibroid uterus, it is better to preserve the ovaries at the start of surgery to avoid problems with the pelvic sidewall. The ovaries should be re-examined after the uterus is out and excised if indicated. In cases where an ovary has been pulled away from its sidewall by interligamentous fibroid growth, early oophorectomy may be necessary for better exposure. With a large fibroid uterus, the utero-ovarian ligament/round ligament/fallopian tube pedicle is markedly elongated. It is suture ligated twice to prevent backbleeding as the procedure continues. In many cases, bipolar desiccation is used.

The vesicouterine peritoneal fold is divided with scissors, electrode, or CO_2 laser. This part of the procedure is done after ligation of the utero-ovarian ligament/round ligament/fallopian tube pedicle in cases where a very large fibroid is present, because the bladder is far down in the pelvis and the vesicouterine peritoneal fold is stretched out. The round ligament is divided with cutting current electrosurgery through a spoon electrode.

At this juncture, it is usually possible to incise both the anterior and posterior vagina laparoscopically and then proceed vaginally. Allan stirrups are changed to candy-cane stirrups, and the surgeon sits between the patient's legs. Vaginal clamps are applied: the uterosacral ligaments, cardinal ligaments, and uterine vessels are clamped, divided, and suture ligated. The uterus is then removed after extensive morcellation.

When very large fibroids are located high above the level of the internal os of the cervix, it is often possible to manipulate the laparoscope above or beneath the large fibroid into the deep pelvis. The ureters on each side are identified using atraumatic forceps and are then separated from the uterine vessels, which are suture ligated, as previously described, using curved needle techniques. The vagina is entered anteriorly and posteriorly and the cardinal ligaments are divided between these two incisions. The free uterus is removed from below after extensive morcellation.

After securing the ovarian arteries from above and the uterine arteries from above or below, a no. 10 blade on a long knife handle is used to make a circumferential incision into the fundus of the uterus, using the cervix as a fulcrum. The myometrium is incised circumferentially, parallel to the axis of the uterine cavity and the serosa of the uterus. The knife is not extended through the serosa of the uterus. The incision is continued around the full circumference of the myometrium in a symmetrical fashion beneath the uterine serosa. Traction is maintained on the cervix, and the avascular myometrium is cut so that the endometrial cavity with a surrounding thick layer of myometrium is delivered with the cervix, bringing the outside of the uterus closer to the operator for further excision by wedge morcellation.[25,26]

Wedge morcellation is done by removing wedges of myometrium from anterior and posterior uterine wall, usually in the midline, to reduce the bulk of the myometrium. After excision of a large core, the fundus is morcellated with multiple wedge resection around either a tenaculum or an 11-mm corkscrew (WISAP, Sauerlach, Germany, or Tomball, TX). The remaining fundus, if still too large for removal, can be bivalved so that one half can be pulled out of the peritoneal cavity, followed by the other half.

At the end of the procedure, a look with a laparoscope should be considered, even if a large myomatous uterus is removed using solely vaginal techniques. Bleeding from the vaginal cuff or from the stretched out pedicles is common and can be readily coagulated laparoscopically, and blood clot seeded with vaginal organisms can be aspirated laparoscopically. Adding laparoscopy to vaginal hysterectomy should reduce the morbidity of vaginal hysterectomy.

Stage IV Endometriosis

In cases of severe endometriosis with cul-de-sac obliteration, the surgeon must first free the ovaries, then the ureters, and finally the rectum from the posterior vagina to the rectovaginal septum. Deep fibrotic nodular endometriosis involving the cul-de-sac requires excision of nodular fibrotic tissue from the uterosacral ligaments, posterior cervix, posterior vagina, and the rectum. Attention is first directed to complete dissection of the anterior rectum throughout its area of involvement until loose areolar tissue of the rectovaginal space is reached. In all cases, a rectal probe (Reznik Instruments) is placed in the rectum. Using the rectal probe as a guide, the rectal interface with the cul-de-sac lesion is identified and opened at this junction with CO_2 laser or scissors. Careful blunt dissection then ensues using the aquadissector for aquadissection and suction-traction. Laser or scissors are used for sharp dissection until the rectum, with or without fibrotic endometriosis, is separated from the posterior uterus and upper vagina and is identifiable below the lesion. Loose areolar tissue of the rectovaginal space should be reached. Only after the rectum is mobilized should excision of the fibrotic endometriosis be attempted from the posterior vagina, uterosacral ligaments, and rectum. Full thickness excision of the vaginal nodular areas usually results in relief of the patient's pain or bleeding[14] (see Figures 30.8.2–30.8.4).

Laparoscopic Uterosacral-Vaginal Suspension

It is possible to suspend the vagina after hysterectomy, using laparoscopic surgical techniques. In cases where hysterectomy is done for vaginal and uterine prolapse, the ureters are dissected laparoscopically before vaginal hysterectomy to better identify the uterosacral ligaments close to the sacrum in a very high position. Sutures are applied to these firm ligaments adjacent to the sacrum and upper rectum. The suture material is left long in the peritoneal cavity for later fixation.

After vaginal removal of the uterus, the previously applied sutures are grasped with the surgeon's index finger high in the pelvis and are brought into the vagina. These sutures are then applied to the vaginal cuff using free curved needles, and are tied after completion of the vaginal closure repair, bringing the vagina into a higher position than is obtained with conventional vaginal surgery.

Laparoscopic Rectocele Repair

Enterocele and rectocele are amenable to a laparoscopic approach. Laparoscopic plication of the levator ani muscles from the anal sphincter results in excellent vaginal and rectal support. To do this procedure, the rectovaginal space is opened with aquadissection or retroperitoneal space expanders (Preperitoneal Distention Balloon, Origin Medsystems). Separation of the rectum laterally results in identification of the levator ani muscles. These are apposed across the midline with 0-Vicryl or Ethibond in an interrupted fashion. Thereafter, the vaginal vault is suspended to the uterosacral ligaments overlying the levator plate and sacrum, as previously described, using a combined laparoscopic and vaginal approach.[27,28]

Clinical Experience

Between April 1983 and July 1992, 167 hysterectomies were done by the author. Of the 167 hysterectomies, 123 women underwent a hysterectomy in association with laparoscopy (Table 30.8.2), 25 women had total vaginal hysterectomy, and 19 women had total abdominal hysterectomy. No abdominal hysterectomies have been performed for benign conditions since July 1987.

Patient age ranged from 30 to 79 years, with an average of 45 years. Weight ranged from 106 to 250 lb (48 to 113.4 kg) with an average of 140 lb (63.5 kg). Indications are listed in Table 30.8.3. Operating time ranged from 45 to 370 minutes with an average of three hours. Blood loss averaged 250 mL. Of 42 women who underwent oophorectomies, 28 had surgical castration and 14 had preservation of one ovary; bipolar desiccation was used in 40 cases and laparoscopic stapling in 2. Additional procedures included: enterolysis (26 women); cul-de-sac dissection (20 women); appendectomy (2 women); repair of umbilical hernia (1 woman); drainage and excision of small bowel abscess (1 woman); and excision of breast papilloma (1 woman). Histologic diagnoses are listed in Table 30.8.4. Average weight of specimen was 216 g with a range of 60 to 937 g. Length of stay ranged from one to five days, with an average of two days.

Conversion to laparotomy was required in one case after laparoscopic repair of four enterotomies; this patient had extensive adhesions from multiple prior surgeries.

TABLE 30.8.2. Laparoscopic hysterectomy classifications.

Diagnostic laparoscopy with vaginal hysterectomy (TVH)	16
Laparoscopic-assisted vaginal hysterectomy (LAVH)	14
Laparoscopic hysterectomy (LH)	36
Total laparoscopic hysterectomy (TLH)	47
Laparoscopic supracervical hysterectomy (LSH)	1
Laparoscopic vault suspension after vaginal hysterectomy	2
Laparoscopic hysterectomy with lymphadenectomy	3
Laparoscopic hysterectomy with lymphadenectomy and omentectomy	2
Laparoscopic radical hysterectomy with lymphadenectomy	2
	123

TABLE 30.8.3. Indications for laparoscopic hysterectomy.

Fibroid uterus		60
Hypermenorrhea	24	
Hypermenorrhea and pain	18	
Pelvic mass without hypermenorrhea and pain	9	
Pelvic pain	6	
Early hydroureter	2	
Severe cervical dysplasia	1	
Persistent symptomatic endometriosis		18
Hypermenorrhea		11
Pelvic pain and hypermenorrhea		9
Pelvic pain		8
Endometrial cancer		8
Adenomatous hyperplasia		3
Ovarian cancer		2
Cervical cancer		2
Uterine prolapse		1
Severe cervical dysplasia		1

Complications managed laparoscopically were laceration of the epigastric artery (two patients), bladder (one patient), and bowel (one patient).

Postoperative complications included febrile morbidity (four patients), ureterovaginal fistula (one patient in 1988), pulmonary embolism (one patient), a vaginal cuff hematoma (one patient), unanticipated blood transfusion (one patient), urinary tract infection (one patient), and urinary retention (one patient). Two delayed postoperative complications were amenable to laparoscopic repair: a peritoneovaginal fistula and an incisional hernia at the right lower quadrant 12-mm puncture site.

Since 1987, in our experience, no patient was denied a vaginal or laparoscopic approach to hysterectomy except when advanced cancer was suspected. Since our practice is largely referral, this represents a significant degree of pathology. Benign histology was present in only 9 of 123 women; hysterectomy was performed for pelvic adhesions, or persistent hypermenorrhea (abnormal uterine bleeding) in these cases. Laparotomy was not needed regardless of size or location of uterine fibroids or extent of endometriosis. Only one woman with extensive bowel adhesions and endometrial cancer had laparotomy to complete the hysterectomy and reinforce four small bowel enterotomy repairs. This supports our belief that most hysterectomies presently performed with the abdominal approach can be done laparoscopically.

Only 23% of the women in this series had surgical castration. In our patients with extensive endometriosis, deep fibrotic endometriosis was excised and the ovaries were usually preserved; no late sequelae have been noted to date. In women with pelvic prolapse, laparoscopic vault suspension has been more successful than previous repairs accomplished transvaginally.

Laparoscopic hysterectomy is a substitute for abdominal hysterectomy, not for vaginal hysterectomy. Most hysterectomies currently done with an abdominal approach may be performed with laparoscopic dissection of part or all of the abdominal portion followed by vaginal removal, including fibroids of 1,000 g. Conversion to laparotomy when the surgeon becomes uncomfortable with the laparoscopic approach should never be considered a complication; it is a prudent surgical decision that will profoundly decrease patient risk.

TABLE 30.8.4. Histologic diagnosis for laparoscopic hysterectomy.

Uterine myoma		60
With adenomyosis	26	
With endometriosis	14	
Adenomyosis		20
Endometriosis		17
Adenocarcinoma		8
Atypical adenomatous hyperplasia		2
Ovarian cancer		2
Cervical cancer		2
CIN II		3
Benign pathology		9

Total number of women with endometriosis/adenomyosis = 77.

Scoring System

The degree of difficulty of a laparoscopic hysterectomy is most dependent on the number of previous laparotomies the patient has had. The severity of endometriosis surrounding the cervix and the degree of entrapment of the ovaries are also important. Fibroid size is rarely related to increased difficulty, because its blood supply is usually easy to identify, and is separate from the ureter; these procedures can be time-consuming, however, because of the degree of morcellation necessary. Unfortunately for the occasional surgeon, the degree of anticipated difficulty is directly related to the severity of symptoms, making indicated procedures demanding in both time and technical expertise required.

A laparoscopic scoring system for determining operative approach has been developed by Kovac, Reich, and Cruikshank (Table 30.8.5).

Uterine and adnexal mobility are first assessed by pel-

TABLE 30.8.5. Laparoscopic scoring system for determining operative approach.

Parameter	Points
Uterine size	
Grade I: 8 weeks or less	1
Grade II: 8–12 weeks	3
Grade III: 12–16 weeks	5
Grade IV: > 16 weeks	8
Mobility of adnexa as judged by stretched length of infundibulopelvic ligament	
Good: > 5 cm	1
Moderate: 2–5 cm	3
Poor: < 2 cm	5
Adhesion of adnexa (Rock's criteria)	
None/mild: no significant paratubal or periovarian adhesions	1
Moderate: periovarian or paratubal adhesions without fixation, minimal cul-de-sac adhesions	3
Severe: dense pelvic or adnexal adhesions with fixation of ovary and tube to either broad ligament, pelvic wall, omentum, or bowel; severe cul-de-sac adhesions	5
Status of cul-de-sac	
Accessible	0
Obliterated	5
Rectal nodule	8
Endometriosis (American Fertility Society classification)	
Stage I	1
Stage II	2
Stage III	3
Stage IV	4

vic examination and by the use of a tenaculum placed in the cervix to move the uterus. The stretched length of the infundibulopelvic ligament is evaluated laparoscopically by placing a probe (marked in centimeters) at the junction of the ovary's distal pole to the infundibulopelvic ligament. Uterine and adnexal size and mobility, and the presence and degree of adhesions and endometriosis including the cul-de-sac are evaluated and recorded. Each parameter is assigned a point count. The total cumulative points provide the surgeon with a basis for deciding the operative approach.

Using this scoring system, the maximum total points in any given case is 30. Patients with scores less than 10 have a successful surgical outcome with traditional vaginal hysterectomy. Conversely, total scores in excess of 10 suggest that laparoscopic hysterectomy or abdominal hysterectomy may be preferred. It should be noted that vaginal surgery may still be considered (laparoscopically and vaginally) by the experienced surgeon in the presence of the following relative contraindications: a very large uterus; severe endometriosis where the rectum is adherent to the back of the uterus; and extensive adhesions. An abdominal incisional approach, total abdominal hysterectomy (TAH) with bilateral salpingo-oophorectomy should be performed, however, on most ovarian masses over 10 cm, if malignancy cannot be ruled out.

Conclusions

Expensive disposable instrument usage must be kept to a minimum. There is a French word, *bricolage,* which means making due with the material at hand. In the popular TV series "MacGyver," the power of bricolage is symbolized by the resourceful hero who saves the world with a minimum of raw materials and a couple of clever tricks. In bricolage we take ordinary materials at hand and change them into new living matter. The fulcrum of this transformation is the mind at play, having nothing to gain or lose and working around the limits of the available tools in the operating room. The gifted surgeon can take the least expensive instrument and do better with it than others can using expensive disposable instruments. The artistic attitude that involves a healthy dose of bricolage frees the surgeon to see the possibilities of taking an ordinary instrument and making it extraordinary.

The place of laparoscopic hysterectomy in the future will be determined by the skill of surgeons with the vaginal approach. This skill will increase as surgeons are stimulated to do the difficult part of a LAVH vaginally. This author suspects that over 50% of indicated hysterectomies can be performed using the vaginal route without laparoscopy. The laparoscope will be used in the remaining 50%. Vaginal hysterectomy after a diagnostic laparoscopy will be possible in one half of those with some relative contraindication to the vaginal approach. In these cases, the laparoscope will be used for diagnosis but no laparoscopic surgery will be done. One half of the remaining indicated hysterectomies will require laparoscopic oophorectomy or adhesiolysis, that is, LAVH. Of the remaining 12.5% of the total, the skilled laparoscopic surgeon will consider laparoscopic hysterectomy in all but 1%.

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30.9 Operations on the Uterus

K. Semm and I. Semm

The purpose of this chapter is to explain the basic endoscopic procedures now routinely performed on the uterus. These operations were performed at the University of Kiel, Germany, as early as 1970. Now, more than 23,000 operative endoscopic interventions later, the feasibility and efficacy of this operative method has finally been accepted. The operations described here are routinely performed at many centers throughout the world. It would be beneficial for the general surgeon to be aware of the great changes occurring in gynecologic surgery.

The bulk of the chapter will deal with the technique of myomectomy. Then a new method of endometrial ablation called TUMA (total uterine mucosal ablation) will be described. Finally, the procedure of pelviscopic hysterectomy, which allows complete preservation of the pelvic floor, will be briefly discussed.

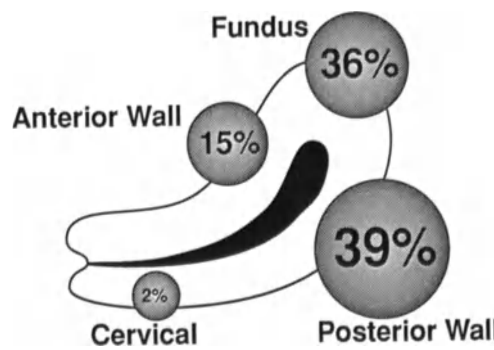

FIGURE 30.9.1. Topographic locations of myomas at the time of pelviscopic enucleation [n = 482 patients (myomas = 1.379 = 100%)].

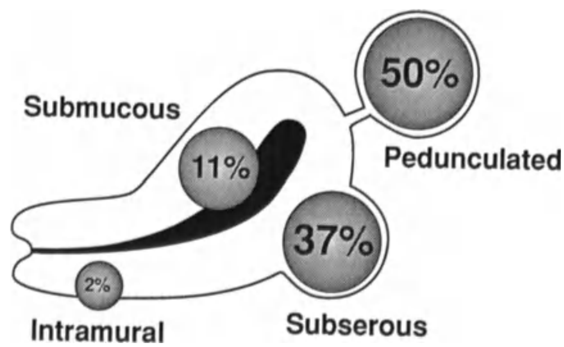

FIGURE 30.9.2. Types of myomas found at pelviscopic myoma enucleation [n = 482 patients (myomas = 1.379 = 100%)].

Pelviscopic Myomectomy

The procedure of myomectomy is performed as a treatment for sterility caused by fibroids, for the symptoms due to fibroids, such as bladder and rectal pressure, or for dysfunctional uterine bleeding. Many perimenopausal patients are opting for this surgery rather than for hysterectomy because they feel preservation of the uterus is important for their self-image.

The position of the myoma (Figure 30.9.1) as well as the type (Figure 30.9.2) determines the operative technique used. Thirty-nine percent of myomas are found on the posterior wall and 36% in the fundal area. Myomas in these positions lend themselves easily to pelviscopic myomectomy. Anterior wall (15%) and cervical (11%) myomas are more difficult to treat because access is awkward, but an experienced surgeon can successfully remove them.

The types of myomas most easily removed are the pedunculated and subserous. They account for 87% of the myomas endoscopically removed. Intramural myomas can now be routinely removed, owing to the development of techniques for controlling blood loss, such as the tourniquet technique (Rubin, 1951) and the introduction of long sharp needles for suturing. Intramural myomas account for 2% of the myomas. (These statistics are based on an ongoing study at the University of Kiel that began in 1981.)

Is the size of the myoma a consideration in the decision to perform endoscopic myomectomy? This depends on the expertise of the surgeon. With reasonable skill, myomas as large as 10 cm in diameter may be removed without great difficulty. Since the introduction of GnRH analogs, larger myomas are often reduced in size and then pelviscopically removed. At the University of Kiel, GnRH analogs are given only to patients with myomas larger than 10 cm in diameter or in a compromising anatomic position, that is, intraligamentary. They are not routinely given because they seem to destroy the capsule of the myoma. Because they induce the degeneration process, enucleation becomes exceedingly difficult.

Small pedunculated myomas are removed without blood loss using the myoma enucleator (Figure 30.9.3) attachment of the Endocoagulator (WISAP) set at 120°C. Note that neither bipolar or monopolar high-frequency current nor laser is used, as these modalities cause carbonization of uterine tissue and subsequent (five to six days postop) sequestration of tissue fluid, which ultimately results in the production of adhesions. Experiments have shown that vaporization with a laser produces significantly more adhesions than endocoagulation. This is because, in carbonized tissue, physiologic inflammatory reactions are more pronounced, more fibrin is exuded, and t-PAA (tissue plasminogen activator activity) is diminished to approximately 5% of its normal rate. A decrease in t-PAA results in increased adhesion formation, as shown by Jackson in 1958 and Stangel and coworkers in 1984. Endocoagulation reduces t-PAA to only 80%; therefore fewer adhesions result from use of this modality. A review of the literature shows that rupture post-endoscopic myomectomy has not occurred on uteri sutured closed.

The initial problem with myomectomy at the end of the 1970s was hemostasis, and endocoagulation was the first step in solving this problem. A further advance came with the introduction of vasopressin solution. We use a very dilute solution of POR-8, which is a synthetic vasopressin, ornipressine. Five international units are diluted in 100 mL of physiologic saline and then 10 mL of this solution is injected into and around the base of the myoma to be enucleated. With larger myomas a few injections of 10 mL may be used.

Larger pedunculated myomas may be effectively removed by setting a Roeder loop around the myoma and closing the loop, thus ligating the supplying vessels (Figure 30.9.4).

Intramural myomas are removed using the following technique: First, the ascending branches of the uterine arteries are bilaterally ligated, using an endoscopic tourniquet technique based on that developed by Rubin in 1951 for myoma enucleation at laparotomy. He advocated using a rubber tube, which was put through either side of the parametrium. In the endoscopic adaptation of this technique (Figure 30.9.5) a suture is put through either side of the parametrium, and the knot is tied extracorporeally and pulled tight. In order to ensure that the ligature does not loosen during the operative procedure, a security knot is tied. This is a temporary ligature that is removed after the myoma enucleation procedure has been completed. The only cases in which this technique is not advisable are large cervical myomas. This technique shortens operative time appreciably. Blood loss does not increase when the temporary ligature is loosened.

After performing the temporary arterial ligature, the myoma is isolated, and the tissue surrounding the myoma is injected with the 0.05% POR-8 (solution mentioned above). Two or three injections may be required in the case of large myomas. A coagulation streak is made along the intended incision with the point coagulator attachment of the Endocoagulator. This prevents bleeding along the wound margins. The myoma is then exposed by incising the uterine serosa with a microscissors down to and including the myoma capsule. Two biopsy forceps expose the myoma further, so that the myoma drill may be screwed into it. The myoma drill is introduced through the central suprapubic 10-mm port. It is part of the serrated edged macromorcellator (SEMM set) used for morcellation (Figure 30.9.6). To begin the morcellation process a thumb-sized core is removed from the myoma after it has been exposed. The core is removed by bringing the

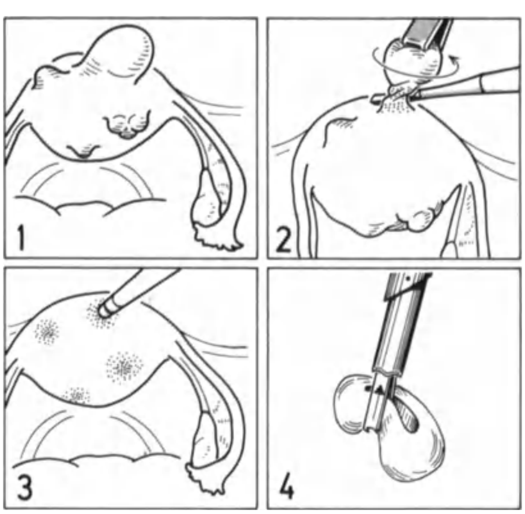

FIGURE 30.9.3. Enucleation of small subserous myomas.

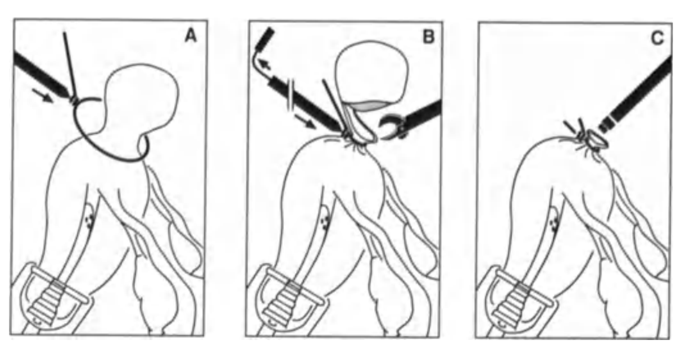

FIGURE 30.9.4. Myoma enucleation using the loop ligation technique.

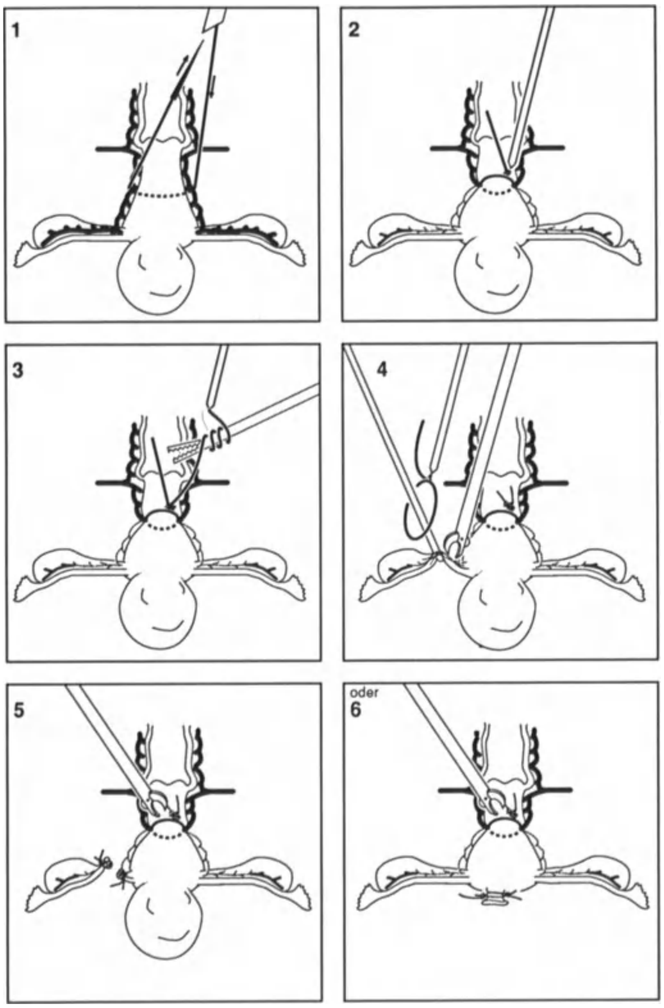

FIGURE 30.9.5. Temporary ligation of the ascending branches of the uterine artery for performing salpingo-oophorectomy or myoma enucleation without blood loss.

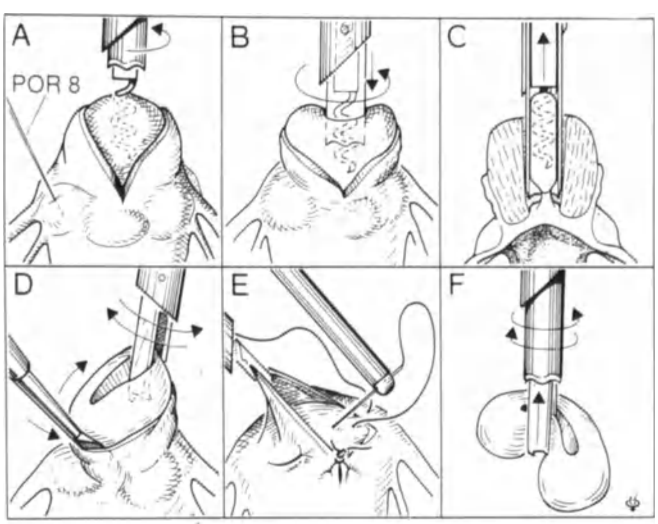

FIGURE 30.9.6. Enucleation of an intramural myoma using the SEMM set.

SEMM cutting tube down around the myoma drill. The myoma can now be easily grasped with the claw forceps, and the myoma enucleator attachment of the Endocoagulator, which was introduced into one of the two lateral suprapubic ports, set at 110°C, now slowly begins to enucleate the myoma from its bed. A slow progression is vital here to give the uterine vessels feeding the myoma time to recoil and contract, thereby reducing blood loss. Laser or high-frequency current, by their very nature, do not allow for a slow and steady progress and are therefore associated with a much greater blood loss.

The uterine wound is closed using endosutures and either intra- or extracorporeal knotting techniques (Semm, 1978). Straight long (3.5-cm) sharp needles are recommended. A Robinson drain is inserted with the twofold purpose of draining wound fluid and immediately exposing any postop bleeding that could occur. The drain is placed through one of the 5-mm ports and should be removed after 24 hours. The Robinson drain is a silicone gravity drain.

In our series of patients, fewer than 5% of patients return for hysterectomy following myomectomy. The operation is therefore worthwhile for those patients wishing to retain their uterus for purely "psychological reasons."

Enucleation of myomas in patients also suffering from adenomyosis is extremely difficult in most cases because of the lack of a capsule. We recommend myolysis (Figure 30.9.7) for the treatment of these myomas. The myoma is heated to 70°C using the myolyser attachment of the

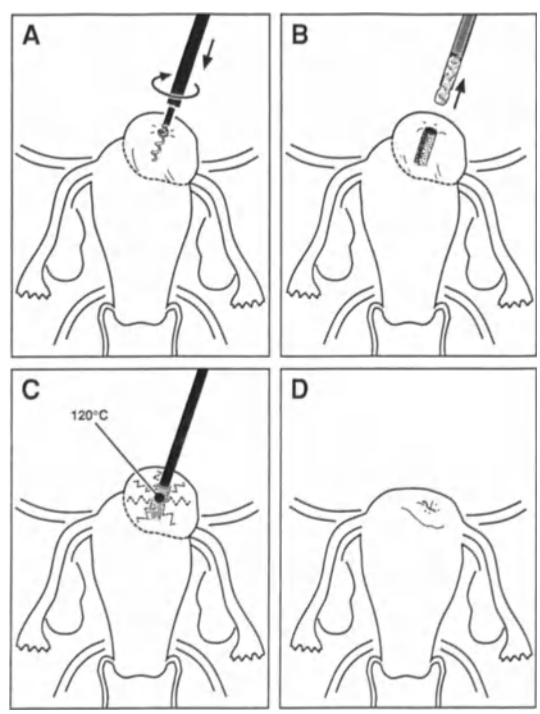

FIGURE 30.9.7. Using the myolyser to reduce the size of the myoma.

Erystop (WISAP). The myolyser is introduced into the central part of the myoma and heated for three to five minutes. Six weeks later the myoma will have nearly totally disappeared.

This myolysis technique may also be used in cases of lyomyomas where enucleation cannot be recommended because of technical difficulties.

TUMA

TUMA may be performed in cases of dysfunctional uterine bleeding unresponsive to hormonal therapy. This procedure is performed instead of endometrial ablation at hysteroscopy using high-frequency current (loop or rollerball) or laser (CO_2, Nd:YAG). The rather high complication rate and the mortality associated with endometrial ablation renders it unacceptable for widespread use. Also, the overall success rates of this procedure are not very promising: permanent amenorrhea is achieved in only 6% of patients. In 60% a hypomenorrhea results, and in 20% normal menstruation recommences after two or three years owing to the regeneration of the endometrium. A further 10% of patients undergo subsequent hysterectomy.

In performing the classic intrafascial SEMM hysterectomy (CISH) operation we saw that excoriation of the tissue cylinder containing the uterine lining caused practically no bleeding. We began asking ourselves in cases of dysfunctional bleeding why remove the uterus at all? Accordingly we started to treat patients with abnormal bleeding with this excoriation procedure. We use the calibrated uterine resection tool (CURT) technique, described below for the CISH operation, to perform this operation.

Excoriation of the cervical tissue is complete in 100% of cases and endometrial tissue is completely removed in 80%. In the remaining 20% of cases the endometrium is destroyed by endocoagulation. The TUMA technique shown in Figure 30.9.8 may be performed as follows:

1. Introduction of the 50-cm long perforation rod following dilatation of the cervix to Hegar 5. The rod is advanced until it reaches the fundus.
2. Manipulation of the uterus pelviscopically until it has the form of a longitudinal muscular tube. The cervix has been fixed transvaginally at three o'clock and nine o'clock.
3. The perforation rod is fixed using a clamp, which also fixes the two tenaculums firmly set paracervically at three o'clock and nine o'clock.
4. Setting SEMMs security ligature around the fundus using two biopsy forceps cranial to the cornuae.
5. Tying the security ligature with a safety knot to prevent it from slipping.

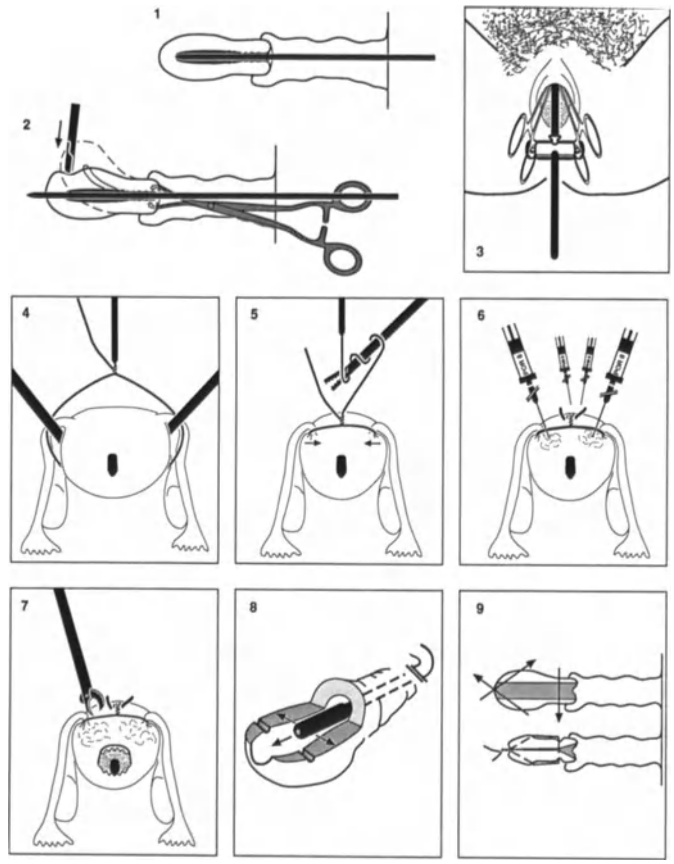

FIGURE 30.9.8. Schematic representation of technique for TUMA using CURT.

6. Injection of 2 × 10 mL of POR-8 (0.05 IU/mL) into the cervix and corpus musculature pelviscopically.
7. Coring out the cervical, endometrial, fundal tissue using CURT and removal of the SEMM security ligature.
8. Removal of the tissue cylinder, insertion of the hemostaser (may also be introduced over the perforation rod); coagulation up to 120°C. Pelviscopic hysteroscopy and visualization of the wound to check for residual bleeding. Prior to this the tissue cylinder is carefully examined for any defects that would require further coagulation under pelviscopic control.
9. The defect caused by coring is not closed with the CISH needle set. A second suture may be set with the shorter needle in case the fundus is not completely closed.

To ensure that the entire endometrium is removed, it is helpful to set a Roeder loop around the fundus. The loop transforms the triangular cross section of this part of the uterus to a more round one (Figure 30.9.8, step 4).

The use of the hemostaser attachment of the Erystop is shown in Figure 30.9.8, step 8. This endocoagulation instrument is set at 120°C and coagulates for five minutes. The tubal ostia are coagulated with the point coagulator. Coagulation produces a myometriolysis that causes shrinkage of the uterus (to approximately 50% of its former size) in the first six postoperative weeks. The great advantage of low-temperature endocoagulation is that the hole within the uterus closes completely from the fundus down to the cervix by granulation in six weeks. There is no chance of developing endometriosis or cervicitis. High-frequency current or laser do not allow for granulation of the tissue defect and a persistent hole sometimes results.

CISH

As we have seen, pelviscopic myomectomy is a good alternative to hysterectomy in cases of symptomatic myomas. TUMA offers an alternative to hysterectomy for patients suffering from dysfunctional uterine bleeding. Similarly, total hysterectomy for benign uterine conditions should be abandoned in favor of CISH. This procedure may be performed on smaller uteri (smaller than a uterus in the 12th gestational week) by pelviscopy and on larger uteri by laparotomy. The vaginal version of this procedure is called intrafascial vaginal hysterectomy (IVH).

Total extrafascial hysterectomy has been the standard procedure for uterine pathology since subtotal hysterectomy went out of vogue in the 1960s because of the 0.3 to 1.8% chance of developing cervical-stump carcinoma. This procedure is a drastic overtreatment because it destroys the topography of the pelvic floor, amputates the cervix, and severely reduces the blood supply to the upper third of the vagina. There is no indication that justifies disrupting or destroying these essential structures. In the 1960s cancer occurred in the cervix left behind after supracervical hysterectomy. In the 1960s the Pap smear was not yet routine and the statistics reported then reflect this. The incidence of cervical carcinoma among women who have undergone hysterectomy with cervical preservation reported in various recent studies is no higher than that among women who have not had total hysterectomy.

We can no longer ignore the fact that the pelvic floor and the vagina are integral in maintaining proper sexual sensitivity, proper functioning of both the bladder and rectum, and, ultimately, psychological health. The presence of the pericervical nerves is mandatory for these functions, and these nerves are completely destroyed at total hysterectomy.

The Advantages of CISH

Surgical Advantages

1. Safe and thorough transvaginal removal of the cervical tissue, including its glandular structures.
2. Preservation of the cardinal ligament.
3. Preservation of the pericervical network of nerves.
4. The uterine artery, bladder, and rectum are less endangered than during classic total hysterectomy.
5. Colpotomy is not performed, that is, the vagina is not opened.
6. No reduction in the length of the vagina.
7. No danger of infection by contamination with vaginal bacteria.
8. Minimal tissue traumatization and less blood loss.
9. Suspension of the round ligament on the remaining cervical tissue (not the vaginal cuff).
10. Better treatment of genital prolapse.

Medical Advantages

1. Complete prophylaxis against cervical carcinoma.
2. Complete preservation of the topography of the pelvic floor and preservation of the suspension by the cardinal ligaments.
3. Less physical stress for the patient.
4. Reduction in hospitalization from weeks to days.
5. Reduction in convalescence from months to days.
6. Complete preservation of the sexual sensitivity, that is, the vaginal and cervical components of sexuality.
7. Complete preservation of sexual function for the partner because the vagina has not been shortened and the cervix is present.
8. Earlier return to normal sexual activity.

Psychological Advantages

1. Preservation of self-image.
2. No feeling of disfiguration.
3. Retention of a better quality of life after hysterectomy.

CISH Technique

In the CISH technique the cervical transitional zone and functional tissue are removed with a special instrument called CURT (calibrated uterine resection tool). The excoriation procedure is performed through the vagina and the rest of the operation is performed endoscopically.

Figure 30.9.9 is a schematic representation of the CISH technique:

A. The uterus is manipulated to form a longitudinal tube of muscle prior to perforation of the fundus with the perforation rod.
B. After the rod has perforated the fundus transvaginally. The left side shows the suture-ligature for hysterectomy without salpingo-oophorectomy. The extracorporeal knotting technique is used.
C. All pedicles (ligaments and adnexa) are ligated twice and transected. (C1) Hysterectomy with salpingo-oophorectomy. (C2) Hysterectomy without salpingo-oophorectomy. Sometimes the round ligament and ad-

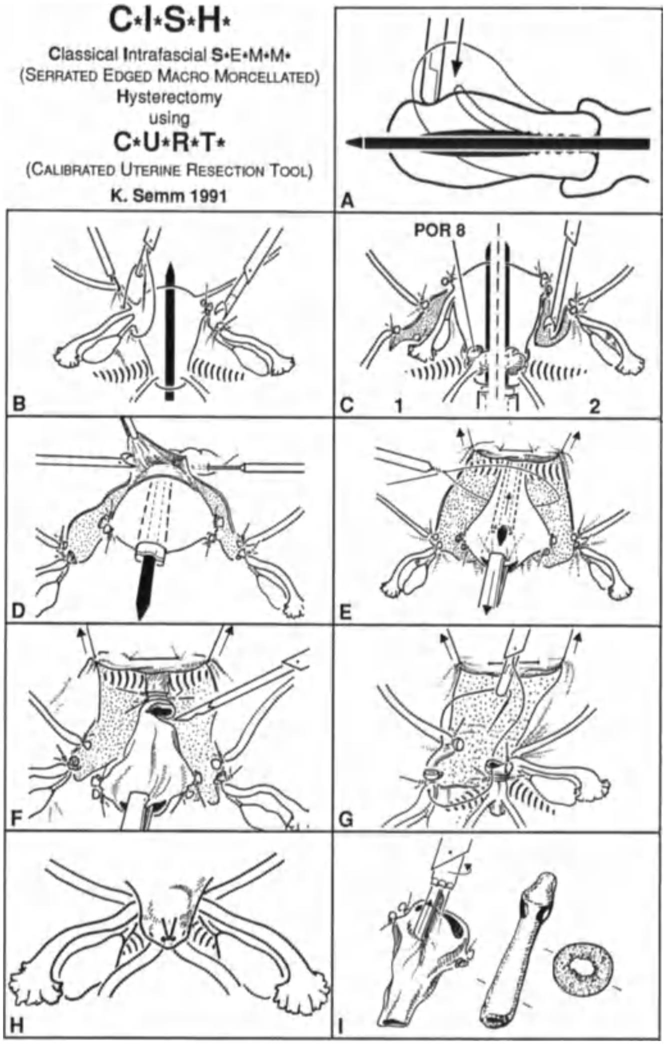

FIGURE 30.9.9. Schematic representation of the CISH technique.

nexa may be incorporated into a single ligature, as depicted in B. The broad ligament is opened, and the anterior and posterior leaves are separated. Ten milliliters of POR-8 solution are injected into the cervix bilaterally.

D. The vesicouterine peritoneum is dissected off using aquadissection. Ten to 20 mL of 0.05% POR-8 solution are injected subperitoneally. The CURT is then applied. As it rotates, it is advanced through the cervix, uterine cavity, and fundus until the cutting edges become visible through the fundus. The tissue cylinder that results may be seen in I.
E. The uterus is grasped with the claw forceps and pulled in the direction of the umbilicus. A Roeder loop is pushed downward over the pericervical tissue before the CURT and the tissue cylinder are removed. The CURT is removed, and the loop is pulled tight. Two further loops are placed, in keeping with the triple-loop ligation technique (Semm, 1978). All loops are tied a second time for security. Alternatively the ascending branches of the uterine arteries are individually suture ligated.
F. As traction is applied to the uterus with the claw forceps, it is resected with a scalpel or hook scissors.
G. The round ligaments are now attached to the cervical stump (with the fallopian tube) using a sharp needle and nonresorbable suture material. This elevates the pelvic floor and therefore prevents any invagination prolapse.
H. After cutting the long needle of the CISH needle set and pulling in the short one, the vesicouterine peritoneum is attached to the uterosacral ligaments. The knot is tied intracorporeally.
I. To the left is the morcellation mechanism that removes the uterus from the abdominal cavity. The morcellators range in size from 10 to 20 mm in diameter. The center drawing shows the excised cylinder of cervical, uterine-cavity, and fundal tissue. To the right are the histologic sections of the cervix made to ensure that functional cervical tissue has been completely removed.

IVH

Laparoscopically assisted vaginal hysterectomy involves laparoscopic dissection of the uterus, which is then removed by the vagina. The CISH technique gave way to IVH, a procedure that maintains the ideals of minimally invasive surgery. After the functional tissue of the cervix is removed using the CURT (Figure 30.9.9C–F), a classic vaginal hysterectomy with anterior colpotomy (anterior removal) is performed. The cardinal and uterosacral ligaments are not transected, and the vagina is not shortened. Since no highly innervated tissue is transected during this procedure, the patient has little postoperative pain. A further advantage of preserving the pelvic nerve distribution is the maintenance of urinary, rectal, and sexual function. The operation time is the same as that for classic total vaginal hysterectomy. The vaginal procedure is made significantly easier by coring out the cervix. This essentially debulks the cervix, providing more operative space and thus the anterior delivery is easily performed. When salpingo-oophorectomy is indicated, the adnexa are separated pelviscopically, a procedure called pelviscopically assisted vaginal hysterectomy (Semm, 1984).

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30.10 The Role of Laparoscopy in the Surgical Treatment of Pelvic-Floor Relaxation

Thierry G. Vancaillie

Introduction

Pelvic-floor relaxation is a common, yet underdiagnosed, condition. The reasons for underdiagnosis are multiple. One is the lack of specific symptoms, and another is that elderly women do not know what to expect from their aging bodies. In some instances the problem is recognized but the surgeon is reluctant to submit the elderly patient to a long surgical procedure with its attendant morbidity. The role of laparoscopy in the treatment of pelvic-floor relaxation is the reduction of postoperative morbidity. Although laparoscopy requires more effort on the part of the surgeon and increases the length and complexity of the procedure, morbidity is drastically reduced. This has been demonstrated by the reduced need for postoperative analgesia among patients undergoing laparoscopic lymph node dissection[1] compared to patients subjected to laparotomy.

Moschcowitz[2] was the first to theorize that prolapse at the level of the perineum results from a herniation through the endopelvic fascia. He based his theory on research performed by the great German anatomist Waldeyer. Other clinicians, such as Bardenheuer, probably had influenced the design of Moschcowitz's procedure of occlusion of the cul-de-sac by purse-string sutures. Nonetheless, Moschcowitz deserves the credit of uniting theory and practice.

It is the author's firm belief that pelvic-floor pathology should be considered as a whole rather than piecemeal, that is, in terms of more-specific conditions, such as stress incontinence or an anatomic defect, such as a rectocele, cystocele, or rectum prolapse. The clinical presentation of pelvic-floor pathology is the result of concomitant factors, such as weakness of fascial structures, atony of the levator plate, childbearing, obesity, constipation, and so on, and reflects the underlying pathology only indirectly. Many surgeons recommend simultaneous rectocele and cystourethrocele repair.[3] It is the author's opinion that correction of an enterocele is also important.

The pelvis can be divided into three compartments: the anterior compartment, where the cystourethrocele occurs; the posterior compartment, where rectocele and rectum prolapse occur; and the middle compartment, where enterocele and vaginal-vault prolapse are the concerns. Reinforcing any of these compartments may shift the vectors of force toward the two others and thereby cause or enhance a defect. The relatively poor long-term results of a single repair, such as correction of stress incontinence, may be in part ascribed to this effect.

The surgeon's reluctance to attack the problem is due to the lack of a good vaginal technique to correct an enterocele. In his seminal article, Moschcowitz reported that "it is exceedingly difficult, if not impossible, to suture together, at such depth, the two levators and the upper layer of the pelvic fascia with the requisite care and exactness." The author's surgical experience bears out this statement. The surgical procedure referred to by Moschcowitz, which was initially described by Mapalkov, combines posterior repair and attempted enterocele repair. This combined vaginal procedure, despite its difficulty, is more effective than repair of an enterocele by the abdominal route only. The ideal approach would probably be to combine vaginal posterior colporrhaphia and abdominal enterocele repair.

The laparoscope can provide excellent surgical access to and exposure of the cul-de-sac. The morbidity of the combined vaginal and abdominal procedure, using the laparoscope, will probably be similar to the morbidity of the vaginal procedure alone, although the complication rates will not necessarily be the same. The correction of an enterocele under laparoscopic control can be combined with laparoscopic correction of stress incontinence. The combination of vaginal reconstruction of the levator plate and resection of redundant vaginal wall and laparoscopic cure of an enterocele and urethropexy provides complete surgical management of pelvic-floor relaxation with acceptably low morbidity.

Technique

The vaginal part of pelvic reconstruction is carried out first. This may encompass vaginal hysterectomy or anterior and posterior repair. Once these procedures are done, the patient is repositioned. It is important that the patient be correctly positioned for the laparoscopic part of the operation. The patient should be supine with the upper leg in line with the trunk. The knees are flexed, to provide stability when the patient is put in the Trendelenburg position. The legs are abducted to provide access to the vagina. This position is sometimes referred to as the frog position. To optimize access to the cul-de-sac, a rolled towel is placed underneath the patient's buttocks. The surgeon stands on the left side of the patient if he or she is right-handed. (The following descriptions assume a right-handed operator.)

Four trocars (Figure 30.10.1) are used for enterocele repair and bladder-neck suspension. The umbilical trocar provides access for the laparoscope. A 10-mm suprapubic trocar is used for introduction of the suture material. Two 5-mm lateral trocars are inserted at the level of the iliac crest, some 3 to 4 cm from the umbilicus.

The enterocele repair is performed first, because access to the cul-de-sac is more difficult after bladder-neck suspension. Pneumoperitoneum is established by insufflating CO_2 through a Veress needle in the umbilicus. If the patient has had any pelvic surgery other than cesarean section, insufflation is performed through a left paramedial incision. Once the pneumoperitoneum is established, the umbilical trocar and laparoscope are inserted. Access to the cul-de-sac is established first; this may require some adhesiolysis and enterolysis. Then the anatomic landmarks are visualized. These are the cul-de-sac, the sacrouterine ligaments, the ureters, and the vaginal enterocele. A forceps introduced into the vagina and pushed upward will stretch the sacrouterine ligaments and highlight the edge of the "hernia."

The next step consists of resection of the hernia sac. The peritoneum of the hernia sac is put under tension with forceps. Scissors are used to incise the peritoneum along the sacrouterine ligaments and the posterior aspect of the vagina. The flap of peritoneum thus created is attached posteriorly to the rectum. The rectum is detached from the peritoneum by sharp and blunt dissection, and the flap is resected. Now the defect in the rectovaginal septum is well-delineated. Closure of the defect will result in occlusion of the enterocele and at the same time suspend the vagina at a higher level. This lengthens the vagina, which has a tendency to be shortened by posterior repair.

The first stitch is applied posteriorly (Figure 30.10.2), 2 or 3 cm in front of the dorsal insertion of the sacrouterine ligaments. The needle is first driven through the right ligament and then several times through the edge of the peritoneal resection at the level of the anterior wall of the rectum. Finally the needle is passed through the left sacrouterine ligament, and the suture is tied with an extracorporeal knot according to the technique described by Weston. Care is taken not to strangle the rectum. Once the suture is tied, the position of the ureters is checked. Invariably there is some degree of medial displacement. Should the displacement be judged excessive, a relief incision into the peritoneum between the ligament and the ureter can be made. The incision need not be deep, because the ureter lies immediately below the peritoneum and above the endopelvic fascia at that level. Relief incisions will therefore not weaken the newly created pelvic floor. Once the posterior border of the hernia has been

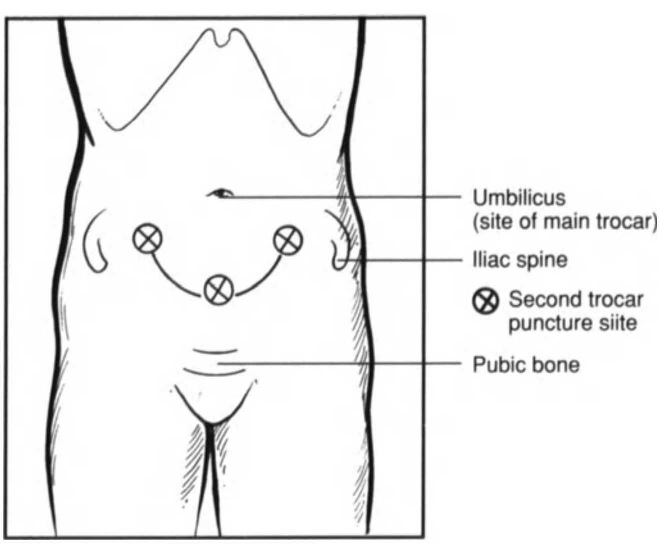

FIGURE 30.10.1. The placement of the main and ancillary trocars.

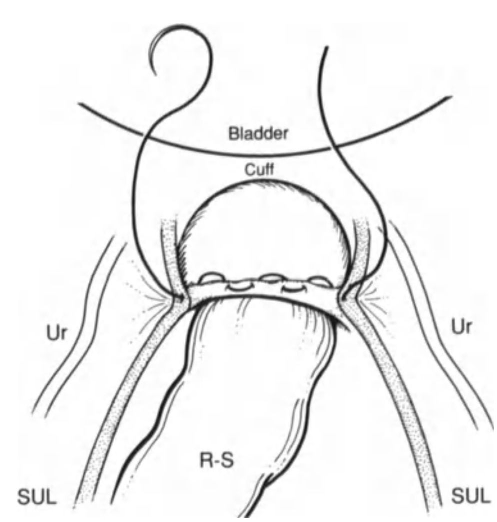

FIGURE 30.10.2. The first suture of the enterocele repair has been placed. Care is taken not to strangle the rectosigmoid.

closed, the large defect in the pelvic floor, between the sacrouterine ligaments, the anterior wall of the rectum and the vagina becomes apparent. The vagina can be forced to occupy this space. A forceps, introduced into the vagina, can be used to evaluate how far the vaginal cuff will move upward without forcing. The needle is passed through the right sacrouterine ligament at this level. Then the needle catches the vaginal wall and the left ligament. When this suture is tied, the vagina is suspended from the sacrouterine ligaments and occupies the space that was previously taken by the enterocele (Figure 30.10.3). It may be said that this surgical procedure reconstructs the rectovaginal septum, because it re-establishes the anatomical relationship between the vagina and rectum. Some degree of overcorrection is, however, unavoidable.

Two or three more sutures are applied to completely close the defect. One or two of these additional stitches are placed in front of the vaginal cuff and will provide some support for the bottom of the bladder. It may be necessary to dissect the bladder off the anterior wall of the vagina prior to closing the enterocele in patients who have undergone hysterectomy.

After completion of the enterocele repair, attention is shifted toward the anterior compartment of the pelvic floor. The landmarks are visualized. The most important one is the left umbilical ligament, which delineates the lateral border of the dissection. The Foley catheter is commonly visible and helps the surgeon locate the bladder. In a patient who has undergone multiple surgeries, locating the bladder is sometimes not an easy task. Filling the bladder can be helpful under those circumstances. The pubic bone can be seen in almost all patients, even the very obese. If it is not readily visible, gentle probing with an ancillary instrument will put the surgeon on the right track. The pubic bone will be at the inferior border of the initial incision into the peritoneum. This landmark allows the surgeon to avoid the superior vesical pedicle, which runs anterior to the round ligament but slightly below the level of the pubic bone. The superior vesical pedicle is not easily recognized, because it is not a well-defined entity. However, its venous plexus will bleed profusely if accidently incised. Avoiding this vascular structure is important, because bleeding will obscure tissue planes and significantly increase the difficulty of the procedure.

The initial incision is made immediately medial to the left umbilical ligament, above the pubic bone (Figure 30.10.4). A left-handed surgeon may choose to approach the space of Retzius from the right. The incision is continued toward the pubic bone in a plane perpendicular to it. There is a tendency to shift toward the midline too early, leading to bladder injury. This happened to us on two occasions, the second one after we had done more than 20 laparoscopic suspensions!

Once the pubic bone is reached, the assistant inserts a blunt instrument into the incision and retracts the bladder to the right. With minimal traction and some blunt dissection, the space of Retzius is easily opened. Using blunt dissection, the entire space is opened, and all anatomic structures are identified. The urachus is seldom an obstacle to complete dissection of the field, but some patients have a patent urachus. The anatomic structures that can be identified at completion of the dissection are: the urethra, the bladder neck, the vaginal wall, the obturator muscles, the pubourethral ligaments, and the pubic bone with its symphysis and ligaments (Figure 30.10.5). Identification of Cooper's ligament is not easy, but a wide dissection of the pubic bone will facilitate it.

Either the technique described by Kranz[4] or the one favored by Burch[5] can be performed at this point. Other

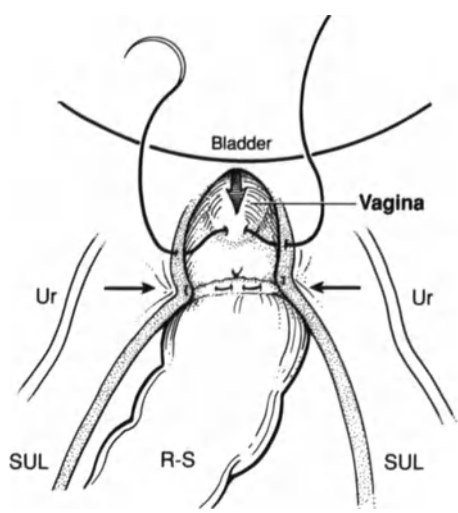

FIGURE 30.10.3. The second suture encompasses both sacrouterine ligaments as well as the posterior vaginal wall.

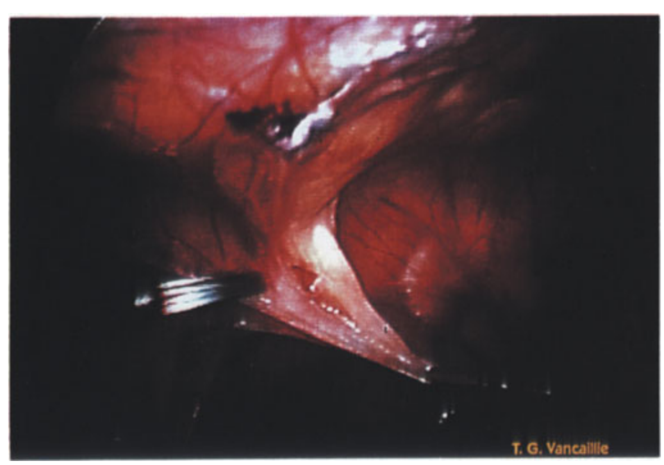

FIGURE 30.10.4. Incision of the parietal peritoneum. The incision is made lateral to the bladder and medial to the left umbilical ligament above the symphysis.

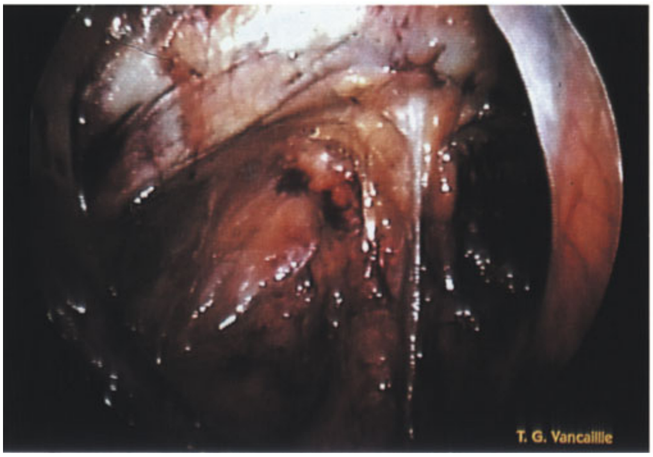

FIGURE 30.10.5. Anatomy of the space of Retzius. The pubic bone and Cooper's ligament are identified. The obturator muscle is visualized on the left, as well as the median attachments of the urethra to the symphysis pubis.

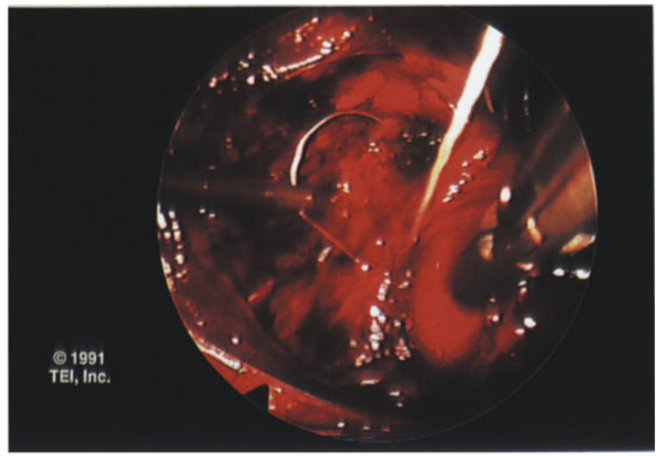

FIGURE 30.10.6. Placement of the right-side stitch in the paraurethral vaginal fascia.

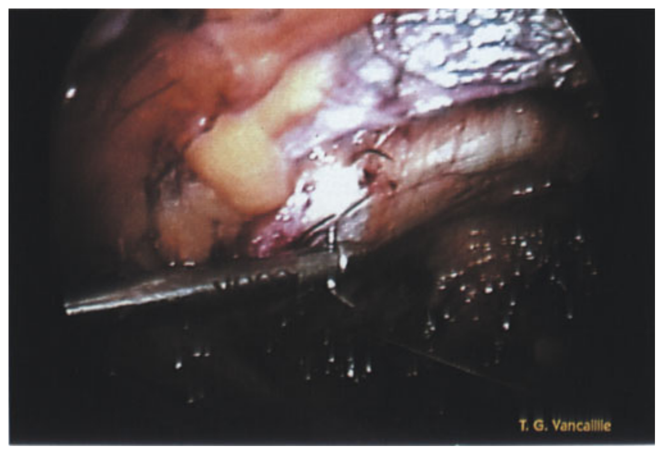

FIGURE 30.10.7. Placement of the left-side stitch through Cooper's ligament.

surgical procedures for correction of stress incontinence may be technically feasible, but we do not have any experience with them. The placement of the suture into the vaginal wall is identical for both the Burch and the MMK (Marshall, Marchetti, Krantz) suspension. The operator places his or her left hand in the patient's vagina, thereby displacing the bladder neck toward the patient's left during the application of the right-sided suture. The vaginal wall is only minimally elevated, because the space between the vagina and the pubic bone is otherwise so small that it becomes difficult to introduce the needle in the right position.

The needle with 36 inches of Ethibond 2–0 suture is introduced through the 10-mm trocar (suprapubic or paramedial). The needle holder is passed through the left lateral or paramedial trocar, not the midline one. The needle is grasped and then inserted into the space of Retzius. The right-sided stitch is placed first. The needle is passed through the fascia of the vaginal wall, along the urethra (Figure 30.10.6). Because the laparoscope is right over the bladder neck, this part of the procedure can be performed with extreme precision. The unsurpassed anatomic detail visible at this point of the procedure would convince even the harshest critic that laparoscopy is at least equal in quality to open procedures.

The next step is more difficult, because of the inherent limitations of laparoscopy: lack of depth perception and restricted access. I initially attempt to attach the suture to Cooper's ligament (Figure 30.10.7). If this fails for whatever reason, I try the symphysis. The problem is that, because of the lack of depth perception, the surgeon may anchor the suture too low on the bone, achieving only minimal elevation of the bladder neck. Manipulation of the bladder neck with the left hand in the patient's vagina compensates for the lack of depth perception to a certain extent. It is recommended that the surgeon perform a trial "bimanual" elevation of the bladder neck. The bladder neck can then be elevated during actual suturing by the assistant.

Knotting is best performed using extracorporeal technique. Tension on the suture is minimized by elevating the vaginal wall during knot tightening. The right-side stitch is placed and tightened before the left-side one is inserted. When performing the Burch procedure, it is important not to tighten the first knot excessively, because this will leave a gap on the other side. One or two extra throws will secure the extracorporeal knot.

One stitch is placed on each side. More recently, in patients with moderate cystocele, we have placed two stitches on each side, in order to correct the cystocele as well as to elevate the bladder neck. It is not technically difficult to place more than one suture on each side. The number of supporting stitches is not a limitation of the procedure as some detractors have maintained. Also we have found that it is possible to wait until all stitches are placed before tightening the knots. In summary, each surgeon's preference in applying the sutures can be accommodated.

Closing the peritoneal defect is not necessary, but it can be achieved by applying one or two more sutures, a good opportunity to increase experience.

In a few patients it will be necessary to "suspend" the vaginal vault. The suspensory structures, such as the cardinal ligaments, are replaced with a mesh. The best material to use is the subject of debate, but slowly resorbing substances such as Vicryl are the current favorites. Tension on the sutures between the vagina and the mesh will loosen the connection between the mesh and vagina and cause the support to fail. Insertion of the mesh should be performed prior to the bladder-neck procedure, because a filling bladder inhibits proper access to the cul-de-sac.

The initial incision is similar to the one made for the enterocele repair. However, in case of vaginal-vault suspension it is important to continue this incision on the right until the promontorium is reached. In addition, care must be taken to dissect the rectovaginal septum as far down as possible. Ideally, the levator muscles should be well identified. It may be advisable to suture the peritoneum of the rectosigmoid to the left wall, so that the rectovaginal space is open, while the mesh is sutured in place. That portion of peritoneum can then be sutured on top of the mesh, along its left border.

When the dissection is finished, a piece of mesh is introduced. The dimensions of the mesh can vary but it should measure about 12 × 4 cm. This apparently excessive length is necessary because the implant must reach far down the rectovaginal space. Ideally, connective tissue ingrowth should be induced between the levator plate, the vagina, and the remnants of the sacrouterine and cardinal ligaments. The mesh is first anchored at the level of the promontorium with one or two stitches of a slowly absorbable or nonabsorbable material. Then the mesh is eased into position along the sidewalls and the rectovaginal septum. The surgeon then evaluates, either with a sponge stick or manually, how high the vaginal vault can be brought up without forcing. That is the level where the vault should be sutured. At least 50% of the length of the mesh will be underneath the vagina (Figure 30.10.8). The remnants of the ligaments are then sutured to the side of the mesh. There is a risk of bleeding from the presacral venous plexus during this step and suturing under laparoscopic control is technically difficult. For a well-trained team, the procedure does not present insurmountable difficulties, but a surgeon should not venture into laparoscopic vault "suspension" until he or she has extensive prior experience with advanced laparoscopic techniques.

After this procedure, the pelvic floor has three reinforced planes perpendicular to a sagittal direction: a posterior one, represented by the apposition of the levator muscles; a middle one formed by the sacrouterine ligaments or mesh; and an anterior level created by the bladder-neck suspension. These three planes counter the downward force of the abdominal contents. Not every patient requires extensive reconstructive surgery, but our only guide to the extent of the reconstruction required in a particular case is clinical experience. No controlled studies of various treatment options have been done.

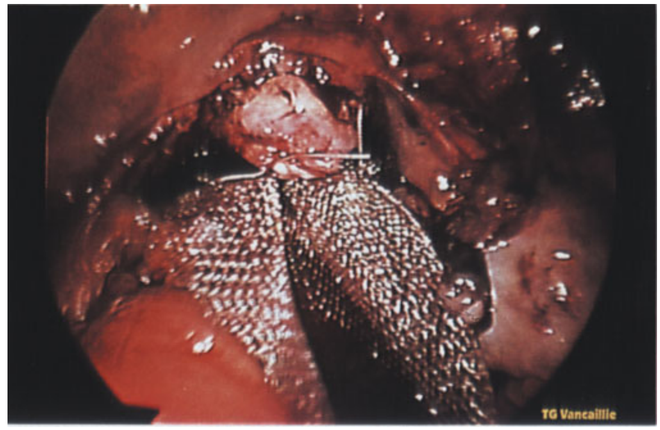

FIGURE 30.10.8. A mesh has been sutured into the rectovaginal septum. It is anchored to the promontorium.

Results

Forty-two women with urinary stress incontinence and varying degrees of pelvic-floor relaxation were seen consecutively from June 1991 to December 1992. Histories were taken and clinical examinations performed. Clinical examinations included vaginal ultrasound to demonstrate the resting position of the urethrovesical junction and the extent of descent during the valsalva maneuver. All 42 patients had descent of the urethrovesical junction at rest and further descent with the valsalva maneuver. A midstream urine specimen was taken for culture and cytology. Cystometrogram and urethral pressure profile studies were obtained in 25 cases. None of these patients had symptoms or study results consistent with detrusor instability or low urethral closure pressures.

The patients ranged in age from 22 to 84, and the mean age was 54. Of these patients, 27 were Caucasian, 13 Hispanic, and 2 were black. The vast majority were multiparous, six were primiparous and two were nulliparous. The mean weight was 78 kg. Twenty-five patients were postmenopausal. Of these, only five were on hormone-replacement therapy at the time of their first visit. Hormone replacement was prescribed to all patients, as part of the overall treatment of their condition. Twenty-one patients had had abdominal or pelvic surgery. Surgeries included: 15 abdominal hysterectomies, 4 vaginal hysterectomies, and 1 uterine suspension. Two patients had had bladder-neck suspension procedures ("needle suspension" type), which had subsequently failed. Six patients had had two abdominal or pelvic operations, and two patients had had three such surgeries. Relevant medical history included nine patients with hypertension, five with adult-onset diabetes, three with asthma, one with emphysema, one with chronic bronchitis, and one with a hiatal hernia. Three patients had jobs that required lifting heavy loads on a regular basis. Of the 42 patients, only 2 admitted to being smokers.

All 42 patients complained of urinary stress incontinence. In addition, nine patients described a pressure sensation or feeling the presence of a mass at the introitus. Four patients reported dyspareunia, and one appeared to have mild urinary retention, which was attributed to a large cystocele. Table 30.10.1 summarizes the extent of pelvic relaxation found.

The various surgeries performed are indicated in Table 30.10.2. There were no major complications. The operative time varied from 40 to 220 minutes. The mean operative time was 117 minutes Blood loss varied from less than 10 cc to less than 250 cc, with a mean loss of less than 95 cc. In the six cases where only a laparoscopic Burch or MMK procedure was performed, the mean operative time was 69 minutes and there was less than 44 cc blood loss. In no case was there any damage to bowel, bladder, or ureter; neither was there excessive blood loss. Conversion to laparotomy was not required in any of the cases. Both bladder injury and conversion to laparotomy had occurred during early experience with the technique, as reported previously.[6]

Postoperative care consisted of prophylactic antibiotics (Kefzol, 1 g intravenously three times over 24 hours, starting in the preoperative phase). Parenteral pain medication is required for the first day only, unless a hysterectomy had also been performed. The suprapubic catheter was left in place for 12 hours, at which point bladder training was started. The first attempt at spontaneous micturition was allowed on the morning following the procedure, and a residual urine was obtained. A residual urine of 150 cc was tolerated. If a larger volume was obtained, the catheter was left in place, and the patient instructed in its care before she was discharged. The catheter was required for 48 hours in four cases, 72 hours in six cases, and 96 hours in three cases. One patient required intermittent catheterization up to six days postoperatively. Thus, 14 of 42 patients required catheterization for more than 24 hours. Ambulation was possible within 12 hours of the procedure in all cases. The majority of patients were discharged within 24 hours of the procedure. Six patients remained in the hospital for 48 hours, six for 72 hours, and two for five days. Twelve of these patients had large residuals and did not want to return home with the catheter. The two other patients had recuperated more slowly. The patients who had a hysterectomy received home healthcare for an additional week. Normal activity was resumed both at work and home within two weeks of the procedure or, in the case of those who underwent hysterectomy, within four weeks.

TABLE 30.10.1. Clinical presentations of pelvic-floor relaxation.

Urethrocele	9
Cystocele	4
Cystocele, rectocele, and uterine prolapse	4
Cystocele and urethrocele	3
Urethrocele and rectocele	2
Enterocele	2
Rectocele	2
Urethrocele, cystocele, and enterocele	1
Urethrocele, cystocele, and rectocele	1
Cystocele, enterocele, and uterine prolapse	1
Cystocele and rectocele	1
Vault prolapse	1

Patients were seen for follow-up within two weeks of their surgery, at three or four months and annually thereafter. Cure of incontinence was assessed by taking a history, by clinical examination, and by transvaginal ultrasound, which demonstrated elevation of the bladder neck to its proper retropubic position and maintenance of this position during the valsalva maneuver.

So far follow-up on these 42 patients ranges from 6 to 24 months. Redescent of the bladder neck occurred between the two-week visit and three-month visit in four cases. Two of these patients had no symptoms, and two had occasional urinary loss with full bladder. Ten patients in all mentioned occasional loss of small amounts of urine, but this was a vast improvement over their preoperative condition and did not interfere with daily activities. One failure occurred in a 74-year-old patient. She reported stress incontinence comparable to her preoperative incontinence. However, she refused to submit to testing and did not return to the office for regular follow-up. Six patients reported a small component of urgency, four reported a pressure sensation, four had dyspareunia (two occasionally and two consistently), and four patients had a small degree of pelvic discomfort. One patient reported a persistent sensation of fullness in the vagina. On

TABLE 30.10.2. Procedures done for pelvic-floor relaxation.*

Enterocele repair	6
Colporrhaphia	3
Colporrhaphia + enterocele repair	7
Hysterectomy + colporrhaphia	3
Hysterectomy + colporrhaphia + enterocele	5
Vault suspension + colporrhaphia	1

*All patients had laparoscopic bladder-neck suspension.

physical examination, the cause appeared to be redundant vaginal mucosa rather than relaxation.

Further follow-up is required before laparoscopic surgery for pelvic-floor relaxation can be definitively assessed. The initial results are very encouraging, however, particularly in view of the success and complication rates reported for equivalent open procedures.[7]

Discussion

This initial series of patients demonstrates the feasibility of laparoscopic reconstructive procedures. In comparison to transabdominal procedures, operative time is not excessive. A bladder-neck procedure, for example, requires an average of 69 minutes and is accompanied by an average blood loss of less than 95 cc. Postoperative pain is minimal and the time from admission to discharge compares quite favorably with laparotomy, as was expected. Twenty-four patients were home within 24 hours; the remaining 14 patients stayed in the hospital longer because of large urinary residuals. Perhaps earlier discharge for this latter group would be possible if home healthcare could be arranged. Definitive statistics on the success rates of laparoscopic pelvic reconstructive procedures will require that more patients are followed long-term. However, the preliminary results indicate that the claim of reduced morbidity will be borne out and that the success rates will be comparable to those of conventional procedures.

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30.11
Laparoscopic Treatment of Urinary Stress Incontinence

C.Y. Liu

Introduction

More than 100 different surgical procedures have been reported for the treatment of urinary stress incontinence in women, including anterior colporrhaphy,[1] paravaginal suspension,[2] various kinds of needle urethropexy,[3–5] sub-urethral sling procedures,[6] retropubic colposuspension,[7] the creation of an artificial sphincter,[8] and the new technique of paraurethral injection of polytetrafluoroethylene (PTFE) and glutaraldehyde cross-linked collagen (GAX). Furthermore, these procedures have many modifications. All of this is somewhat confusing for the practicing surgeon who must choose a surgical procedure for his or her incontinent patient.

It is important to point out that in most patients with genuine stress urinary incontinence, the intrinsic urethral sphincteric mechanism is intact, although functioning poorly because the loss of fibromuscular support has led to the displacement of the urethrovesical junction and the proximal part of the urethra. Therefore, the ultimate goal of the surgery is to restore the normal anatomic position of the urethrovesical junction and the proximal part of the urethra. Given this understanding of the pathophysiology of the genuine urinary stress incontinence, an anti-incontinent procedure must meet the following objectives[9,10]:

1. To elevate and maintain the urethrovesical junction and the proximal part of the urethra within the abdominal pressure zone, so that pressure is equally transmitted to the urethrovesical junction and the proximal part of the urethra.
2. To allow the posterior rotational descent of the base of the bladder in response to the downward thrust of the posterosuperior viscera.
3. To preserve the compressibility and pliability of the urethra.
4. To avoid compromising the urethral sphincteric mechanism.

In recent years, a consensus has developed, especially among gynecologists, that the retropubic colposuspension (Burch procedure) is the treatment of choice for patients with genuine stress urinary incontinence who have an intact urethral sphincter but a displaced urethrovesical junction.

Evolution of the Procedure

In 1949, Marshall, Marchetti, and Krantz (MMK) reported the results of vesicourethral suspension done on 50 patients (5 men and 45 women) with stress urinary incontinence, 25 of whom had had unsuccessful surgical procedures for incontinence. In their original procedure, the retropubic space was widely dissected, and the urethra was dissected to within 1 cm of the external urethral meatus. Three sutures of no. 1 chromic catgut were placed equidistant from each other on either side of the urethra and then sutured through the periosteum of the pubis. The overall success rate was 82%; 7% improved and 11% were failures.[11] This retropubic suspension of the bladder neck has been modified by many surgeons since its publication.

In 1961, Burch reported a modified MMK procedure in which he used Cooper's ligament instead of the periosteum of the pubic bone to obtain more secure urethrovaginal fixation. Burch used three no. 2 chromic-catgut sutures on either side of the urethrovesical junction and suspended the anterior vaginal wall from Cooper's ligaments. In his initial series, all 53 patients were relieved of their incontinence. In 1968, Burch reported a subsequent series of 143 patients. His overall success rate was 93% after at least 20 months of follow-up. The major complication was the development of enterocele (7.6%), and Burch emphasized the need for obliteration of the cul-de-sac to prevent its occurrence.[12] The procedure described by Burch has received wide acceptance.

In 1976, Tanagho, discussing the Burch procedure, recommended that there be no dissection within 2 cm of the urethra on each side. The procedure requires removal of all fatty tissue in the paravaginal area in order to stimulate fibrosis and fixation to the retropubis. If the suspension sutures are under undue tension, necrosis and breakdown will occur at the suture-placement site. Tanagho used four delayed-absorption sutures (no. 1 Dexon), one at midurethral level and another at the urethrovesical junction, on both sides of the urethra. He emphasized that sutures should not be tied too tightly. It is not necessary to bring the anterior vaginal wall all the way up to meet Cooper's ligaments; indeed, doing so might compress or kink the proximal portion of the urethra.[13]

In 1979, Cardozo and Stanton and colleagues reported that 18% of patients who underwent retropubic urethropexy developed detrusor instability. Potential etiological factors include sutures through the bladder, vesical neck obstruction, and extensive surgical dissection around the urethrovesical junction.[14] This finding further supported the surgical principles outlined by Tanagho, which are widely accepted by gynecological surgeons and have become the standard for performing the Burch procedure.

Thanks to advances in laparoscopic and video equipment and improvement in operators' laparoscopic skills, modern operative laparoscopy now meets the stringent surgical criteria for retropubic colposuspension: adequate exposure with good visibility of the operative field; accurate dissection of the retropubic space; perfect hemostasis; precise placement of paraurethral sutures; and apposition of tissue without undue tension.

Laparoscopic Treatment for Genuine Urinary Stress Incontinence

Preoperative Evaluation

The preoperative evaluation includes a complete medical history and physical examination with particular emphasis on neurologic history and current medication. Urinary incontinence questionnaires and patient's voiding diaries (urologs) can give invaluable information. Pelvic examinations and lower neurologic examination with emphasis on the sensory and motor dermatome pattern of S_2, S_3, and S_4 are also necessary.

Other office tests should include urinalysis and urine culture, a stress test, and a Q-Tip test, as well as a simple office cystometry and the measurement of residual urine. If there is any deviation from normal in these tests, if the patient is frail and old (over 60), or if the patient has had failed anti-incontinent surgery, she should undergo more sophisticated multichannel urodynamic studies before treatment (Table 30.11.1).

Operative Technique

Under general anesthesia with endotracheal intubation, the patient is placed in a low dorsolithotomic position with both legs supported in Allen stirrups (Edgewater Medical System, Cleveland, OH) (Figure 30.11.1). A 20F Foley catheter with a 30-mL balloon tip is then inserted into the bladder. After the bladder is emptied, 50 mL of concentrated indigo-carmine dye is instilled into the bladder. The Foley catheter is then clamped. Accidental penetration of the bladder during the procedure will immediately be recognized by the escape of blue dye. A 10-mm laparoscope is inserted through a vertical intraumbilical incision, and four 5-mm puncture sites are made in the abdomen (Figure 30.11.2). The lower pair of punc-

TABLE 30.11.1. Patients who require multichannel urodynamic studies.

1. Age > 60
2. Previous unsuccessful anti-incontinence surgery
3. Any deviation from normal in the office tests
4. Continuous or unpredictable leakage

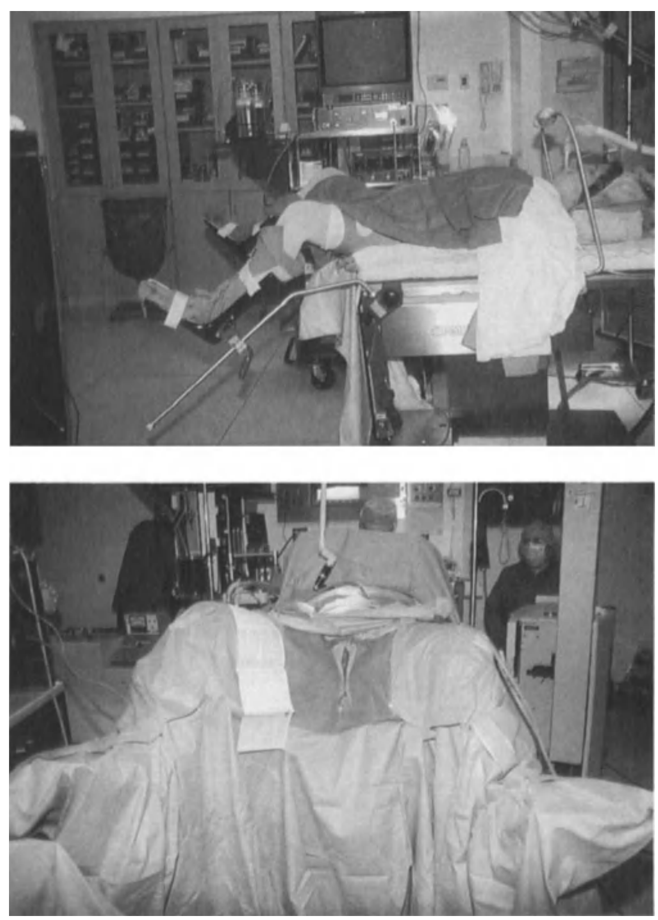

FIGURE 30.11.1. Patient is placed in the low dortholithotomic position, with both legs supported in Allen stirrups.

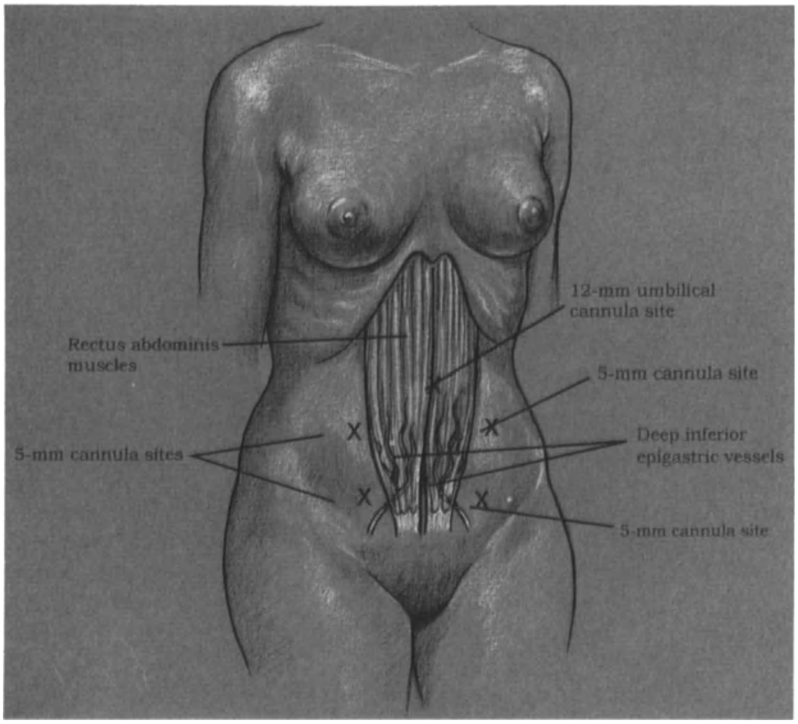

FIGURE 30.11.2. The trocar sites. The lower two 5-mm trocars are placed in the low abdomen, lateral to the deep inferior epigastric vessels. The upper two trocars are placed at about umbilical level, lateral to the abdominal rectus muscles.

ture sites are lateral to the deep inferior epigastric vessels, and the upper pair are lateral to the abdominal rectus muscle at about the umbilical level. Careful inspection is made of the internal viscus, and the patient is then placed in a 15 to 20° Trendelenburg position and the pelvic organs are meticulously examined. All visible pathologies, such as adhesions and endometriosis, are excised. Additional procedures, such as adnexectomy and hysterectomy, are performed if indicated.

The cul-de-sac is obliterated with 2–0 permanent sutures, following the technique Moschcowitz developed.[15] One or more purse-string sutures may be needed to obliterate the cul-de-sac. It is important to obliterate the channels on either side of the sigmoid colon to prevent future enterocele formation.

After the cul-de-sac is obliterated, a transverse incision is made with laparoscopic scissors in the parietal peritoneum about 1½ in. above the symphysis pubis and in between the two umbilical ligaments. The anterior peritoneum is dissected away from the anterior abdominal wall toward the pubic bone, and the retropubic space is entered. The retropubic space is dissected, but no dissection is performed within 2 to 2.5 cm of the urethra. Anatomic landmarks, such as the obturator canal, the aberrant obturator vein, the white line, or the arcus tendineous fascia are identified. As much retropubic fat as possible is removed in order to promote fibrosis and scar formation in the paravaginal area. Hemostasis is achieved by bipolar electrocoagulation. The bladder is mobilized and the paravaginal fascia are identified on both sides of the urethra by their pearly white glistening appearance. Four sutures of nonabsorbable material, such as no. 2 Gore-tex, are used to raise and pull the anterior vaginal wall forward to Cooper's ligament.

A pair of sutures is placed at the level of the middle of the urethra and the urethrovesical junction (Figure 30.11.3). The sutures are inserted at least 2 cm from the urethra. A double bite is taken of the whole thickness of the anterior vaginal wall, avoiding the vaginal canal. The needle is then passed through Cooper's ligament on the

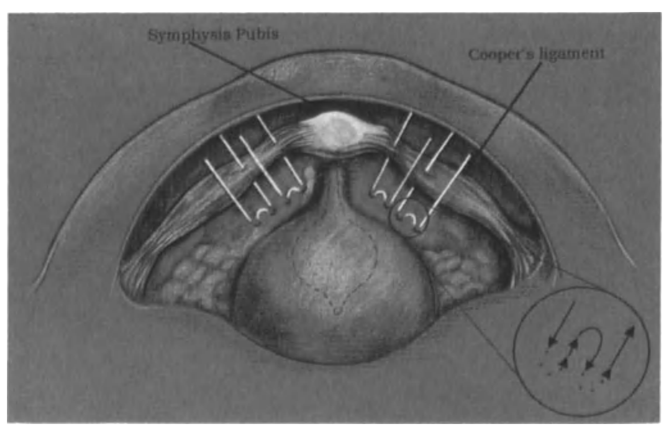

FIGURE 30.11.3. Burch colposuspension. Two permanent sutures are placed on either side of the urethra. A double bite is taken of the entire thickness of the anterior vaginal wall, excluding the vaginal canal. The suture is then passed through Cooper's ligament on the ipsilateral side. The sutures are placed at the level of the middle of the urethra and the urethrovesical junction and at least 2 cm from the urethra.

ipsilateral side at a level immediately above the sutures on the anterior vaginal wall. During the placement of these sutures, the assistant puts his or her middle and index fingers in the vagina at the level of the urethrovesical junction. The tips of the fingers are at the junction of the Foley catheter balloon and the drainage tube. The assistant should wear protective devices on the fingertips to prevent accidental needle stick. Tenting of the anterior vaginal wall in this manner facilitates correct placement of the sutures. Once the sutures are correctly placed, they can be tied using the extracorporal knot-tying technique and the Clarke-Reich knot pusher.[16] Tying is facilitated if the assistant pushes his or her fingers up towards Cooper's ligament. The procedure is then repeated on the contralateral side.

During the tying of knots, particular care must be taken to avoid compressing or kinking the urethra. It is not necessary to have the vaginal wall in direct contact with Cooper's ligament. Adequate support will be obtained if the sutures are tied without undue tension. Excessive tension, on the other hand, will produce necrosis at the suture sites, possibly resulting in suture release and surgical failure.

The retropubic space is then irrigated with copious amounts of Ringer's lactate solution. Any bleeders are coagulated with bipolar forceps. A suprapubic catheter is inserted into the bladder under direct visualization, and the peritoneal defect is closed with 2–0 absorbable sutures. Cystoscopic examination is then performed to ensure that no suture material has penetrated through or into the bladder wall. Five milliliters of indigo-carmine dye and 10 mg of furosemide (Lasix) may then be injected intravenously to confirm the integrity of the ureters. Peristalsis and ejection of dye from ureteral orifices can be clearly observed cystoscopically.

Alternative Techniques of Laparoscopic Retropubic Colposuspension

Some investigators are currently using synthetic mesh to suspend the anterior vaginal wall and elevate the urethrovesical junction, stapling one end of the mesh to the anterior vaginal wall and the other end to Cooper's ligament. Others are using a combined laparoscopic and vaginal approach. Under laparoscopic guidance, the Pereyra needle with suture on it is used to puncture Cooper's ligament and the anterior vaginal wall. The sutures are then tied laparoscopically. The results of these alternative techniques are currently unknown.

Postoperative Care

Postoperative care is similar to that given after any major laparoscopic surgery. The majority of patients can be discharged from the hospital within 24 hours of the surgery with mild analgesic medication. These patients, however, will go home with an indwelling suprapubic catheter, which can be removed three to four days postoperatively. When their catheter is removed, they are taught self-catheterization and given six disposable plastic catheters to take home.

All patients are allowed to drive and return to work one week after surgery, providing their jobs do not require much physical exertion. Detailed instructions regarding their postoperative physical activities are given. Patients are instructed to limit their activities for at least three months following surgery to ensure that strong fibrosis and scar tissue has formed in the retropubic area. No heavy lifting, pushing, stooping, bending, or reaching should be undertaken during this time. Strong scar tissue ensures a better long-term result for the surgery.

Complications of Laparoscopic Retropubic Colposuspension

The reported complications of abdominal retropubic colposuspension include intraoperative urethral and bladder injury, ureteral kinking and obstruction, retropubic hematoma and abscess, urinary tract infection, urinary retention, postoperative detrusor instability, enterocele and genital prolapse, and sexual dysfunction. In our series of 132 laparoscopic retropubic colposuspensions, the overall complication rate was 9.9% (Table 30.11.2). Four of our patients had intraoperative bladder injuries. The injuries, which were on the dome of the bladder, occurred during the initial entry into the retropubic space. These injuries were recognized and repaired laparoscopically. Four patients developed postoperative voiding difficulty with urinary retention and required catheterization for more than 10 days. Three patients developed *de novo* detrusor instability, but all improved with the administration of oxybutynin and bladder retraining. One patient developed a right ureteral obstruction postoperatively; second-look laparoscopy and cystoscopy were performed 10 days after

TABLE 30.11.2. Complications in 132 laparoscopic retropubic colposuspensions.

Complication	Number of patients	Rate**
Bladder injury	4	3.0
Urinary retention	4	3.0
Ureteral obstruction	1	0.7
Detrusor instability	3	2.3
Gross hematuria*	1	0.7
Total	13	9.8

*Gross hematuria was secondary to the insertion of suprapubic catheter.

**Rate per 100 women undergoing laparoscopic Burch procedures.

initial surgery, revealing a kinked right ureter, which was relieved by releasing the retropubic colposuspension sutures on the right side. Another patient had gross hematuria from the suprapubic catheter site, which required a second-look cystoscopic examination. The suprapubic catheter was removed, and the bleeder was coagulated cystoscopically. No other complications, such as retropubic hematoma, abscess, urethral injury, or urinary fistula occurred in our series.

Clinical Results

Review of the literature reveals that the cure rate for the abdominal Burch procedure is approximately 80 to 85%.[20] However, those patients who have had unsuccessful anti-incontinence surgery or who have incontinence and low urethral-closure pressure (< 20 mm H_2O) have a higher failure rate. In our series of 132 laparoscopic Burch procedures, concomitant surgeries included laparoscopic hysterectomy and salpingo-oophorectomy, rectocele repair (low rectoceles were repaired vaginally along with perineorrhaphy), vaginal-vault suspension, and cystocele repair. Concomitant hysterectomy was not performed unless indicated.[21] In this series, six patients had had unsuccessful anti-incontinence surgeries; the remaining 126 patients were having primary surgery.

Although follow-up has been short, ranging from 2 to 31 months (Table 30.11.3), 127 of the 132 patients (96.1%) are satisfied and remain asymptomatic. At 6 weeks and again at 12 weeks, a stress test was performed on all patients.

The good results of this series may be attributed to the fact that the laparoscopic surgical procedure is accomplished in exactly the same way as a traditional laparotomy, and to the fact that only 6 of the 132 patients had previously undergone anti-incontinence surgery. Also, patients with low urethral closure pressure (< 20 mm H_2O) were excluded from this study, except for one patient, who had had no anti-incontinence surgery and who had a positive Q-Tip test. She was informed of the high failure rate of this procedure for patients in her condition, underwent the procedure, and had a satisfactory result.

We recognize that our follow-up is relatively short and that a good surgical result was defined as a negative stress test and the patient's subjective feeling that her symptoms had improved. Although not economically feasible in a private-practice setting, multichannel urodynamic studies before and after surgery in all patients would provide a more objective measure of the success of the surgery.

TABLE 30.11.3. Length of follow-up (as of August 1993).

Follow-up	Number of patients
< 6 mo	31
6 mo–1 yr	36
1–2 yr	55
> 2 yr	10
Total	132

Discussion

Genuine urinary stress incontinence is a result of defect in the pelvic-floor support system. When such a defect is of such magnitude that surgery is required, the defect in the pelvic floor is usually not limited to the presenting symptom. Therefore, surgery for the urinary stress incontinence, vaginal prolapse, or any other pelvic-floor defect, must not be thought of as an isolated procedure; the pelvic floor must be treated as a whole instead of piecemeal. Restorative surgery for urinary incontinence, for example, will result in anterior displacement of the vagina. This will change the force vectors in the middle and posterior compartments of the pelvic floor, so that a slight deficiency in these compartments may well become marked postoperatively, necessitating further surgery. More than 15% of patients having anterior urethropexy develop mid- and posterior-compartment deficiency, and subsequently manifest enterocele, rectocele, and vaginal-vault prolapse.[7]

For this reason, the entire pelvic floor must be thoroughly investigated before proceeding with any reconstructive surgery. The increased intra-abdominal pressure during laparoscopy allows pelvic-floor defects to be more easily identified. Repair of these defects, either laparoscopically or vaginally, must be carried out at the time of laparoscopic retropubic colposuspension.

Recent evidence suggests that the failure rate of patients with low urethral closure pressure who undergo the Burch procedure is high. McGuire noted a high incidence of unsuccessful anti-incontinence surgery among such patients.[17] Sand and colleagues found that the failure rate of retropubic colposuspension among patients with low urethral closure pressure was 54%.[18] Bowen came to the same conclusion.[19] Therefore, it is important to recognize this risk factor and to properly screen and counsel patients before surgery. A suburethral sling procedure or periurethral GAX injection might be preferable for these patients.

The laparoscopic approach to retropubic colposuspension provides better visualization of the space of Retzius than traditional laparotomy. This facilitates dissection of the retropubic space and mobilization of the bladder. The magnification of the video display system allows important anatomic landmarks and blood vessels to be more easily visualized, thus contributing to greater accuracy in the placement of sutures, a decrease in blood loss, and the elimination of drains.

Although the majority of failures of anti-incontinence surgery occur within the first two years, the failure rate continues to increase with time. I have been performing laparoscopic retropubic colposuspensions for the past three years and although my series is still small and follow-up short, I remain encouraged by the results. Patients who had a laparoscopic retropubic colposuspension had less discomfort, much shorter hospital stay, and quicker recoveries than patients who underwent a similar procedure through an abdominal incision. I believe laparoscopic retropubic colposuspension can be a satisfactory alternative to abdominal retropubic colposuspension in well-selected patients.

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30.12
Laparoscopic Management of Vaginal Aplasia with or Without Functional Noncommunicating Rudimentary Uterus

Leila V. Adamyan

Introduction

Colpopoiesis is defined as the creation of an artificial vagina (from the Greek *colpos,* meaning vagina, and *poiesis,* meaning to create). Colpopoiesis is any method of opening the vesicorectal space and keeping it open.

For more than 180 years, surgeons have attempted reconstructive operations for vaginal aplasia. The materials used to create an artificial vagina include skin grafts or transplants, the small and large intestine, amnion, polymers, and pelvic peritoneum. Creation of a canal in the vesicorectal space is common to all these operations. Although colpopoiesis can be done by a variety of techniques, all are traumatizing and involve significant risk of injury to adjacent organs. Some of the methods are ineffective, and others require a prolonged epithelialization and thus lengthy recuperation.

After more than 20 years of surgical experience in creating an artificial vagina from different tissues and materials (intestine, polymers, peritoneum), this author believes the method of choice is one-stage colpopoiesis using pelvic peritoneum.[1,2] This operation has been successfully completed in 297 patients. The major disadvantage of this method is its technical complexity. It is difficult to identify the pelvic peritoneum and to create the vaginal fornix.

Laparoscopy facilitates the most difficult steps of this procedure. We have performed laparoscopic colpopoiesis in 27 patients. The new laparoscopic technique was particularly helpful in the management of three women with vaginal and cervical aplasia who had a functional rudimentary uterus. In these cases, the laparoscope was used to assist simultaneous hysterectomy performed through perineal access.

History of Colpopoiesis for Vaginal and Uterine Aplasia

The first colpopoiesis operation was performed in 1810 by C. Dupuytren, who was trying to relieve the suffering menstrual hemorrhage caused women with vaginal aplasia. He created a passage between the urinary bladder and rectum to empty the hematometra. This operation proved to be a failure. In spite of bougie and prosthetic insertion, the neovagina atrophied and scarred before epithelialization occurred.

K.F. Hepner (1872) was one of the first to use autotransplants for tunnel widening. He used a skin flap taken from the hip.[3] This method was modified by C. Cree in 1884. Later, many methods were proposed; although the transplants differed in size and form, these methods were essentially similar.

In 1888, Shalita suggested spreading the vaginal canal by transplanting flaps according to a method devised by Tirsh.[4] Many authors applied this technique. Prostheses and frameworks were used to attach a transplant. Then, thin skin flaps taken with a dermatome were used to create an artificial vagina. Necrosis and skin flap rejection were frequent complications, resulting in a small vagina. Also, hair continued to grow in the skin transplant.

In 1934, the method of colpopoiesis using amnion was suggested, but these operations were not adequate.

In 1892, Snegiryov used distal rectum for colpopoieses. Many modifications of this method were devised, but it was ultimately rejected because of its difficulty and the frequency of complications.[5–7]

Baldwin (1904) was the first to use small intestine. This approach was also modified by a number of surgeons. Its primary disadvantage was that the transplanted intestine continued secreting, an effect patients tolerated poorly. This operation also had a high complication rate. It is no longer employed.

The next innovation was use of the sigmoid colon. Alexandrov (1932) used colon to form a double-barreled vagina.[8] Gydovsky (1949) developed the one-barrel colpopoiesis operation using the sigmoid colon, and this procedure is still performed today,[9] although there is a risk of severe complications.

Ott was the first to use pelvic peritoneum, but his method did not enjoy widespread acceptance.[10] In 1933, Ksido also employed the pelvic peritoneum, as did Arist and Davidov.[11,12] This technique was improved by Kurbanova and Kravkova, who performed a one-stage operation using perineal (transintroital) access.

In recent years, polymer materials (Cambutec 2, Collacyl) have been used to widen the vaginal bed, when the approach to the peritoneum is complicated by scarring and adhesions, or there is insufficient peritoneum available to cover the bed.[13] Of all the materials suggested, we prefer pelvic peritoneum for neovaginal lining.

One-Stage Colpopoiesis Using Pelvic Peritoneum and Perineal Access

A diagnosis is established after a thorough history is taken, and physical and ultrasound examination, urography, karyotyping, and laparoscopy (if indicated) are performed. As always, the most important stage is the creation of a bed for the vagina. The danger of injuring the bladder or rectum is always a concern. The patient is placed on the table in the supine position with the legs wide apart. The surgeon must have adequate access to allow manipulation of tissue with a vaginal retractor.

After the labia minora are spread wide apart, a 3- to 4-cm incision is made in the introitus along the lower edge of the labia minora between the urethra and the rectum. Dissection should proceed through the epithelial layer and include 1 to 1.5 cm of deep fascia. When the fascial plate is opened, the operator inserts two fingers and moves them straight forward to the small pelvic peritoneum, thus dividing the tissue between the bladder and the rectum. The operator may insert a speculum to separate the tissue. The lateral movement of the speculum or fingers creates a tunnel for transplant placement. Sometimes this is easily accomplished. If the tissue must be dissected near the bladder or the rectum, there is a risk of injury. Dissection is continued until the pelvic peritoneum is exposed. The pelvic peritoneum, which appears as a sagging, thin, pale, yellow plate, is difficult to identify. Using long forceps, the peritoneum is opened, placed along the tunnel, and sutured to the introitus. Then, using the uterine rudiment, a neovaginal fornix is formed, by placing three or four Vicryl or Dexon sutures with a small round needle between the rudiment and the top of the tunnel peritoneum. If a uterine remnant is not present, the peritoneal cavity is closed using two hemi-purse-string sutures, which penetrate the peritoneum of urinary bladder, sigmoid colon, and pelvic sidewalls.

Justification of the Laparoscopic Approach to Colpopoiesis

The points justifying laparoscopic application are:

- The pelvic peritoneum is difficult to identify from a perineal approach.

  Laparoscopy permits identification not only of the tissue to be opened but also of its most mobile portion. This makes it easier to select sufficient tissue to cover the walls of the vesicorectal space without tension.
- High risk of bladder or rectal injury.

  Laparoscopy allows the direction of the tunnel to be accurately determined, avoiding injuries.
- Difficulty forming the neovaginal fornix.

  With laparoscopy, the placement of the neovaginal fornix is determined from the abdominal cavity, and the fornix is created under direct visualization.
- One-stage peritoneal colpopoiesis by perineal access is a difficult, traumatizing procedure performed almost blindly, which can be accomplished only by highly experienced pelvic surgeons.

  Laparoscopy significantly facilitates the technique, reduces operating time and risk, and makes the operation available to more surgeons, provided they are skilled in laparoscopy and pelvic surgery.
- In patients with vaginal and cervical aplasia and a noncommunicating functional rudimentary uterus the operation is usually performed in two stages: hysterectomy is done by laparotomy, followed by colpopoiesis by combined perineal/abdominal access. This operation is prolonged and traumatizing.

Laparoscopy is the method of choice in this situation: the hysterectomy is done with a transintroital approach, and colpopoiesis is then performed under laparoscopic control.

Laparoscopic Technique

The equipment needed for laparoscopically assisted colpopoiesis using pelvic peritoneum includes:

1. Standard set-up for laparoscopy, including needle holder, forceps, knot pusher, absorbable suturing material (Vicryl, Dexon), and curved needles;

2. Set-up for vaginal surgery;
3. Sterile soft gauze tampon moistened with oil, or a hydrogel tampon impregnated with antiseptic (chlorhexidine);
4. Fibrin glue.

The patient is placed on the operating table in the supine position with legs wide apart. First, diagnostic laparoscopy is performed. The principle trocar is inserted through an incision in the infraumbilical fold and short 5-mm ancillary trocars are placed through lateral punctures in the suprapubic area. The ancillary trocar sleeves with screw-grid surfaces facilitate manipulation of the needle holder, forceps, and Aquapurator.[14]

The status of the pelvic organs, the nature of any malformations, the mobility of the peritoneum, and the location of ovaries and uterine rudiment are determined (Figure 30.12.1). Women with vaginal and uterine aplasia frequently have a muscular "embankment" across the small pelvis between the bladder and the rectum. The peritoneum in this area has ample mobility. Generally, the most mobile part of the peritoneum is approximately 5 to 7 cm behind the muscular embankment.

The perineum is transversely incised midway between the urethra and anus. The best place for this incision is at the lower edge of the labia minora. A tunnel is created in the vesicorectal space using both blunt and sharp dissection until the pelvic peritoneum is reached. The most crucial step of the operation—identification of the most mobile zone of peritoneum—is next. The peritoneum is then grasped with atraumatic forceps and moved under laparoscopic guidance to the tunnel, where it is grasped with forceps from below, dissected with scissors either laparoscopically or perineally, and pulled through to the dissected perineum (Figure 30.12.2). The peritoneum is sutured to the perineum with separate 2–0 catgut stitches (Figure 30.12.3). As a result, the urinary bladder and rectum are completely peritonized. If fibrin glue (FG-1, Beriplast) is available, it is advisable to use it while apposing the peritoneum to the walls of the tunnel before suturing it to the perineum. Fibrin expedites adherence of the peritoneum to the neovagina and affords complete hemostasis.

The second-most-important step is laparoscopic crea-

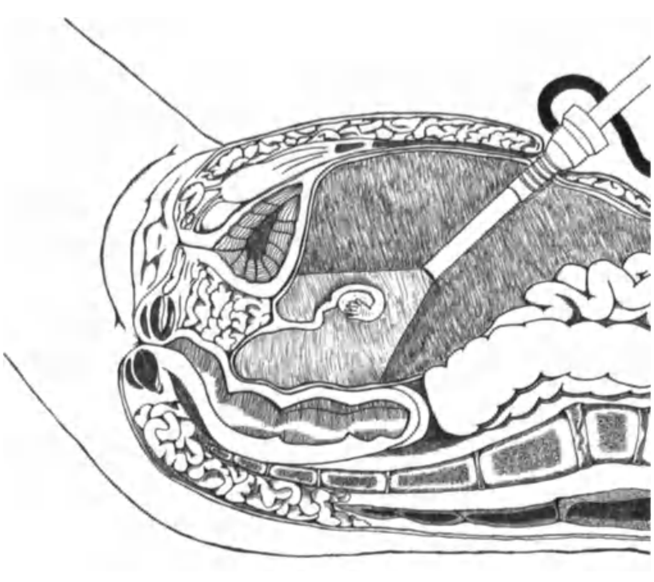

FIGURE 30.12.1. Laparoscopic view of the cul-de-sac in a case of vaginal aplasia.

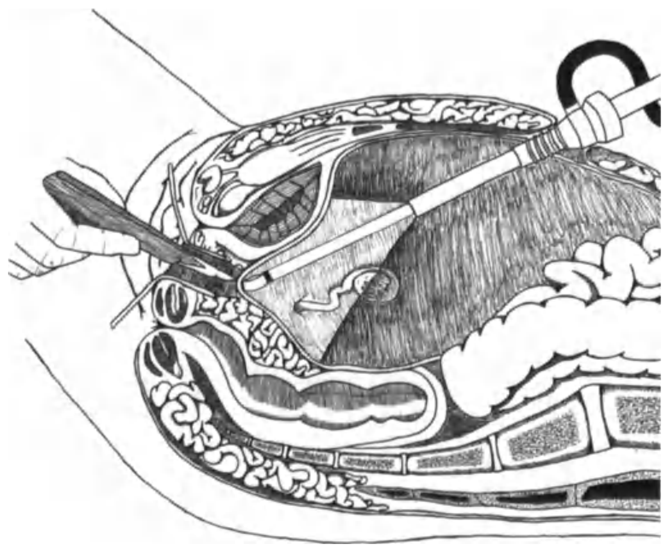

FIGURE 30.12.2. Perineal cavity is made between the bladder and rectum until the peritoneum is identified with the aid of laparoscopic indentation. The peritoneum is then mobilized until it can be stretched down to the hymenal ring.

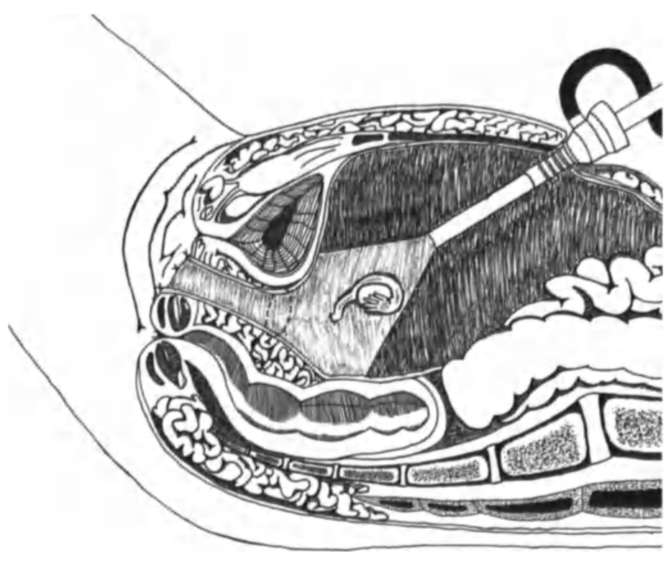

FIGURE 30.12.3. The peritoneum is sutured to the hymenal ring. Thereafter, a purse-string suture is applied laparoscopically to the future vaginal apex, approximately 10 cm from the hymenal ring. The peritoneum lining the neovagina will metaplase into vaginal squamous epithelium.

tion of neovaginal fornix. Adequate lighting is essential. The peritoneum covering the urinary bladder, lateral pelvic walls, sigmoid colon, and uterine rudiments is grasped laparoscopically and sutured with two hemi-purse-string absorbable stitches (Vicryl, Dexon) (Figure 30.12.3). A curved needle and extracorporeal knotting are employed to make the sutures.[15]

The neovaginal fornix is created 10 to 12 cm from the vaginal orifice (the perineal skin incision). Sometimes, when there is enough tissue tension, it is possible to create the fornix by suturing the bladder peritoneum and the uterine rudiment to the pelvic sidewall peritoneum. The main advantage of the laparoscopic approach is visual control of the suturing, which prevents injury to adjacent organs.

Sudden loss of pneumoperitoneum can be avoided by tamponade of the neovagina. Special dilators or molds are not necessary. A soft gauze tampon moistened with Vaseline and antiseptic solution may be kept in place for one day. In some cases, a hydrogel tampon impregnated with chlorhexidine is inserted for 36 or 72 hours.[13] Slow discharge of antiseptic inhibits infection in the operated area.

After the operation is completed, significant drawing of perineal skin towards the artificial vagina and a corresponding displacement of the external urethral os are observed and may impede urinary catheterization. Placement of a Foley catheter is advised for one to two days.

The peritoneum has the ability to adhere rapidly (within 24 or 48 hours). Because of this, patients recuperate quickly, and early initiation of vaginal intercourse is possible.

Duration of laparoscopically assisted colpopoiesis is approximately 1 hour. Wide-spectrum antibacterial preparations are prescribed for 48 to 72 hours postoperatively. Early ambulation is encouraged, with discharge after four to six days. Before discharge, the patient is advised to start coitus two weeks after surgery.

Clinical Results

Medical and genetic examination of 576 patients with genital malformations revealed different cytogenetic and genetic biochemical indices in 35%. The reconstructive operations we most frequently performed were removal of a rudimentary uterine horn and promotion of menstrual outflow (46), reconstruction of uterus for septum (84), and creation of neovagina for aplasia (324).

A neovagina was created laparoscopically in 27 of the 324 cases. In three cases of vaginal aplasia with functional noncommunicating rudimentary uterus, hysterectomy and colpopoiesis were performed by combined laparoscopic and perineal access.

Comparative analysis of traditional colpopoiesis by transintroital access and laparoscopically assisted colpopoiesis was done. The operating time for the 297 patients who underwent traditional colpopoiesis by transintroital access was 98.1 ± 25.4 minutes; the operating time for the 27 patients who had laparoscopically assisted colpopoiesis was 52.3 ± 12.4 minutes. Blood loss was minimal with either technique. Bowel injury requiring immediate repair (two cases) and bladder injury (one case) occurred during conventional colpopoiesis. Healing of the injuries occurred without further complications or breakdown in these cases. There were no intraoperative complications in the laparoscopic group.

The average length of postoperative stay after traditional colpopoiesis was 11.4 ± 2.5 days; women who had laparoscopically assisted colpopoiesis averaged 2.1 ± 2.2 days.

Results of long-term follow-up after traditional colpopoiesis (2 to 11 years) and for laparoscopically assisted colpopoiesis (6 to 24 months), were similar for all patients. Evaluation criteria were: ability to have vaginal coitus and assessment of neovagina characteristics (depth, width, scarring, cytologic and morphologic features). Seven of 324 patients had no sexual partners and, thus, the inability to maintain an adequately pliable neovagina resulted in partial stenosis. The remainder of patients reported adequate sex lives. The depth and width of the vagina were considered satisfactory if a vaginal speculum and speculum levator (10 to 12 cm) could be inserted. Pliability was adequate if the neovagina easily admitted two fingers. Kurbanova used cytologic and morphologic data to show that epithelialization of a neovagina created from pelvic peritoneum is similar to that of a natural one; it has an acid pH, and the same cyclic changes. Long-term results are affected by the timing of initiation of sexual activity; the optimal timing is two weeks postoperatively.

Operative Technique for Total Vaginal and Cervical Aplasia with Functional Noncommunicating Rudimentary Uterus

The traditional procedure for complete vaginal and cervical aplasia with a functional, noncommunicating rudimentary uterus has two stages. First, hysterectomy by laparotomy is performed; as a rule hematometra, adenomyosis, and external endometriosis are present. Then colpopoiesis is done. This operation is effective, but traumatizing.

Three women in our series had laparoscopically assisted hysterectomy and colpopoiesis (Table 30.12.1).

Stage 1: Diagnostic laparoscopy was done using the incisions previously described. In two cases inspection of

TABLE 30.12.1. Description of operative technique for laparoscopically assisted hysterectomy and colpopoiesis.

Stage 1	Diagnostic laparoscopy to determine the character of the malformation and to plan operative procedures (division of adhesions, excision of endometriosis)
Stage 2	Creation of a tunnel in the vesicorectal space
Stage 3	Hysterotomia, hematometra evacuation, and hysteroscopy through the created tunnel
Stage 4	Hysterectomy through the created tunnel with laparoscopic control: 1. Opening of plica vesiouterina 2. Opening of the cul-de-sac peritoneum 3. Ligation of the round and broad, utero-ovarian ligaments, and the proximal end of the fallopian tubes, and transection and ligation of the uterine vessels 4. Removal of the uterus
Stage 5	Laparoscopically assisted colpopoiesis: 1. creation of neovaginal orifice 2. creation of neovaginal fornix

the pelvic organs revealed a globe-shaped five- to six-week gestational-size uterus with poorly expressed uterosacral ligaments. One patient had unilateral ovarian and cul-de-sac endometriosis; a second had an endometrioma and ovarian adhesions. The adhesions were divided, endometriosis was coagulated, and the endometrioma cyst was shelled using unipolar scissors and knife and bipolar coagulation. The third patient had two rudimentary uteri (3 × 4.5 cm) located near the pelvic sidewall. The ovaries and tubes appeared normal. There was a transverse serous/muscular embankment 0.7- to 1.0-cm thick and 5- to 6-cm long in the center of small pelvis between the two uteri. This patient also had a dystopic kidney in the left small pelvis at the level of linea terminalis.

Stage 2: Access was then gained to the rudimentary functional noncommunicating uterus and pelvic peritoneum. As previously described, a transverse perineal skin incision was made between the external orifice of the urethra and the anus at the level of lower edge of labia minora. Then, a tunnel directed toward the uterus was created in the vesicorectal space, using blunt and sharp dissection with scissors, a tight tampon, and fingers. The reference point was the aplasic cervix.

Stage 3: The cervix was grasped with a tenaculum, the cervical canal of the uterine rudiment, if present, was probed, and hysterotomy and hysteroscopy were performed through the aperture. In two cases, hematometra was discovered. The length of the uterine cavity was 3 to 4.5 cm. In the woman with two uteri, the tunnel to the pelvic peritoneum was created between the uteri, and the pelvic peritoneum was opened laparoscopically at the level of the transverse fold.

Stage 4: A hysterectomy was done through the newly created tunnel under laparoscopic control. The peritoneum was grasped with endoscopic atraumatic forceps close to the uterus, drawn toward the surgeon, and dissected. It is very important to choose the correct place for dissection of the peritoneum, so that there is no deficiency of peritoneum for the neovagina. After the peritoneum had been opened, hysterectomy was performed. The round and the utero-ovarian ligaments and the proximal ends of the fallopian tubes were coagulated and transected laparoscopically. The uterine vessels were transected and ligated through the newly created tunnel. The uterus was then removed from the abdominal cavity. Precise hemostasis and peritonization were obtained both laparoscopically and by tunnel access.

Stage 5: Laparoscopically assisted colpopoiesis was then performed much as described earlier. The edges of the peritoneal aperture were mobilized, drawn down to the neovaginal orifice, and sutured circumferentially to the perineal skin with separate catgut stitches. Then the neovaginal fornix was formed laparoscopically by placing separate absorbable sutures on a curved needle or hemi-purse-string sutures through the peritoneum of the pelvic sidewalls, urinary bladder, and sigmoid colon.

The most important aspect of this step is handling the peritoneal tissue, which can be easily traumatized during hysterectomy, division of adhesions, elimination of endometriosis, and suturing, as delicately as possible. Indeed these procedures would not be possible without laparoscopic assistance.

Clinical Results

The operation was successful in all three cases. Surgery averaged 125 minutes. No injuries occurred, and blood loss was minimal. Average length of hospital stay was 10 days. Follow-up examinations at 4, 11, and 16 months demonstrated satisfactory health in all three patients. There were no complaints regarding sexual activity. The ovarian endometrioma had resolved.

Discussion

In my experience, laparoscopic technique is highly advisable when creating a neovagina from pelvic peritoneum. The most difficult stages of the procedure, that is, identification of pelvic peritoneum, the choice of a place to transect it, and creation of a neovaginal fornix, are more easily and accurately performed with the help of laparoscopy. Laparoscopy also reduces operating time and risk and expedites patient recuperation. Perhaps the most important advantage is the lower risk of injury to adjacent organs, which will make this procedure available to more surgeons, provided they are experienced in endoscopic technique.

Recently, Popp and coworkers have accomplished the

Vecchietti technique of colpopoiesis laparoscopically.[16] Laparoscopy eliminates the primary disadvantage of this technique: a pfannensteil incision. Initial results are promising.

For those women with total vaginal and cervical aplasia and a functional noncommunicating rudimentary uterus, laparoscopic technique is invaluable not only for colpopoiesis, but also for assisting hysterectomy. This procedure, however, must be done by surgeons experienced in pelvic surgery.

To date, no surgical method of treating these malformations restores reproductive potential because it is not possible to create an adequate cervical canal. Attempts to solve this problem by forming a "fistula" connecting the uterus and artificial vagina were not successful because of "fistula" scarring, and inflammatory complications (hematopyometra, pyosalpinx). A long-sought advancement of reconstructive gynecologic surgical technology is the development of a material or tissue (artificial skin) that could serve as a mucous lining for the cervical canal. Our attempts to use polymers (Cambutec, Collacyl) for this purpose were ineffectual.

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30.13 Laparoscopic Management of Gynecologic Malignancies

Nicholas Kadar

Introduction

In 1988, Dr. Harry Reich performed the first laparoscopically assisted hysterectomy in the world.[1] What was then a highly controversial undertaking foreshadowed the most remarkable development in surgery in recent times, the acme of which must surely be our ability to perform radical pelvic surgery laparoscopically. It is an astonishing fact that those of us who have been intimately involved in the development of laparoscopic techniques clearly foresee the day when almost all women with endometrial and cervical carcinoma who are surgical candidates will be treated laparoscopically. To the extent that any one individual can claim to have fathered these developments, that individual must surely be Dr. Harry Reich.

In 1988, Reich not only performed the first laparoscopic hysterectomy but also successfully performed the first transperitoneal pelvic lymph node sampling in a patient with ovarian carcinoma.[2] The following year he and Schussler first performed pelvic (obturator) lymphadenectomy to stage prostate cancer.[3] Finally, in 1991 Reich assisted this author in performing the first laparoscopically assisted radical vaginal (Schauta) hysterectomy and pelvic lymphadenectomy for cervix cancer in the United States—the first time bulky lesions had been treated by any kind of laparoscopically assisted radical operation.[4]

Although it required Reich's far-sightedness to launch these initiatives, laparoscopic surgery is not difficult in the sense that playing Chopin's heroic polonaise is. Anyone who can learn gynecologic surgery can learn to do it laparoscopically, and laparoscopic technique does not take years to master. Nor does it depend on high technology so much as on the use of sound surgical techniques of sharp scissors dissection and the blunt development of tissue planes. The challenges of laparoscopic surgery are more intellectual than mechanical; they require a better understanding of the precise anatomic relations between pelvic structures and the deployment of different strategies than are used at laparotomy, rather than the acquisition of a technical ability not already possessed by the surgeon.

In this chapter, the author's laparoscopic techniques of retroperitoneal dissection, pelvic and aortic lymphadenectomy, and simple and radical hysterectomy will be described. These techniques are now used routinely in his practice.[4–10] A detailed discussion of the malignancies treated and the role of surgery in their management is outside the scope of this chapter. Suffice it to say that the indications for laparoscopic surgery are the same as those for laparotomy, and no patient has ever been treated differently as a consequence of having opted for a laparoscopic approach.

Role of Laparoscopic Surgery in Gynecologic Malignancies

Endometrial Carcinoma

The laparoscopic treatment of women with endometrial carcinoma is outlined in Figures 30.13.1 and 30.13.2. The most noteworthy aspect of our management is that we restrict aortic lymphadenectomy to patients who have positive pelvic nodes. Although this strategy will result in two operative procedures for a few patients, this is less of a drawback if the procedures are laparoscopic. Fewer aortic lymphadenectomies will be required than if deep myometrial invasion were used as the criterion for aortic lymphadenectomy, yet more patients with positive aortic nodes will be identified. The two-stage approach will result in two operations in approximately 7% of patients, but it will identify 23% more patients with aortic lymph node metastases, and at least 35% fewer aortic lymphadenectomies will be required.[11] It will also simplify therapy by avoiding the need for intraoperative frozen sections or expensive preoperative imaging studies to determine the depth of myometrial invasion.

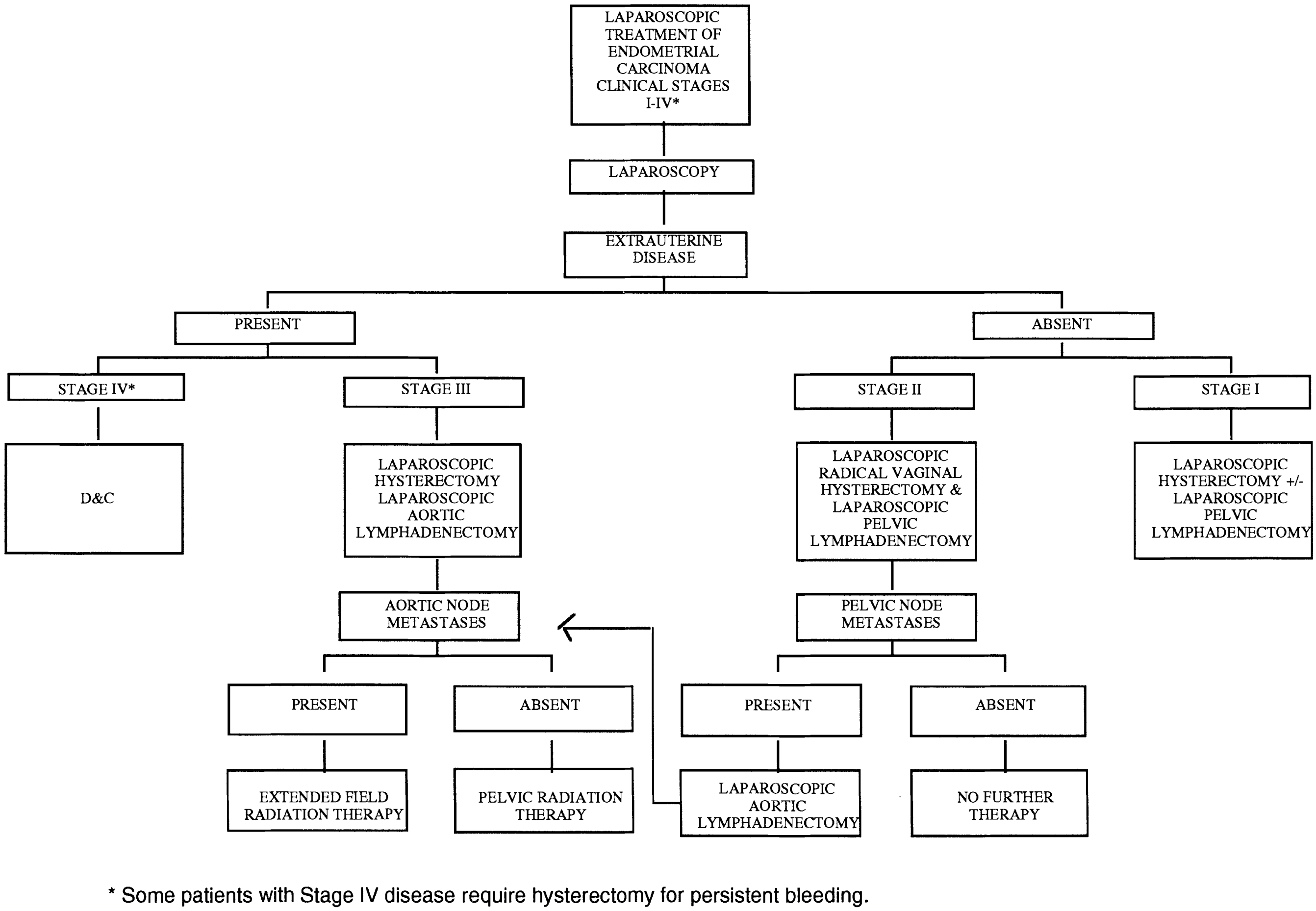

FIGURE 30.13.1. Laparoscopic management of carcinoma of the endometrium.

Cervix Cancer

The treatment of patients with cervix cancer is outlined in Figure 30.13.3. Laparoscopic surgery for the management of this malignancy is in its infancy, but it promises to be revolutionary. Laparoscopic aortic lymphadenectomy for patients with positive pelvic nodes or advanced disease is arguably the most cost-effective laparoscopic procedure in gynecology. Patients go home in 1 to 2 days, start radiation in 10 to 12 days, and have virtually no pain or morbidity. What was once a questionable staging operation has been transformed into one with about the same morbidity as laparoscopic removal of a tubal pregnancy.

The reduction in morbidity from laparoscopic radical vaginal hysterectomy is perhaps even more remarkable. One patient telephoned the author a week after surgery to enquire if she could go swimming! This is of course a complicated operation to learn, and it will have to pass the test of time. However, this author predicts that it will become the standard therapy for operable stage IA2 to IIA cancer of the cervix within at most 10 years. Moreover, although complication rates of any new technique are inevitably higher at first, it is inconceivable that morbidity will not be dramatically reduced by adoption of this approach.

Cancer of the Ovary

The only really controversial area in the laparoscopic management of gynecologic malignancies is its role in the management of ovarian carcinoma, which is still evolving. Its most obvious role is in the management of stage-I disease because huge, fixed pelvic masses that require extensive retroperitoneal dissection and often proctocolectomy and retrograde hysterectomy cannot be removed laparoscopically. However, it is possible to conceive of a significant role for laparoscopic therapy even in the management of more advanced disease. For example, approximately 10% of women with advanced ovarian cancer have normal-sized ovaries and no bulk disease, and obviously do not require debulking surgery. Laparoscopic surgery may be both feasible and preferable in these patients. Patients with stage-III borderline tumors are also potential candidates for a laparoscopic approach,

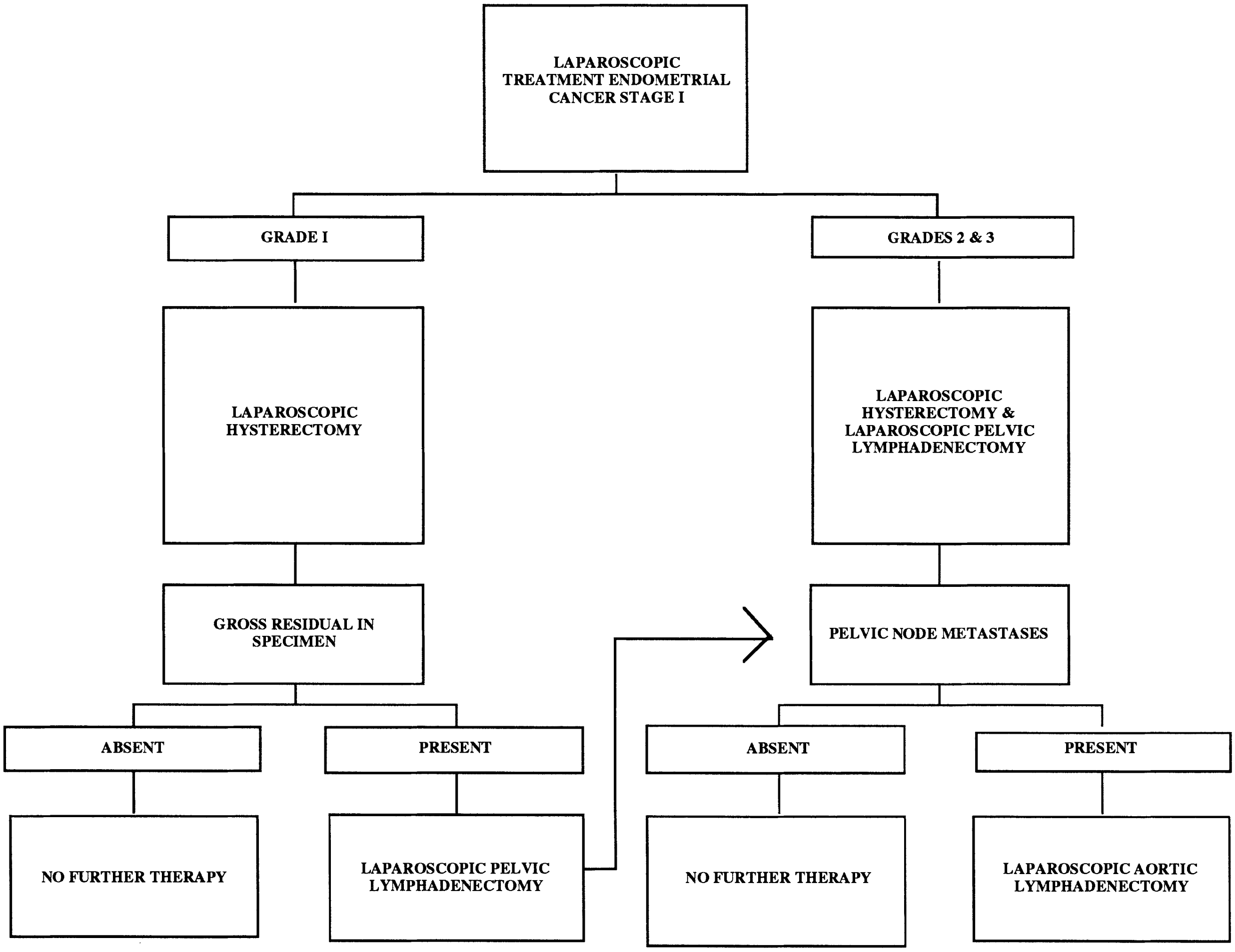

FIGURE 30.13.2. Laparoscopic management of carcinoma of the endometrium grossly confined to the uterus.

because the treatment of these indolent malignancies relies much more on repeated surgical resection than on adjunctive chemotherapy or radiation therapy, whose efficacy in borderline tumors has yet to be established. Clearly, the advantages of a laparoscopic approach compound if therapy involves multiple surgeries.[12] The value of neoadjuvant chemotherapy in the management of large irresectable stage-III lesions is currently being investigated. Final answers are not available as yet, but we may find that neoadjuvant therapy, by shrinking the malignancy, allows us to circumvent debulking surgery altogether. Moreover, even if the disease cannot be treated laparoscopically after neoadjuvant chemotherapy has done its work, the laparoscope will still have spared the patient one laparotomy, which, given what these patients usually have to undergo, is not something to be dismissed lightly.

Definition of the role of laparoscopic surgery in the management of ovarian malignancies has been hampered by the quality of literature on this subject. For example, a study that has been widely quoted to condemn the use of laparoscopy for treatment of this malignancy is nothing more than a survey of selected physicians that had a poor response rate and established no denominators for the outcome of interest.[13] Other than to document that patients with ovarian cancer are sometimes mismanaged, a fact we might have surmised without the survey, this study provided no information that helped in any way to define the indications for laparoscopy in this disease or to design protocols that might determine its role. All it did was to invite the conclusion that because someone had misused the laparoscope in some cases of ovarian cancer, any use of the laparoscope in this disease must *ipso facto* be misuse, a line of reasoning not at all conducive to clear thought in an area already rife with high emotion and patent bias.[14] Indeed, a similar survey of traditional surgical management is likely to have shown that early invasive disease is sometimes mismanaged by generalists in exactly the same way.

The implantation of tumor in trocar tracts used during laparoscopy is an undeniable possibility that must be considered when devising protocols for the use of laparoscopy in the management of ovarian carcinoma.[15] However, without knowing the frequency of this event it is not

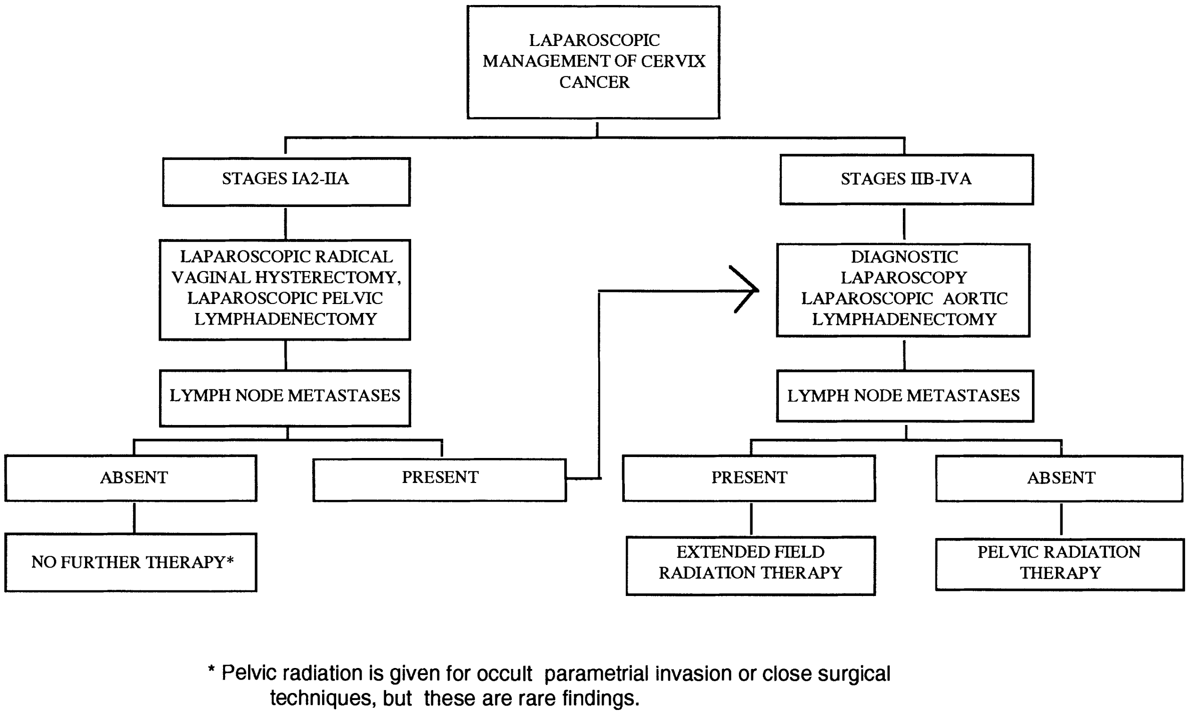

FIGURE 30.13.3. Laparoscopic management of cervix cancer.

possible to determine whether this disadvantage offsets the advantages of laparoscopy or is itself offset by them. Tumor implants are rarely, if ever, seen in a laparotomy scar following surgery for advanced ovarian cancer and ascites. It should therefore be possible to prevent implants in trocar tracts by closing the peritoneum beneath them and irrigating or fulgurating the tract.

The greatest potential for laparoscopic surgery in the management of ovarian cancer is in the management of stage-I disease. Most oncologists were reluctant to treat these patients laparoscopically until they had perfected their techniques for pelvic and aortic lymphadenectomy, but as techniques for these procedures have matured, the fear of rupturing a malignant cyst has been increasingly mentioned. Although the adverse effects of rupturing a cyst have been overstated,[16] the rarity of stage-I disease, and the impossibility of conducting a prospective trial that would answer this question mean that any claim that cyst rupture "makes no difference" must be made with some circumspection. Even if survival were to be marginally compromised by cyst rupture, this would not automatically rule out laparoscopic management of pelvic masses, because most masses are benign. The increased morbidity and mortality from laparotomy in the majority of women who do not have a malignancy might more than offset a slight decrease in the survival of women who turn out to have ovarian carcinoma.[17] Laparoscopic staging is, moreover, the treatment of choice in patients who are discovered to have ovarian carcinoma after ovarian cystectomy or simple oophorectomy because, clearly, the issue of cyst rupture does not arise in these cases.

Laparoscopic Techniques

Robbed of the ability to palpate tissues, the laparoscopic surgeon must rely entirely on sight to identify normal structures in the abdomen and pelvis. Thus laparoscopy requires detailed knowledge of pelvic anatomy and more extensive dissection of the retroperitoneum to display normal structure than is required by an open technique. The technique of pelvic dissection used during laparotomy does not lend itself to a laparoscopic approach, however. If the same sequence of steps is followed, the operator will find that tissues become progressively more slack and difficult to place on tension. This in turn makes blunt dissection of the retroperitoneal spaces increasingly difficult and eventually impossible. The strategy for laparoscopic retroperitoneal dissection developed by the author allows all vital retroperitoneal structures to be freed and identified, but its success depends on executing the steps of the dissection in a precise sequence.[5]

Preliminaries

While they are awake, patients are positioned in Allen stirrups, with the knees flexed and the thighs abducted, but not flexed at the hips. This position is used for all laparoscopic operations except laparoscopic aortic lymphadenectomy, for which patients are placed flat on the operating table. Ureteric stents are also routinely passed because this makes the ureters much more prominent and aids in their identification and retraction. (The purpose of the stent is *not* to help "palpate" the ureter endoscopically with instruments.)

The author's current preference is to use Dexide trocars, which have a built-in basket-like retention device that can be expanded once the trocars are in the abdomen, a rubber washer on the outside that prevents leakage of gas, and a non–flapper-valve mechanism on which instruments, particularly those with curved ends, do not snag. Three working ports are placed in addition to the subumbilical port that is used for the laparoscope. A 5- or a 10-mm port is placed suprapubically, and a 5-mm port is placed on either side of the rectus muscles, just above a line joining the anterior superior iliac spines. A 10-mm trocar is inserted suprapubically for radical cases, but a 5-mm port is used for all other cases (Figure 30.13.4).

All trocars are inserted directly, and a Veress needle is not used. After the infraumbilical trocar is inserted, its intraperitoneal location is checked with the laparoscope, and the abdomen is insufflated using a high flow rate (6 to 9 L/min, depending on the machine available). If there has been significant prior intraperitoneal surgery, open laparoscopy is performed.

Anatomy

Ureter

Approximately halfway between the pelvic inlet and the renal pelvis the ovarian vessels cross the abdominal ureters to lie lateral to them at the pelvic brim (Figure 30.13.5). Here, the ovarian vessels enter the infundibulopelvic ligament and cross the ureters again to lie first above and then medial to them, as the vessels run medially in the roof of the broad ligament to the ovaries. The surgical significance of this relation is that: (1) the ureter cannot be damaged if the pelvic sidewall peritoneum is incised lateral to the anatomic position of the infundibulopelvic ligament; and (2) the infundibulopelvic ligament must be retracted medially to expose the ureter at the pelvic brim and on the medial leaf of the broad ligament.

Throughout their pelvic course the ureters lie in a connective tissue sheath attached to the medial leaf of the broad ligament. Upon crossing the pelvic brim, the ureters descend quite abruptly and follow the contours of the pelvis. This means that, at first, they actually bend laterally to run along the pelvic sidewalls just above the internal iliac arteries (Figure 30.13.6). This is not appreciated surgically, however, because once the broad ligament is opened, the ureters are displaced medially from their natural position on the pelvic sidewall and are seen as following a more-or-less straight course from the renal pelvis to the bladder, turning medially to join the bladder only after they have entered the ureteric tunnel in the vesicocervical ligaments.

In the undisturbed state, at about the level of the ischial spines, the ureters run forward and medially in the base of the broad ligament, passing under the uterine arteries approximately 1.5 cm lateral to the internal cervical os. (The left ureter is usually closer to the cervix than the right one.) The ureters then abruptly turn medially, passing over the anterior vaginal fornices as they enter the bladder. The terminal 1 to 2 cm of the ureter is called the genu or knee of the ureter. It lies in the vesicocervical ligament (also called the vesicouterine ligament, or blad-

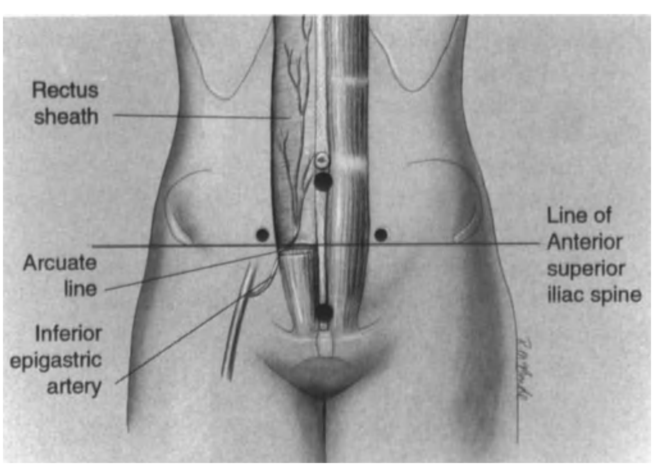

FIGURE 30.13.4. Trocar placements for laparoscopic radical pelvic surgery. (From Kadar, *Atlas of Pelvic Surgery*, 1994. Reprinted by permission of Blackwell Scientific Publications, Inc.)

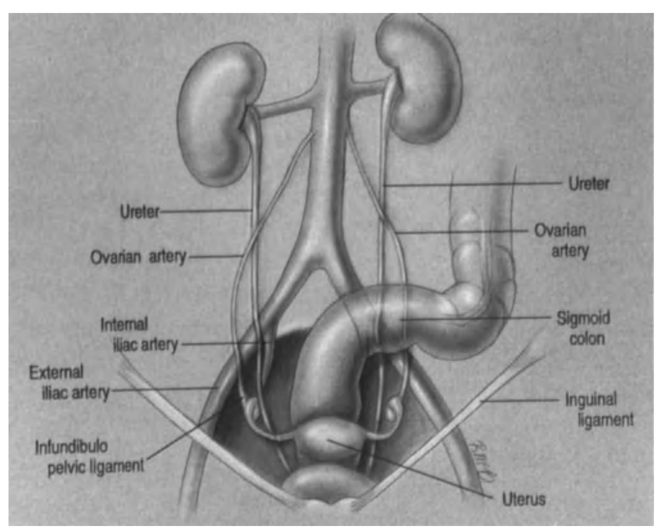

FIGURE 30.13.5. Relation between the ureter and the ovarian vessels in the abdomen and pelvis. (From Kadar, *Atlas of Pelvic Surgery*, 1994. Reprinted by permission of Blackwell Scientific Publications, Inc.)

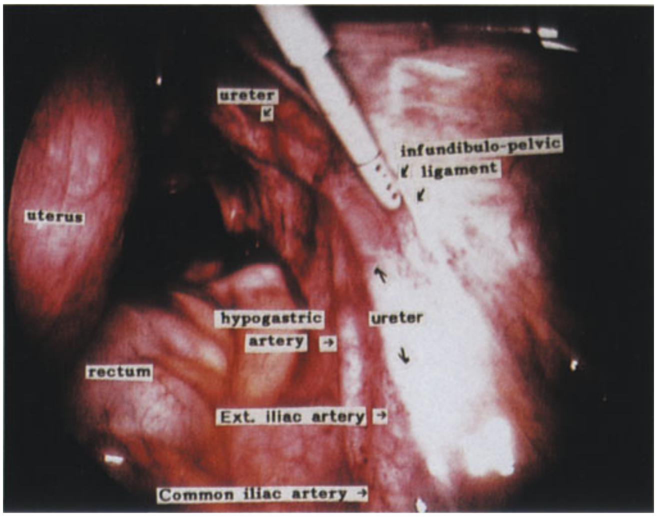

FIGURE 30.13.6. The anatomic position of the ureter as seen laparoscopically.

der pillar) the surgical anatomy of which can only be fully appreciated during radical vaginal hysterectomy or the Schauta-Amreich operation (see below).

Pelvic Spaces

It is impossible to exaggerate the importance of being able to develop the paravesical and pararectal spaces confidently, because this is a prerequisite for identifying the vital structures in the retroperitoneum and dissecting them free.

The paravesical and pararectal spaces are potential spaces that extend from the base of the broad ligament to the floor of the pelvis. At laparotomy, the broad ligament peritoneum can be opened in several ways, but most commonly, the round ligament is first divided and the peritoneum is incised in a cephalad direction parallel and lateral to the infundibulopelvic ligament up to the pelvic brim. The broad ligament is then opened bluntly by traction on its medial leaf. This maneuver will separate the loose areolar tissue between the leaves of the broad ligament, but an impasse will eventually be reached at about the level of the ureter and the internal iliac artery, where the areolar tissue is more condensed and will not separate any further. This point at the base of the broad ligament marks the roof of the pararectal space. The pararectal and paravesical spaces are opened at laparotomy in the following way.

The bifurcation of the iliac artery is first identified by palpation, and the index finger is placed just medial to the internal iliac artery. (Identification of the bifurcation ensures that the dissection is medial to the internal iliac artery, not the external iliac artery. Inadvertent dissection medial to the external iliac artery risks injuring the external iliac vein, which lies between the internal and external iliac arteries.) The tissues medial to the dissecting finger are put on tension by traction in the direction of the patient's contralateral femoral head. A bloodless space will start to develop, and as it does, the plane of dissection should follow the curve of the pelvis, which, with the patient in a Trendelenburg position, is at first downwards and forwards but then curves upward. The surgeon will find the ureter (still attached to the medial leaf of the broad ligament) lying against the dissecting finger. The ureter marks the medial border of the pararectal space, and its lateral border is formed by the internal iliac artery.

Quite frequently, especially in thin, young patients, the dense connective tissue forming the roof of the pararectal space cannot be dissected bluntly, and a small opening must first be made in it with the point of a tonsil clamp or dissecting scissors as the tissue is held taut by medial traction with the dissecting finger. Once a small opening is made, the index finger is insinuated into the pararectal space, which will open up readily if its medial wall is retracted toward the contralateral femoral head as previously described.

After the pararectal space has been opened, the paravesical space is easily developed by running the index finger along the medial border of the external iliac artery in a caudad direction until the pubic ramus is reached. At the pubic ramus the direction of the dissection is rotated through 90° and is again directed medially towards the patient's contralateral femoral head. The large bloodless plane that opens up is the paravesical space. The cord-like structure found on the dissecting finger is the lateral umbilical ligament, or obliterated hypogastric artery.

The pararectal spaces cannot easily be developed laparoscopically in the same way as at laparotomy. First, the internal iliac artery is buried in areolar tissue and cannot be immediately visualized after the broad ligament is opened out. Obviously, it cannot be palpated. Second, the precise level (in a cephalad-caudad direction) at which to begin dissecting the pararectal space is also not obvious, and troublesome bleeding can occur if the dissection is begun over the cardinal ligament rather than proximal to it. Finally, with each successive step of the dissection—that is, division of the round ligament, opening of the broad ligament, and separation of the areolar tissue—the tissues become progressively more slack and more difficult to work with.

A technique developed specifically to overcome these difficulties makes use of two strategies. First, the round ligament is divided late in the course of the dissection rather than at the beginning of it, which allows it to provide some countertraction on the broad ligament when the uterus is displaced to the contralateral side. Second, the obliterated hypogastric arteries (the lateral umbilical ligaments) are used to identify the origin of the uterine arteries, which are then used as landmarks for locating the pararectal space and ureter.

Obliterated Hypogastric Arteries

Although the anatomy of the internal iliac artery is complicated for it has many visceral and parietal branches, its surgical anatomy is really quite straightforward. After giving off the uterine arteries, the anterior division of the internal iliac arteries sweeps sharply upwards on either side of the bladder as the obliterated hypogastric arteries to cross the superior pubic rami and run beneath the peritoneum of the anterior abdominal wall to the umbilicus.

The obliterated hypogastric arteries (the lateral umbilical ligaments) are easily identified laparoscopically as prominent peritoneal folds that hang laterally from the anterior abdominal wall on either side of the bladder. Since they are relatively fixed structures, they are also easily dissected free of the bladder and the surrounding areolar tissues. Once freed, the hypogastric arteries can easily be traced retrogradely to identify the uterine arteries, which run on top of the cardinal ligaments and provide an important landmark for the pararectal spaces, which lie proximal and medial to the vessels.

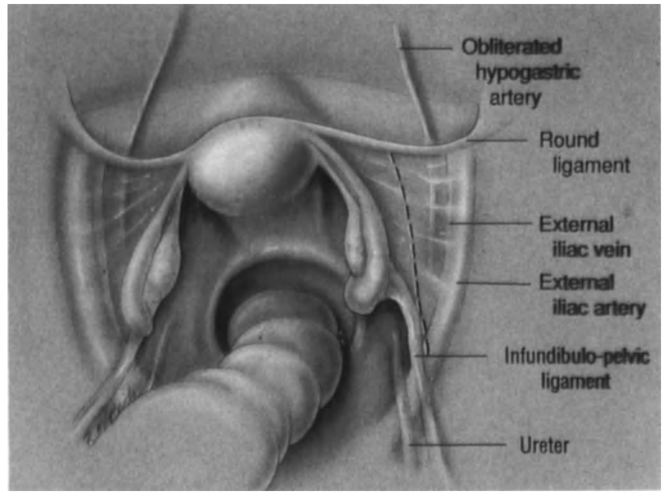

FIGURE 30.13.7. The incision in the pelvic sidewall peritoneum is made along the dashed line. (From Kadar, *Atlas of Pelvic Surgery*, 1994. Reprinted by permission of Blackwell Scientific Publications, Inc.)

Laparoscopic Dissection of the Pelvic Retroperitoneum[5]

Step 1. The Pelvic Sidewall Triangles Are Opened

The pelvic sidewall triangle is delineated by displacing the uterus to the contralateral side. The base of this triangle is formed by the round ligament, the lateral border by the external iliac artery, the medial border by the infundibulopelvic ligament, and the apex by the intersection of the infundibulopelvic ligament and the common iliac artery (Figure 30.13.7). The peritoneum in the middle of the triangle is desiccated with bipolar current and incised with dissecting scissors, and the broad ligament is opened by bluntly separating the extraperitoneal areolar tissue. Even tiny vessels should be coagulated, because the slightest amount of bleeding can stain the extraperitoneal areolar tissue and obscure the underlying structures.

The peritoneal incision is extended first to the round ligament, which is *not* divided at this time, and then to the apex of the triangle, lateral to the infundibulopelvic ligament (Figure 30.13.8). It is important not to displace the infundibulopelvic ligament from its anatomic position before the peritoneal incision is completed; otherwise the natural anatomic relation between the infundibulopelvic ligament and the ureter, which serves to protect the ureter from injury, is lost.

On the left side, so-called congenital adhesions attach the rectosigmoid to the peritoneum laterally, at or just above the pelvic brim. These usually cover the apex of the pelvic triangle. The dissection on the left side is begun by separating these adhesions from the underlying peritoneum, and the pelvic sidewall triangle is then opened at or near its apex (Figure 30.13.9). (The external iliac artery will be below the plane of dissection.) The peritoneal incision is carried distally to the round ligament, which again is not divided at this time.

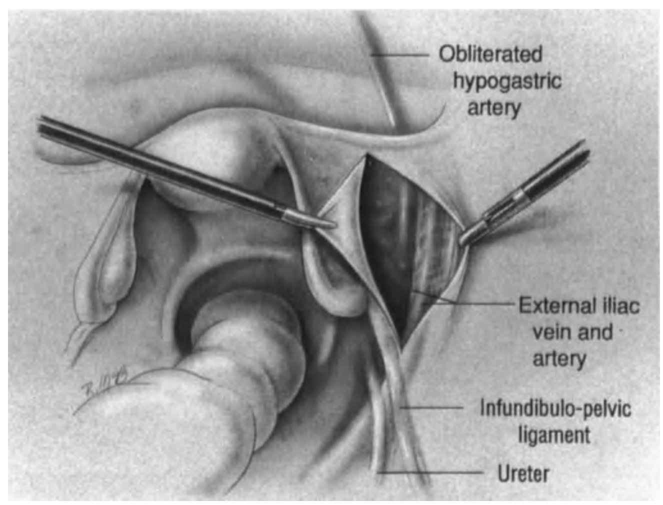

FIGURE 30.13.8. The broad ligament is opened. (From Kadar, *Atlas of Pelvic Surgery*, 1994. Reprinted by permission of Blackwell Scientific Publications, Inc.)

Step 2. The Ureter Is Identified at the Apex of the Pelvic Triangle

The infundibulopelvic ligament is pulled medially with grasping forceps to expose the ureter at the pelvic brim, where it crosses the common or external iliac arteries (Figure 30.13.10). This is a crucial step, and a good, non-

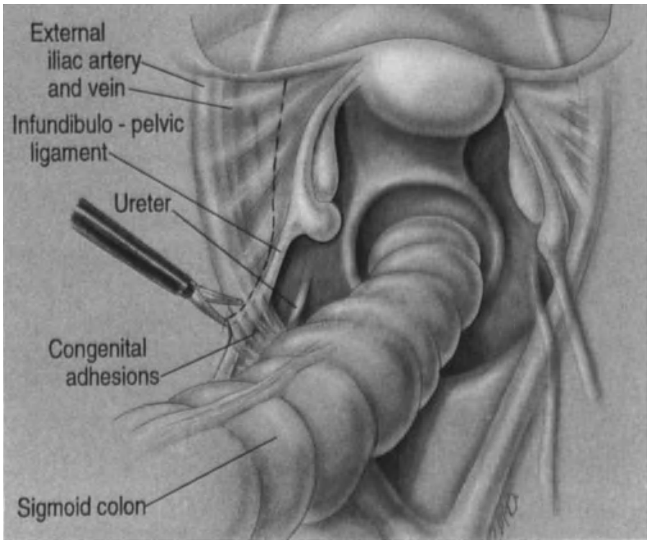

FIGURE 30.13.9. The attachments of the sigmoid colon are divided, and the incision on the left is started at the apex of the pelvic sidewall triangle. (From Kadar, *Atlas of Pelvic Surgery*, 1994. Reprinted by permission of Blackwell Scientific Publications, Inc.)

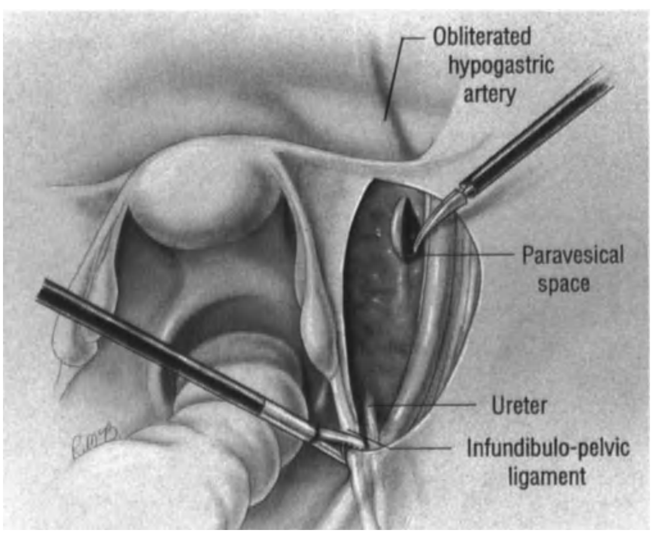

FIGURE 30.13.10. The infundibulopelvic ligament has been pulled medially to expose the ureter at the pelvic brim. The extraperitoneal portion of the obliterated hypogastric artery is identified. (From Kadar, *Atlas of Pelvic Surgery*, 1994. Reprinted by permission of Blackwell Scientific Publications, Inc.)

traumatic instrument is invaluable here. It may be necessary to reflect the ureter off the medial leaf of the broad ligament for a short distance to aid in its identification.

It is important to mobilize the infundibulopelvic ligament adequately; otherwise it will not be possible to retract its proximal end sufficiently medially to expose the ureter at the pelvic brim. Failure to achieve adequate mobilization of the infundibulopelvic ligament is the most common error in carrying out the dissection. The operator then searches for the ureter distal to the pelvic brim and lateral to the infundibulopelvic ligament but frequently fails to find it because the ureter is covered at that point by fatty areolar tissue or, more distally, by the infundibulopelvic ligament itself and cannot be seen except in the thinnest of patients. The error stems from the fact that the peritoneal incision must extend proximally much farther in the laparoscopic case than in the open case. The incision frequently has to be extended to where the peritoneum covering the infundibulopelvic ligament blends with the mesentery of the cecum (on the right) or of the descending colon (on the left).

The dissection of the apex is more difficult on the left side, partly because the ureter is covered by the mesentery of the sigmoid colon but mainly because it crosses the iliac vessels higher (more proximally) and lies more medial than the right ureter. As a result, it is more difficult to expose the left ureter by retracting the infundibulopelvic ligament medially. The peritoneal incision frequently has to be extended to the white line in the paracolic gutter to mobilize the sigmoid colon and the infundibulopelvic ligament, which at this point lies extraperitoneally, under the mesentery (Figure 30.13.11). It is also frequently necessary to free the medial leaf of the broad ligament from the pelvic brim and sacrum. To do this, the operator has to dissect bluntly in a medial direction under the infundibulopelvic ligament, taking care not to perforate the medial leaf of the broad ligament so that the right plane of dissection will not be lost. Finally, the operator needs to be aware that the external iliac artery will be below the plane of dissection much of the time.

Step 3. The Obliterated Hypogastric Arteries Are Identified Extraperitoneally

The dissection is carried bluntly underneath and caudad to the round ligament, until the obliterated hypogastric artery is identified extraperitoneally (Figure 30.13.10). Although the anatomy will be unfamiliar to most general gynecologists, this step is in fact the most straightforward part of the dissection. If any difficulty is encountered, the artery should first be identified intraperitoneally, where it hangs from the anterior abdominal wall, and traced proximally to where it passes behind the round ligament. Then, with both its intraperitoneal portion and the dissected space under the round ligament in view, the intraperitoneal part of the ligament should be moved back and forth. It will almost always be possible to detect corresponding movements in the extraperitoneal portion of the ligament.

Step 4. The Paravesical Spaces Are Developed

Once the obliterated hypogastric arteries have been identified extraperitoneally it is a simple matter to develop the paravesical space by bluntly separating the areolar tissue on either side of the artery. The dissection is started lateral to the artery, bearing in mind that the external iliac vein is just lateral to it. The tips of the closed dissecting scissors are placed against the lateral edge of the artery, and the artery is simply pulled medially, whereupon a bloodless plane opens lateral to it (Figure 30.13.12). The medial border of the artery is then freed by working in the opposite direction. During this maneuver the operator must take care not to press on the external iliac vein as the artery is displaced laterally (Figure 30.13.13). The paravesical space should be developed adequately to obtain good distal exposure of the uterine arteries and cardinal ligaments. This provides complete control of the operative field, especially if the arteries bleed when they are divided, which can occur, despite what appears to be adequate bipolar desiccation.

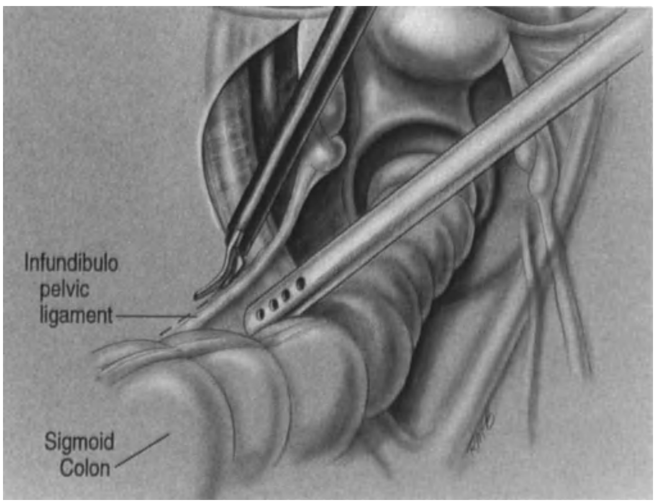

FIGURE 30.13.11. Mobilization of the left infundibulopelvic ligament. (From Kadar, *Atlas of Pelvic Surgery*, 1994. Reprinted by permission of Blackwell Scientific Publications, Inc.)

Step 5. The Pararectal Spaces Are Developed

The obliterated hypogastric arteries are next traced proximally to where they join the uterine arteries, and the pararectal spaces are opened by blunt dissection proximal and medial to the uterine vessels, which lie on top of the cardinal ligaments. Once a pararectal space has been opened, the ureter on the ipsilateral side is easily identified on the medial leaf of the broad ligament, which forms the medial border of the pararectal space. The uterine artery and cardinal ligament at the distal (caudal) border of the space and the internal iliac artery on its lateral border also become clearly visible at this stage (Figure 30.13.14). Starting proximal to the cardinal ligament, the ureter is then dissected off the medial leaf of the broad ligament for a short distance, in preparation for division of the uterosacral ligament.

Simple Hysterectomy[6]

The retroperitoneal dissection prepares the stage for a simple hysterectomy, and very little remains to be done. The hysterectomy is completed in three steps.[6–8]

Step 6. The Uterine Arteries, Round Ligaments, and Infundibulopelvic Ligaments Are Divided

The uterine arteries are freed from any areolar tissue still covering them and desiccated with bipolar forceps. The round ligaments and infundibulopelvic ligaments are also desiccated before the arteries are divided to avoid re-

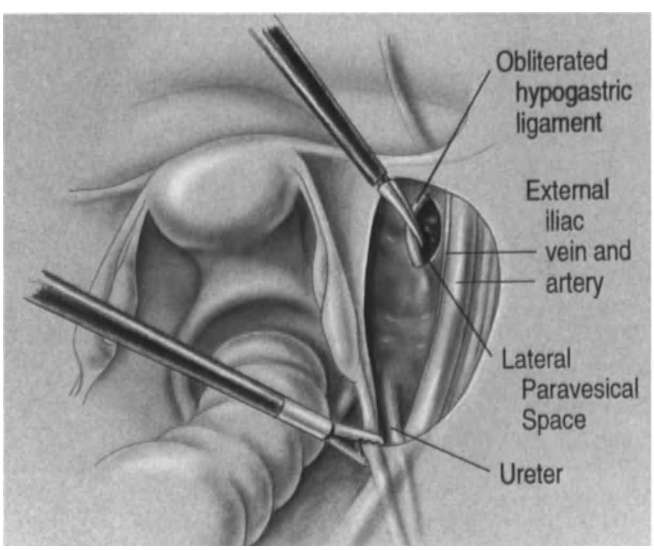

FIGURE 30.13.12. The lateral paravesical space is opened. (From Kadar, *Atlas of Pelvic Surgery*, 1994. Reprinted by permission of Blackwell Scientific Publications, Inc.)

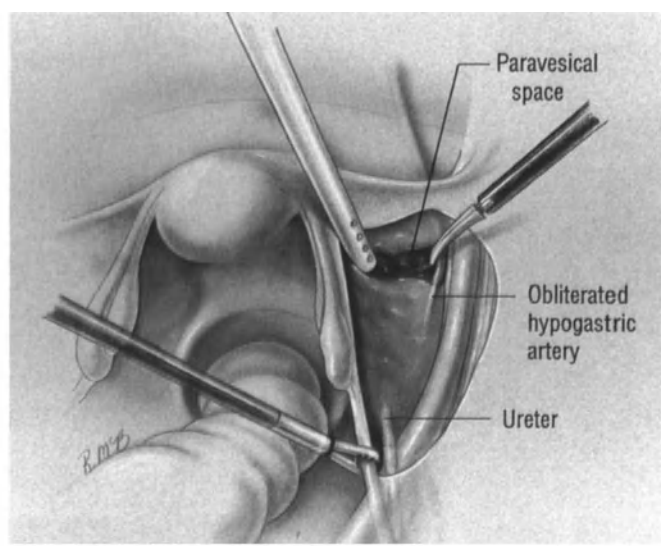

FIGURE 30.13.13. The medial paravesical space is opened. (From Kadar, *Atlas of Pelvic Surgery*, 1994. Reprinted by permission of Blackwell Scientific Publications, Inc.)

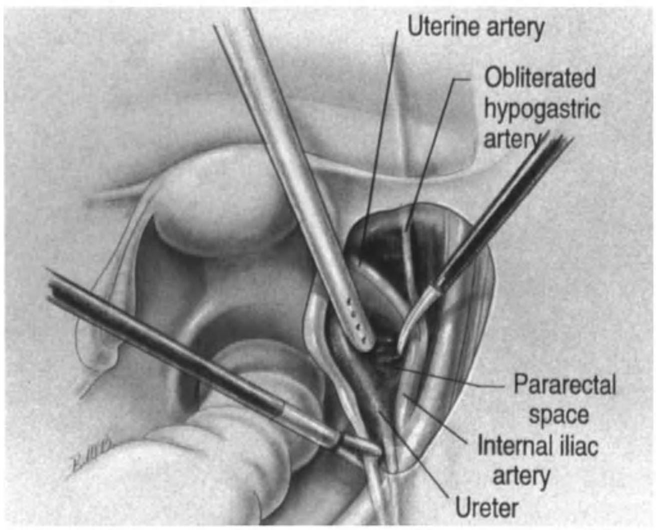

FIGURE 30.13.14. The pararectal space is developed. (From Kadar, *Atlas of Pelvic Surgery*, 1994. Reprinted by permission of Blackwell Scientific Publications, Inc.)

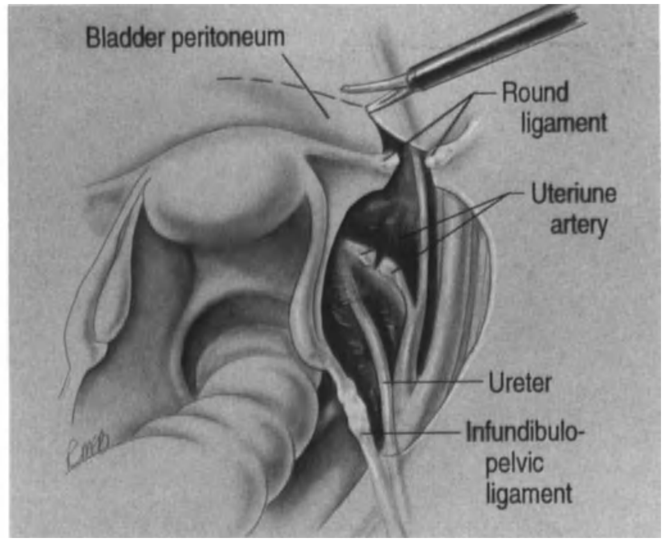

FIGURE 30.13.15. The uterine artery and round ligament have been divided, and the incision is being extended along the anterior broad ligament and bladder peritoneum. (From Kadar, *Atlas of Pelvic Surgery*, 1994. Reprinted by permission of Blackwell Scientific Publications, Inc.)

peatedly taking the bipolar forceps in and out of the peritoneal cavity. The smoke generated by desiccation must be continuously suctioned out of the cavity. All the structures are then divided, starting with the uterine artery (Figure 30.13.15). After the round ligament is divided, the incision is continued along the anterior leaf of the broad ligament and the bladder peritoneum to the contralateral side, but the bladder is not dissected off the vagina.[18] After the infundibulopelvic ligament is divided, the incision is continued along the medial leaf of the broad ligament to the point where the ureters are reflected laterally.

Step 7. The Uterosacral Ligaments Are Divided, and the Posterior Vaginal Wall Opened

A plane is developed between the peritoneum and the uterosacral ligaments. The peritoneum is incised, and the incision is extended to the pouch of Douglas, which is opened. The incision is continued across the midline to meet a similar incision in the peritoneum of the opposite broad ligament. The ureters are retracted laterally, and the uterosacral ligaments are divided with the closed tips of the dissecting scissors, using a monopolar current (Figure 30.13.16).

If a Pelosi mobilizer (Nova Endoscopic, Palm, PA) is available, the posterior vaginal wall is opened at this time; otherwise the operation is continued vaginally. To open the posterior vaginal wall laparoscopically, the uterus is sharply anteflexed with the mobilizer to an almost vertical position, whereupon a bulge resembling the cervix will appear at its lower end. This is, in fact, the hub of the instrument pressing against the posterior vaginal wall. The posterior vaginal wall is then incised over this bulge with closed dissecting scissors, using monopolar current (Figure 30.13.17). The incision should not be too close to the cervical attachment of the vagina, or the vaginal part of the procedure will be more difficult.

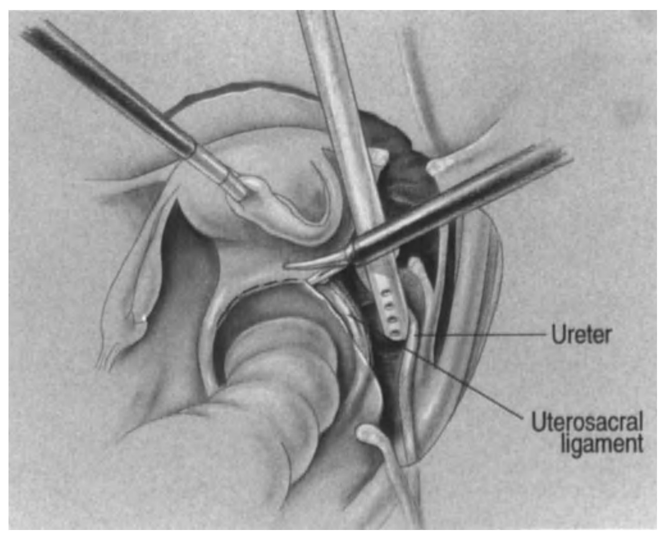

FIGURE 30.13.16. The infundibulopelvic ligament has been divided, and the incision has been extended along the broad ligament to the uterosacral ligament. The peritoneum has been separated from the uterosacral ligament, and the peritoneal incision is being continued along the cul-de-sac. (From Kadar, *Atlas of Pelvic Surgery*, 1994. Reprinted by permission of Blackwell Scientific Publications, Inc.)

Step 8. The Hysterectomy Is Completed Vaginally

The cervix is grasped with two single-toothed tenacula and elevated to expose the incision in the posterior vag-

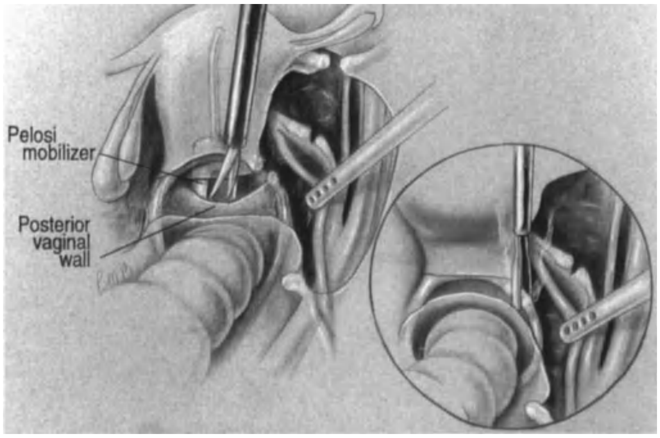

FIGURE 30.13.17. The ureter is retracted laterally while the uterosacral ligament is desiccated and divided. The posterior vaginal wall is opened against the hub of the Pelosi mobilizer. (From Kadar, *Atlas of Pelvic Surgery*, 1994. Reprinted by permission of Blackwell Scientific Publications, Inc.)

inal wall, and an 8-in. Auvard speculum is placed in the peritoneal cavity. The vaginal incision is then continued across the front of the cervix with a scalpel, the bladder is dissected sharply off the cervix, and the anterior cul-de-sac is entered. A Zeppelin clamp is placed on each cardinal ligament, and the ligaments are divided and sutured and the specimen removed. The vagina is closed horizontally with a running nonlocking stitch. The pneumoperitoneum is re-established, and the pelvis is irrigated copiously and checked for hemostasis.

Comment

Once the retroperitoneal dissection has been completed, one must decide which structures, besides the uterine arteries, round ligaments, and infundibulopelvic ligaments (step 6), to divide laparoscopically. Before settling on the uterosacral ligaments and the posterior vaginal wall (step 7), the author tried completing the entire hysterectomy laparoscopically, as well as opening the anterior vaginal wall after dissecting the bladder off the cervix and vagina. The following conclusions were reached.

First, it is both tedious and unnecessary to divide the cardinal ligaments laparoscopically. After the uterosacral ligaments have been divided, the hysterectomy can always be completed vaginally, even in morbidly obese nulligravidas, and completed more easily and quickly vaginally than laparoscopically. Rarely, if ever, will situations arise in which laparoscopic completion of the hysterectomy would be preferable.

Second, the vaginal part of the operation is not much facilitated by opening the anterior vaginal wall laparoscopically. If the vagina is opened from below, the vaginal incision is made distal to the bladder, and the bladder is dissected cephalad. If the vagina is opened laparoscopically, however, the bladder is first dissected in a caudal direction, and the incision is made proximal to the bladder. When the vaginal cuff is then closed from below, the sutures are placed proximal to the bladder and distal ureter, which can be injured in the process.[18]

Third, although it used to be rather tedious to open the posterior vaginal wall, the Pelosi mobilizer has made this so straightforward that the author now routinely opens the posterior vaginal wall laparoscopically in simple hysterectomies. Laparoscopic incision of the posterior vaginal wall does not have the disadvantages of the anterior incision and makes the vaginal part of the operation much easier, provided the incision is not too close to the cervix.

Laparoscopic Pelvic Lymphadenectomy[7]

Once the pelvic spaces have been developed, laparoscopic pelvic lymphadenectomy also poses no special problems. Exactly the same technique can be used as in the open case, but the surgeon will find that he obtains a far better view of the obturator fossa. The Endoshears substitute for the Metzenbaum scissors and the Endodissect for the dissecting forceps.

The first step is to delineate the surgical limits of the dissection, which are: the *common iliac artery* proximally (cephalad); the *psoas muscle* laterally; the *circumflex iliac vein* and pubic bone distally (caudad); the *obliterated umbilical artery* medially; and the *obturator fossa* inferiorly (ventrally). During the preceding retroperitoneal dissection, the proximal, distal, medial, and inferior limits of the dissection have already been delineated. All that remains to be done is to separate the external iliac vessels from the psoas muscle.

This is easily done by scoring the dense areolar tissue that attaches the external iliac artery to the psoas muscle very superficially with scissors. The incision should extend from the common iliac artery all the way down to the circumflex iliac vein, a branch of the external iliac vein that courses outwards and laterally across the lower portion of the external iliac artery. The incision must be very superficial to avoid injuring the external iliac vein that lies just below the artery. Using blunt dissection with the back of the dissecting scissors or dissecting forceps, the external iliac artery and then the external iliac vein lying under it are peeled off the psoas muscle. Once the vein is freed, progressively deeper dissection will gain entry into the obturator fossa, which is identified by bright-yellow fatty nodal tissue. By continuing the dissection lateral to this tissue, the nodal bundle of the obturator fossa is mobilized medially. There are no branches lateral to the external iliac artery or vein, but very occasionally nutrient muscular branches may be encountered. These can be safely coagulated or clipped.

The lymphadenectomy proper begins after the external iliac vessels and the contents of the obturator fossa have been mobilized medially. The first step is to remove the fatty nodal tissue lying lateral to and in front of the common iliac artery, although sometimes there is scanty tissue at this site. The nodal tissue is freed by dividing the loose areolar tissue that anchors it to the psoas muscle and the common iliac artery, using sharp scissors dissection. Special attention is required when the uppermost part of the nodal mass is being freed; an artery is always encountered deep on the lateral aspect of the common iliac artery. This vessel has to be either cauterized or clipped.

The external iliac artery and vein are next freed from their areolar investments. Each vessel is completely surrounded by its own distinct areolar sheath, and the two sheaths are fused along the entire course of the vessels. The sheath of the external iliac artery is incised with the scissors along its anterior surface from the level of the common iliac artery all the way down to the circumflex iliac vein. There are never any branches of the external iliac artery in this region, but a hairlike vessel that crosses the artery obliquely at its midportion on top of its sheath usually needs to be coagulated. After the sheath is opened, its medial border is grasped with the dissecting forceps, and the artery is peeled off the inferior surface of the sheath using mostly blunt dissection with the back of the Endoshears but cutting areolar attachments as needed. The same process repeated on the lateral surface of the artery will free it completely from the underlying vein.

At this point, the sheaths of the external iliac artery and vein are still joined along the undersurface of the artery, and the next step is to cautiously incise the sheath of the external iliac vein. This step requires more care than any other in the dissection, because the edge of the vessel can easily be compressed and it merges imperceptibly with the areolar sheath that covers it. However, once a nick has been made in the sheath, the glistening surface of the vein becomes unmistakably clear. The same technique of sharp and blunt dissection that was used to free the artery can then be used to free the vein from its sheath. The final step in this part of the dissection is to free the inferior border of the vein, which is tethered by loose areolar tissue to the pelvic sidewall and obturator fossa. This is done not because there are noticeable nodes attached to the sheath but rather to gain free access to the proximal obturator fossa. Occasionally, an aberrant obturator vein is encountered at this point, coursing upwards from the obturator fossa to join the external iliac vein rather than the internal iliac vein, as is usually the case. An aberrant obturator vein has to be clipped using the Endoclip and divided in order to mobilize the external iliac vein completely.

The external iliac nodes are distributed along the external iliac artery in a cephalad-caudad, or north-south, direction and are attached laterally to the psoas muscle and medially to the sheath of the external iliac artery by loose areolar tissue. Distally, at the level of the circumflex iliac vein, there are quite prominent nodes lying in a lateral-medial, or east-west, direction across the lower part of the external iliac artery. The lateralmost part of this nodal bundle is 2 to 3 cm from the artery itself, and a nutrient branch of the artery usually has to be coagulated as these nodes are freed from the inferolateral part of the psoas muscle. The medial attachments of these nodes were freed when the external iliac vessels were dissected from their sheaths; all that remains, then, is to free their lateral attachments in the psoas muscle. As this is done, the ileofemoral and genitofemoral nerves are encountered, but these can easily be pushed laterally. The nodal tissue and the areolar sheaths of the external iliac vessels to which they are attached can be removed at this point and sent as a separate specimen or be allowed to fall away from the vessels into the obturator fossa and removed later, *en bloc* with the remainder of the pelvic nodal tissue.

Finally, the obturator fossa and internal iliac vessels are freed. This is best done by retracting the external iliac vessels laterally and teasing out the obturator nerve from the inferiormost part of the obturator nodal bundle using the unopened Endoshears. Once the nerve is freed, the distal attachments of the nodal bundle can be freed from the pubic bone by dividing them with a cutting current that seals the lymphatics. The nodal bundle is then held with the grasping forceps, elevated and placed on tension, and teased off its ventralmost attachments below the obturator nerve using a gentle sweeping motion with the partly opened scissors. As this nodal tissue is freed in a cephalad direction, residual attachments to the external iliac vein usually need to be divided. Eventually, the internal iliac artery is reached, and the nodal tissue lying anterior, lateral, and medial to it is freed with the obturator-fossa nodal mass. The nodal tissue can be quite adherent in this region, because the internal iliac artery, unlike the external iliac vessels, does not have an areolar sheath. With further dissection in a cephalad direction, the crura, or bifurcation, of the iliac arteries is reached. This region must be cleaned with care, ever mindful of the fact that the external and internal iliac veins lie just lateral to these structures. Once the attachments of the nodal bundle in this region are divided, the dissection is complete (Figure 30.13.18).

It is essential that the spoon forceps be used to remove the fatty nodal tissue, because this instrument will compress tissue into the hollow of its jaws, enabling large chunks of nodal tissue to be removed without fragmenting it. The author has used a surgical glove or an endobag in the abdomen to store nodes prior to their extraction but has not found this to offer any advantages.

Laparoscopic Aortic Lymphadenectomy[8,9]

The patient is placed in the Trendelenburg position and rotated slightly to her left. After the abdomen and pelvis

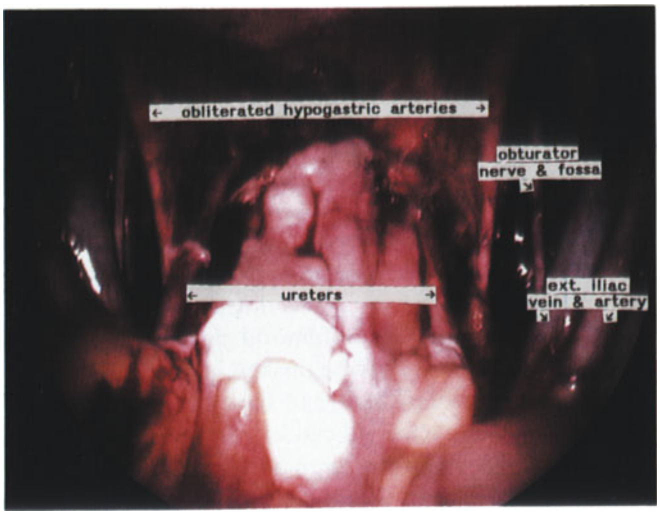

FIGURE 30.13.18. Right and left laparoscopic pelvic lymphadenectomy; completed operation.

are inspected, washings are taken, the sigmoid colon is retracted laterally, the small bowel is displaced from the pelvis, and the root of the mesentery is elevated. The posterior parietal peritoneum is opened in one of several ways: over the right common iliac artery, medial to the right ureter; parallel to the small bowel mesentery; vertically downwards in the midline from the root of the mesentery; or in the reverse direction, starting above the sacral promontory medial to the sigmoid mesentery. The peritoneum is desiccated with bipolar forceps, incised with scissors, and using mostly blunt dissection, a plane is developed between the peritoneum and the node-bearing fatty areolar tissue overlying the great vessels. It is important to develop this plane properly and widely before carrying the dissection down to the adventitia of the aorta; otherwise the nodal tissue may be elevated with the bowel mesentery and retroperitoneal fat during retraction and may not be removed.

The node-bearing areolar tissue in front of the aorta is then incised, and the incision is carried down to the adventitia of the aorta. This is not always easy, because the great vessels are covered by node-bearing tissue and cannot be seen at this stage, except in thin patients without retroperitoneal pathology. There are also no certain landmarks other than the root of the mesentery, which, however, was elevated to retract the bowel and is not in its normal position. It is usually possible to "feel" the sacrum with a dissecting probe, which is a useful guide to the location of the midline, but the point at which to start the dissection in the superior-inferior plane is not always obvious, because the level of the aortic bifurcation above the sacrum is highly variable. Often the pulsations of the aorta can be "felt" if it is gently pressed with a probe, but they are felt much less clearly than one might imagine. It is much safer to start higher than to start lower (which is the natural tendency) because there are no important structures in front of the aorta below the root of the mesentery except for the inferior mesenteric artery, which usually lies lateral to the aorta at this point. On the other hand, if the dissection is started too low, there is a danger of injuring the left common iliac vein below the bifurcation of the aorta. Once the plane between the aorta and the overlying nodal tissue has been developed, however, and the glistening surface of the aorta is seen, the dissection is very straightforward, provided one is cautious and knows the anatomy. The only real challenge is to keep bowel out of the way.

The limits of the dissection are the bifurcation of the aorta inferiorly, the proximal part of the common iliac artery inferolaterally, and the ureters laterally. The superior extent of the dissection is either the third part of the duodenum or the renal vein, in which case the duodenum must be mobilized. The nodal tissue is removed in as systematic fashion as possible, but the plan of attack often needs to be modified if there is either very little or a great deal of tissue in the area.

We usually start with the left-sided dissection. Although some oncologists consider the left-sided dissection more difficult than the right-sided one,[19] in this author's opinion it is no more difficult and much safer, because there are no large veins to contend with. The inferior mesenteric artery does, however, need to be dissected free, and if its origin is lower than usual, this can make exposure more difficult.

Working in a broad plane, the surgeon mobilizes the nodal tissue *en bloc* from the front of the aorta and upper part of the left common iliac artery and to the lateral extent possible. The tissue is frequently stuck posteriorly by the left edge of the aorta, and it is often advantageous to "skip" to a more lateral point, identify the left ureter, elevate it on the peritoneum, and dissect the tissue in front of the psoas muscle from lateral to medial until the sticking point beside the aorta is reached. The nodal bundle is then transected either proximally or distally, wherever it is most free (usually in front of the common iliac artery), and the tissue is teased off the psoas, while the wall of the aorta is pushed somewhat medially. One needs to take care not to injure the vertebral arteries, and on no account should one pull hard if resistance to the dissection is encountered. If these arteries are injured and retract into the vertebral foramina, laparotomy will be necessary, and even then hemostasis may be difficult to secure.

The problem on the right side stems from the inability to see the wall of the inferior vena cava clearly until the areolar sheath investing it has been incised. The wall of the vein merges imperceptibly with the investing tissue, placing it at risk of injury during the initial incision into the sheath. The dissection is actually easier if there is more rather than less nodal tissue in the area, because the tissue can then be grasped very superficially and elevated. Cautious dissection below the elevated tissue will allow one to enter the caval sheath, and once the glistening surface of the cava is seen, the incision is extended proximally to the duodenum and inferiorly to the level of the right common iliac artery. Working again in a broad plane, a combination of sharp and blunt dissection is used to clean the cava of fatty areolar tissue, continuing laterally along the psoas muscle as far as the right ureter.

It is a simple matter to extend the dissection to the left renal vein. Blunt dissection is used almost exclusively, and the duodenum is elevated towards the right using the bowel graspers in the left upper and left lower trocars. The plane of dissection is along the front of the aorta, above the inferior mesenteric artery. The left renal vein is cleared of areolar tissue, but it is not elevated. The dissection continues to the left of the aorta, above the inferior mesenteric artery, and nodal tissue is cleared from the front of the psoas muscle. Here one encounters the left ovarian vein medial to the left ureter and, lower down, the left ovarian artery, which may need to be divided. On the right side the vena cava is cleaned of node-bearing tissue as far as the left renal vein, but the right renal vein is not identified. The right ovarian vein in front of the vena cava usually has to be sacrificed, together with the right ovarian artery. The completed dissection is shown in Figure 30.13.19A, B.

Comment

In our experience and that of others, laparoscopic aortic lymphadenectomy is superior to its open counterpart because patients recover much faster and radiation can be started sooner. Laparoscopic aortic lymphadenectomy is a straightforward operation for surgeons trained in the open procedure who have mastered laparoscopic techniques. Exposure can be difficult if the malignancy fixes the rectosigmoid in the pelvis and it cannot be easily elevated or if the root of the mesentery is attached to the posterior parietal peritoneum low in the abdomen. Although some oncologists have apparently had difficulty on the left side,[19] this has not been the author's experience; in fact in two cases fixed lymph nodes containing metastases were resected from the side of the aorta.[9]

Although staging laparoscopic aortic lymphadenectomy in cervix cancer has been shown to be feasible and safe, some investigators have obtained far fewer nodes laparoscopically than with an open technique, and lymph node metastases have been detected in very few patients. In the largest series pertaining to the laparoscopic staging of cervix cancer, Childers and colleagues did not separately enumerate pelvic and aortic nodes.[20] In a heterogeneous group of 42 patients undergoing laparoscopic aortic lymphadenectomy, however, these authors recovered an average of only 1.9 nodes (range 0 to 3), and only 3/42 (7%) patients had nodal metastases.[21] Of 16 patients subjected to laparoscopic aortic lymphadenectomy, 50% of whom had disease advanced to at least stage IIB or positive pelvic nodes, only 1 (6.3%) with stage-IV disease and grossly enlarged pelvic lymph nodes had positive nodes.[21] This frequency is much lower than that reported for an open approach in similar patients[22] and than that in the author's practice.[9] For example, in patients who had stage-IB disease and positive pelvic nodes, or stage-IIB or IIIB disease, the author recovered an average of 12.6 aortic nodes and 4/5 (80%) patients had positive nodes.[9]

Although many factors besides the technique of lymphadenectomy can influence the node count and proportion of positive nodes, the difference in these results is probably due to differences in surgical technique. According to the same authors, in patients with stage-IB carcinoma of the cervix, the frequency of *pelvic* lymph

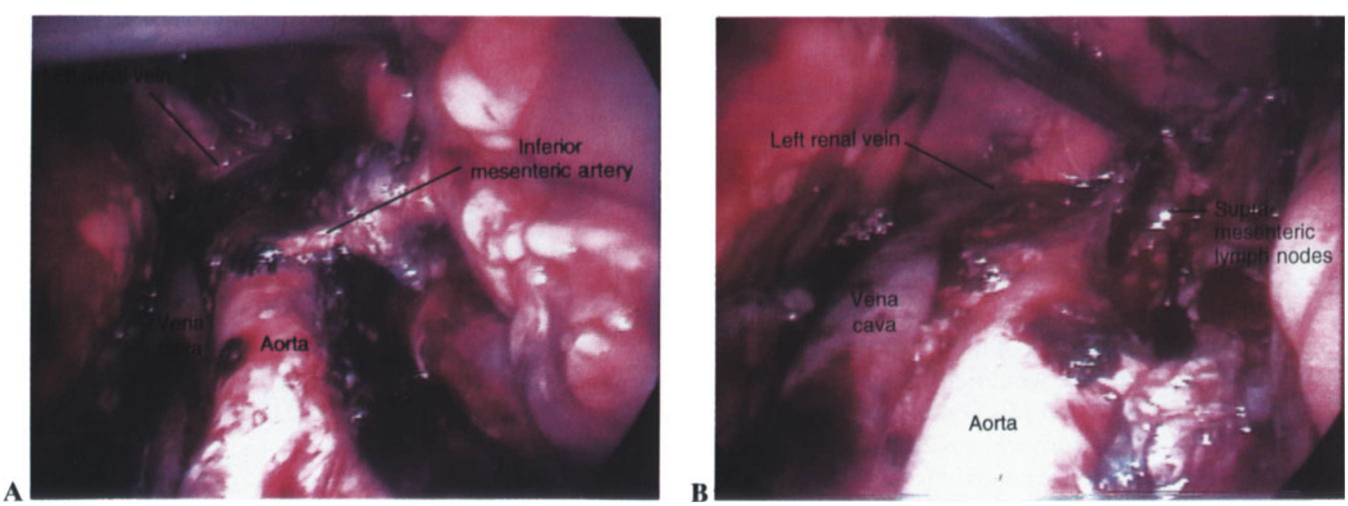

FIGURE 30.13.19. (A, B) Laparoscopic aortic lymphadenectomy extended to the renal vessels.

node metastases and the overall average node count after laparoscopic pelvic lymphadenectomy are similar to those reported for an open technique.[21] This makes it unlikely that the results in the case of aortic lymphadenectomy are attributable to the method of counting or processing the lymph nodes. The most likely explanation for the difference between the results obtained with laparoscopic aortic lymphadenectomy and open aortic lymphadenectomy is that if the dissection is carried down to the adventitia of the aorta at the very outset, some nodal tissue around the great vessels may be elevated with the peritoneum, preperitoneal fat, and bowel mesentery and will not be removed. There is no other plausible explanation for the fact that a dissection that has ostensibly reached the renal veins yields only zero to three nodes, yet, at the same time, harvests an adequate number from the pelvis. If a laparotomy is then carried out, and the dissected area inspected directly,[21] the missing nodes would still not be detected because they were retracted away from the operative field.

Laparoscopic Radical Vaginal Hysterectomy (Modified Schauta-Amreich Operation).[4,10]

Radical vaginal operations for cervix cancer offered several advantages over their abdominal counterparts but fell into disuse because they did not allow removal of the pelvic lymph nodes.[23] Mitra tried to correct this deficiency by combining the Schauta-Amreich procedure with bilateral extraperitoneal pelvic lymphadenectomy,[24] but his operation never gained popularity because the reduction in morbidity that derives from the vaginal approach was largely lost.

Laparoscopic lymphadenectomy, developed independently by a number of gynecologic oncologists, has been shown to be both feasible and safe.[7,21,24] Frozen sections of lymph nodes obtained in this way have been used to select patients with stage-IB cervix cancer for radical abdominal hysterectomy (those without nodal metastases) or radiation therapy (those with nodal metastases).[21,24] It seemed much more logical to this author to try to combine the procedure with a radical vaginal operation, so that therapy could be completed in most patients without the use of pelvic radiation or laparotomy.[4]

The author's original plan was to combine a laparoscopic lymphadenectomy with laparoscopic division of the proximal attachments of the uterus, the uterine arteries, and the upper portions of the cardinal and uterosacral ligaments and freeing of the ureter from the broad ligament. The operation would continue as a Schauta-Amreich procedure, but, it was hoped, without the Schuchardt incision. This approach was used in the first two cases, but several difficulties were encountered with both the laparoscopic and vaginal parts of the procedure. These were resolved by the development of the author's technique for retroperitoneal dissection, described above, by the use of a more logical partitioning of the operation into laparoscopic and vaginal components, and, finally, by retracting the ureters out of the pelvis laparoscopically and keeping them retracted throughout the vaginal part of the operation. Only the author's mature technique will be described.

Laparoscopic Phase of the Operation

Step 1. The Cul-de-sac Peritoneum Is Incised

The pouch of Douglas is incised with dissecting scissors, and the incision is extended proximally on either side of the rectum, below the uterosacral ligaments. It is much more difficult to carry out this step if it is left to the last because the tissues become too slack. A rectal probe developed by Reich is used to displace the rectum to the contralateral side (Figure 30.13.20). The ureters may or may not be seen on the medial leaf of the broad ligament, but because they always lie above and lateral to the plane of dissection, they are not at risk, and no effort should be made to identify them at this stage.

Steps 2 to 6

These steps are almost identical to the steps previously described under dissection of the retroperitoneum and simple hysterectomy, with three exceptions. First, the paravesical and pararectal spaces are developed all the way to the levators. Second, the ureters are reflected off the medial leaf of the broad ligament as far as the pelvic brim. Third, the uterosacral ligaments are not divided, and the vagina is, of course, not opened. Also, the uterine arteries are divided more proximally, where they join the

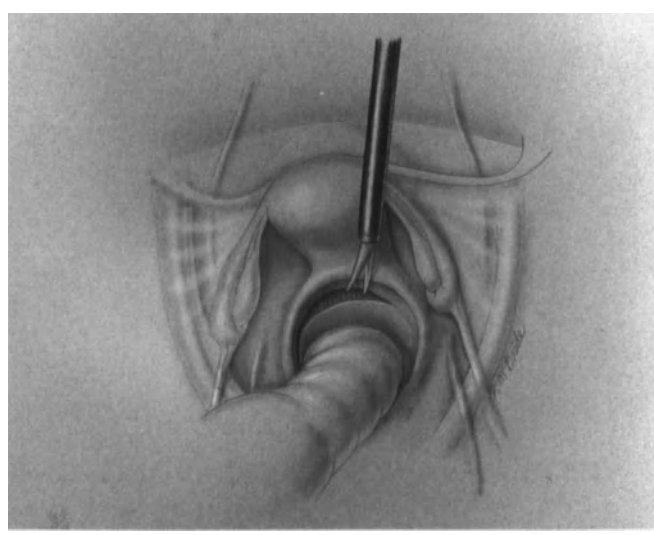

FIGURE 30.13.20. The posterior cul-de-sac peritoneum is incised, and the incision extended on either side of the rectum below the uterosacral ligaments. (From Kadar, *Atlas of Pelvic Surgery*, 1994. Reprinted by permission of Blackwell Scientific Publications, Inc.)

hypogastric arteries, and the distal stumps are dissected free of the underlying tissues and ureter (but the ureteric tunnel is not dissected laparoscopically). Laparoscopic pelvic lymphadenectomy is then carried out as previously described.

To summarize: Step 2. The pelvic sidewall triangle is opened; Step 3. The paravesical and pararectal spaces are developed; Step 4. The uterine artery and its ureteric branch are coagulated and divided; Step 5. The ureter is reflected off the broad ligament; Step 6. The round ligament and adnexal pedicles are coagulated and divided, and the bladder peritoneum is incised; Step 7. Bilateral pelvic lymphadenectomy is performed; and Step 8. The ureters are retracted out of the pelvis.

Before the vaginal part of the operation begins, one end of a vascular tape is inserted through each lateral trocar, passed around the ureters, and withdrawn through the trocars. The trocars are then withdrawn, and the tapes are used to retract the ureters out of the pelvis during the vaginal phase of the operation (Figure 30.13.21).

Vaginal Phase of the Operation

Step 9. Formation of the Vaginal Cuff, Division of the Supravaginal Septum

The vagina is grasped with four Kocker clamps at approximately the 10, 2, 4, and 8 o'clock positions, at the level at which the vagina is to be transected (usually at midvagina or at the junction of the middle and upper third). If there is superfluous tissue, more Kocker clamps may be needed to ensure that the vagina is stretched out flat and there are no ridges in its wall when it is incised. After the vaginal fascia is infiltrated with phenylephrine solution (10 mg in 250 mL saline), the vagina is incised circumferentially with cutting diathermy (Figure 30.13.22A, B). The vesicovaginal and rectovaginal spaces are then developed with sharp scissors dissection, and the posterior cul-de-sac is entered. T-clamps are placed on the distal cut edge of the vagina for traction (usually three or four) and a long-weighted Auvard speculum is placed in the cul-de-sac.

The anterior dissection proceeds without much effort until an impasse is reached at the level of the supravaginal septum, which separates the vesicovaginal space from the vesicocervical space. This tissue is placed on tension by appropriate traction on the T-clamps and anterior retraction. The bladder is pulled up with forceps, and the supravaginal septum is incised. The incision is made approximately a centimeter above the vaginal attachments of the septum, which can usually be discerned. The bladder immediately becomes visible and can be freed further with sharp scissors and then blunt finger dissection to gain entrance to the anterior cul-de-sac (Figure 30.13.22C, D).

Step 10. The Paravesical and Pararectal Spaces Are Entered, and the Vesicocervical Ligaments (Bladder Pillars) Are Formed

The cut edge of the distal vagina is pulled laterally, that is, everted, and rendered taut, and the tissue just under the vaginal fascia is incised with scissors to gain entrance into the paravesical space (Figure 30.13.23A). Since the paravesical space has already been opened laparoscopically, this is a surprisingly easy maneuver. Nevertheless, the position of the pubococcygeus muscle should be checked before making the incision to ensure that the dissection is not too lateral; if it is, some of the muscle fibers may be pulled medially, making the bladder pillars thick and the ureters more difficult to feel. If there is any uncertainty, the pneumoperitoneum can be re-established and a probe passed laparoscopically into the paravesical space medial to the obliterated hypogastric artery. The probe, which can be readily felt vaginally, allows the paravesical space to be opened without any further difficulty. The vaginal incision is then enlarged bluntly with the index fingers and extended posteriorly (Figure 30.13.23B). The rectum is retracted medially, and the pararectal space is entered. Usually dense bands of connective tissue separate the paravesical and pararectal spaces

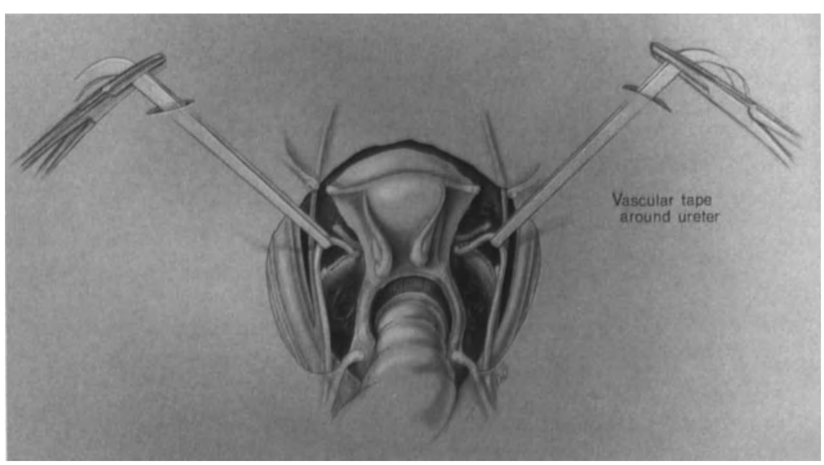

FIGURE 30.13.21. Vascular tapes are passed around the ureters, and they are retracted out of the pelvis laparoscopically. (From Kadar, *Atlas of Pelvic Surgery*, 1994. Reprinted by permission of Blackwell Scientific Publications, Inc.)

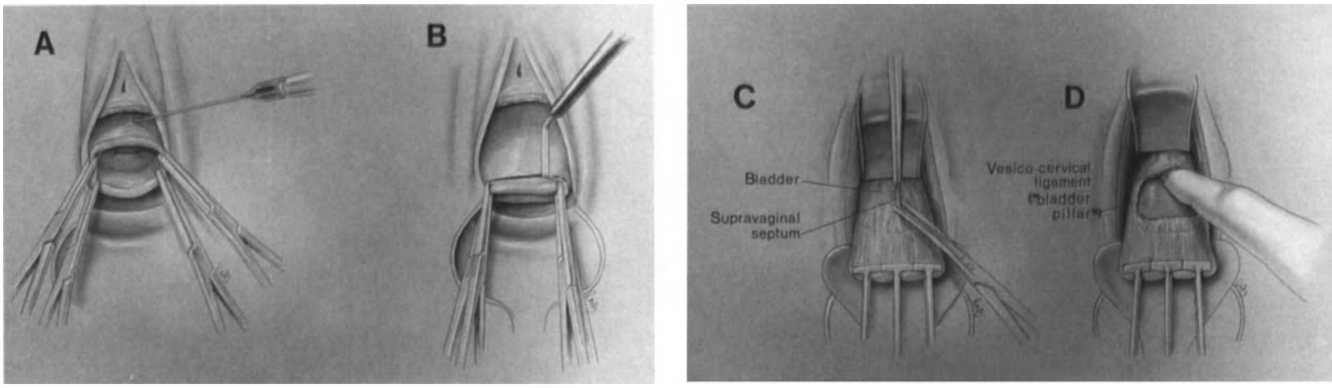

FIGURE 30.13.22. (A) The position of the cuff is demarcated with Kocker clamps, and the vaginal wall is infiltrated with phenylephrine solution. (B) The vaginal wall is incised circumferentially with diathermy, using a cutting monopolar current. (C) The vesicovaginal and rectovaginal spaces have been developed, the posterior cul-de-sac has been entered, T-clamps have been placed on the vaginal cuff, and the supravaginal septum is being incised. (D) The vesicocervical space is developed with sharp scissor and blunt finger dissection. (From Kadar, *Atlas of Pelvic Surgery*, 1994. Reprinted by permission of Blackwell Scientific Publications, Inc.)

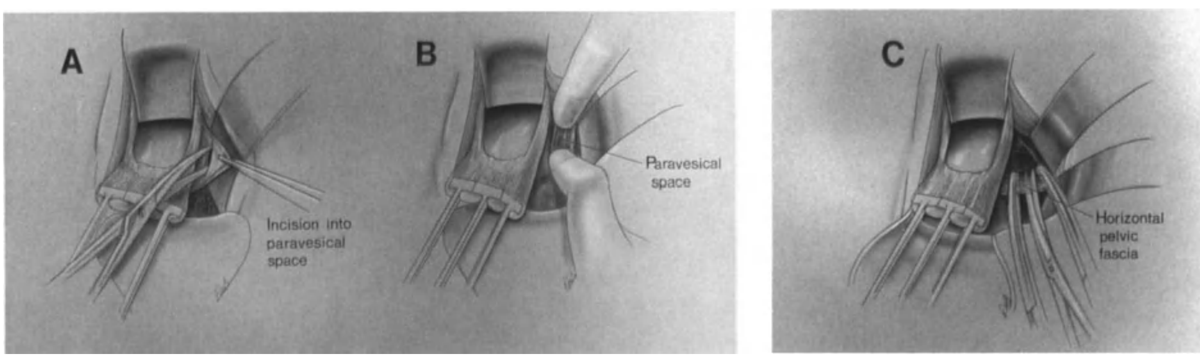

FIGURE 30.13.23. (A) The lateral vaginal wall is incised to enter the paravesical space. (B) The vaginal incision is enlarged. (C) The horizontal pelvic fascia is divided.

(the horizontal fascia), and these need to be divided to unite the spaces (Figure 30.13.23C). Once the paravesical and pararectal spaces have been united, the entire hand can be placed into the peritoneal cavity lateral to the uterus and cervix. The paravesical and pararectal spaces on the contralateral side are then developed in an identical fashion.

Step 11. Division of the Uterosacral Ligaments (Rectal Pillars)

Starting on the left side, the uterosacral ligament is placed on tension by pulling the T-clamps upwards and to the right. The rectum is retracted medially, and any peritoneal attachments not freed laparoscopically are divided at this time. The position of the ureter is verified by palpation, and the uterosacral ligament is clamped close to the rectum with Zeppelin clamps, divided, and suture ligated (Figure 30.13.24). The right uterosacral ligament is divided in an identical manner.

The uterus is usually rendered quite mobile by division of the rectal pillars, and the operation can proceed with

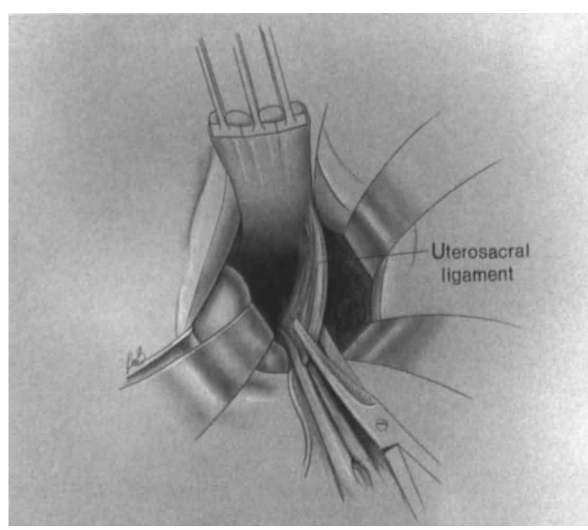

FIGURE 30.13.24. The left uterosacral ligament is being divided. (From Kadar, *Atlas of Pelvic Surgery*, 1994. Reprinted by permission of Blackwell Scientific Publications, Inc.)

either unroofing of the distal ureters or division of the cardinal ligaments. The latter sequence will be described. Although the next steps are largely interchangeable, if access is still suboptimal after the uterosacral ligaments have been divided, it is better to divide the cardinal ligaments first (step 13). In this case, however, it will then not be possible to deliver the fundus through the anterior vagina. If lateral access is limited, the clamps on the cardinal ligaments can be left in place until the ureters are unroofed, and the specimen can be removed before the pedicles are sutured.

Step 12. The Ureters Are Freed (Unroofed) from the Vesicocervical Ligaments

The left bladder pillar, or vesicocervical ligament, is placed on tension by pulling downwards and to the right on the T-clamps and by using suitable retraction in the vesicocervical and paravesical spaces. The ureter can be easily palpated between the middle finger and forefinger in the upper part of the distal ligament and lower down in the proximal ligament. The relation between the ureter and the uterine artery is different in the vaginal and abdominal approaches because, in the vaginal approach, the uterus is pulled downward rather than upward and the bladder is pushed upward rather than downward. A ureteric loop, or knee, is thereby artificially created. The uterine artery runs obliquely upwards from the cervix to the hypogastric artery through the knee (Figure 30.13.25A, B). The ureteric tunnel is entered by gradually snipping away the bladder pillar below the bend in the ureter. Once entered, it is enlarged with finger dissection. The lateral wall of the tunnel is clamped with a fine tonsil clamp, divided, and suture ligated (Figure 30.13.25C, D). The medial wall is divided without ligation, but the uterine artery is cauterized medial to the ureteric loop to avoid backbleeding. The right ureter, which tends to be higher, is freed in the same way.

Step 13. Division of the Cardinal Ligaments

The fundus is delivered through the anterior vagina. Starting on the left side, the index and middle fingers are placed on either side of the cardinal ligament (from above if possible), the uterus and cervix are pulled medially, the bladder and rectum are retracted out of the way, and the position of the ureter is checked again. The cardinal ligament is then clamped at the pelvic sidewall (or closer to the uterus in the case of smaller lesions), divided, and suture ligated (Figure 30.13.26). The right ligament is divided in the same way and the specimen is removed (Figure 30.13.27).

Step 14. The Cuff Is Closed, and the Pelvis Inspected Laparoscopically

The vagina is closed horizontally with a running nonlocking chromic suture around a suction drain, which is removed the next day. The pneumoperitoneum is re-established, and the pelvis is copiously irrigated and checked for hemostasis (Figure 30.13.28). The operative steps are summarized in Table 30.13.1.

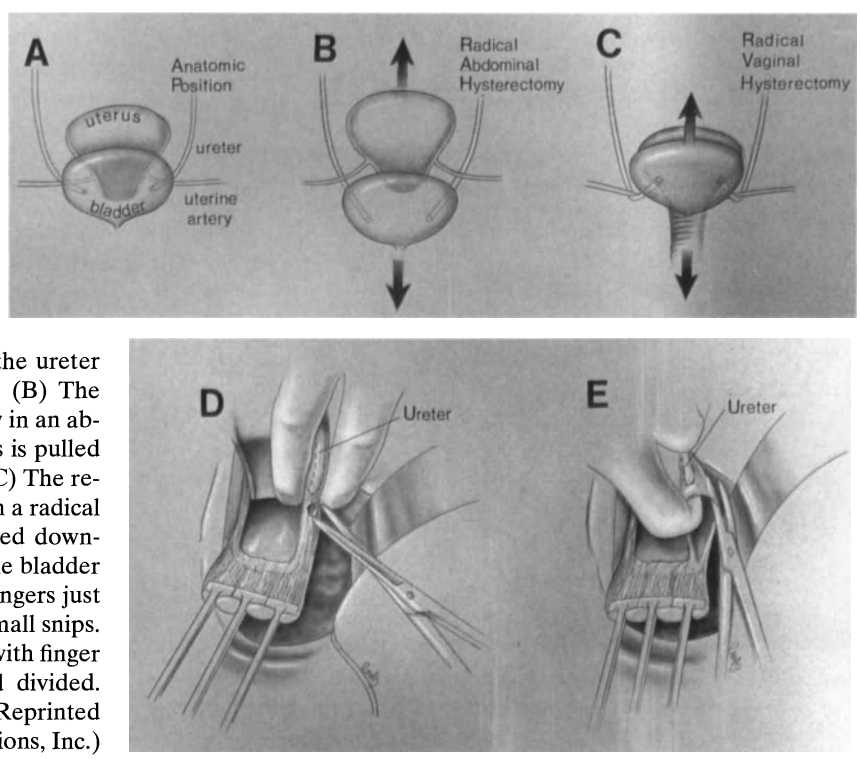

FIGURE 30.13.25. (A) The relation between the ureter and uterine artery in the anatomic position. (B) The relation between the ureter and uterine artery in an abdominal radical hysterectomy after the uterus is pulled upward and the bladder pushed downward. (C) The relation between the ureter and uterine artery in a radical vaginal hysterectomy after the uterus is pulled downward and the bladder pushed upward. (D) The bladder pillar is held between the index and middle fingers just below the ureters and divided in a series of small snips. (E) The ureteric tunnel is developed bluntly with finger dissection, and its lateral wall clamped and divided. (From Kadar, *Atlas of Pelvic Surgery*, 1994. Reprinted by permission of Blackwell Scientific Publications, Inc.)

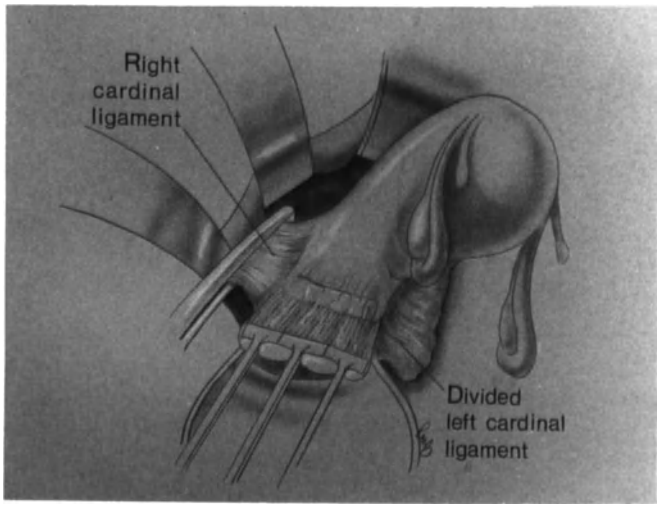

FIGURE 30.13.26. The fundus has been delivered through the anterior vagina, and the left cardinal ligament is being divided. (From Kadar, *Atlas of Pelvic Surgery*, 1994. Reprinted by permission of Blackwell Scientific Publications, Inc.)

FIGURE 30.13.27. Laparoscopic radical vaginal hysterectomy specimen.

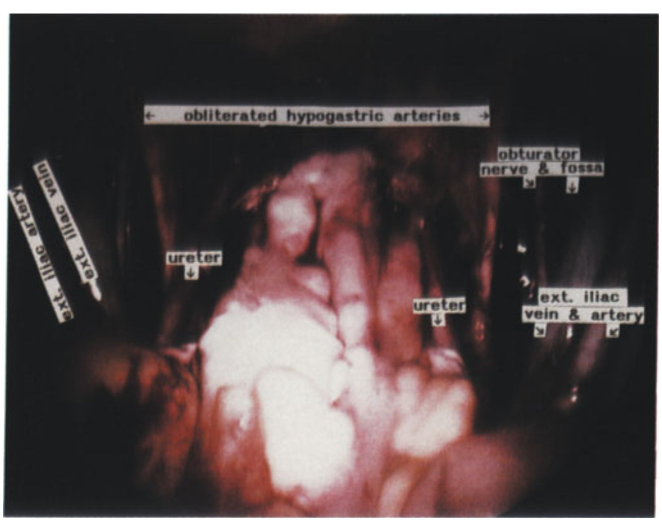

FIGURE 30.13.28. Laparoscopic view of the completed operation.

TABLE 30.13.1. Summary of the operative steps.

Laparoscopic phase	
Step 1.	The cul-de-sac peritoneum is incised, and the peritoneal incision is carried proximally along each lateral border of the rectum, below the uterosacral ligaments.
Step 2.	The pelvic sidewall triangle is opened.
Step 3.	The paravesical and pararectal spaces are developed.
Step 4.	The uterine artery and its ureteric branch are coagulated and divided.
Step 5.	The ureter is reflected off the broad ligament.
Step 6.	The round ligament and adnexal pedicles are coagulated and divided, and the bladder peritoneum is incised.
Step 7.	Lymphadenectomy is then performed.
Step 8.	Each ureter is tagged with vascular tape, and the tape is pulled out through the inferior ports.
Vaginal component	
Step 9.	The vaginal cuff is formed, the rectovaginal and vesicovaginal spaces are developed, and the supravaginal septum is divided.
Step 10.	The paravesical and pararectal spaces are developed, the vesicocervical ligament (bladder pillar) is formed, the horizontal pelvic fascia is divided, and the paravesical and pararectal spaces are united.
Step 11.	The uterosacral ligaments are divided.
Step 12.*	The ureters are unroofed, and the vesicouterine ligament is divided.
Step 13.*	The cardinal ligaments are divided, and the specimen is removed.
Step 14.	The vagina is closed with a running suture around a suction drain, the pelvis is inspected and irrigated laparoscopically, and trocars are removed.

*Steps 12 and 13 are usually interchangeable.

Comment

The argument for a combined laparoscopic and vaginal approach to radical hysterectomy is compelling. Radical vaginal hysterectomy is an effective operation with lower morbidity than its abdominal counterpart, and laparoscopic lymphadenectomy complements the operation by correcting its only deficiency, the inability to remove the pelvic lymph nodes.

The laparoscopic component contributes more than removal of the lymph nodes to the procedure because it allows a natural partitioning of the operation into symbiotic abdominal and vaginal phases. Only those steps of the hysterectomy that are easier to perform vaginally than abdominally are carried out from below—formation of the cuff, division of the cervical ligaments, and freeing of the distal ureters—and their execution is greatly facilitated by the preceding abdominal phase of the operation. Strategies that involve either performing the entire hysterectomy laparoscopically,[25,26] or following the laparoscopic lymphadenectomy with a radical vaginal hysterectomy[24,27] are, in this author's opinion, ill-conceived, because they do not make the best use of either laparoscopic or vaginal technique, nor do they exploit the potentially symbiotic relation between them. This is also true of the author's initial plan to divide the cervical ligaments partly laparoscopically, a tactic that proved to be of no benefit whatsoever.[4]

Vaginal entry into the paravesical and pararectal spaces, which can be difficult even for experienced surgeons, is very straightforward after these spaces have been developed laparoscopically. Laparoscopic division of uterine vessels makes it easier to unroof the ureters vaginally, because it eliminates the need to ligate the vessels repeatedly, at successively more proximal points, as in the Schauta operation. Finally, the radical hysterectomy is also facilitated by laparoscopic division of the proximal attachments of the uterus, and by laparoscopic freeing of the ureters from the broad ligaments. Only distal structures then have to be approached vaginally, and lateral exposure sufficient to divide the cervical ligaments can usually be obtained without a Schuchardt incision. The ureters can be retracted away from the operative field for the duration of the vaginal part of the operation, making it possible to divide the uterosacral and cardinal ligaments before the distal ureters are freed. This also makes it easier to unroof the ureters and to eliminate the another reason for a Schuchardt incision.

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30.14 Laparoscopic Para-Aortic Lymphadenectomy

Joel M. Childers

Until recently, operative laparoscopy in patients with gynecologic malignancies was limited. However, as modern laparoscopic equipment became available and advanced operative procedures were developed, the number of indications for operative laparoscopy in these patients has grown. The feasibility of both pelvic and para-aortic lymphadenectomy has now lured gynecologic oncologists into operative laparoscopy, resulting in new indications for this approach in our subspecialty.

Currently only a handful of reports in the literature describe a series of patients who have undergone laparoscopic transperitoneal pelvic or para-aortic lymphadenectomy for a gynecologic malignancy. Querleu and coworkers described their experience with pelvic lymphadenectomy for staging early carcinoma of the cervix.[1] Schuessler and colleagues reported their experience with laparoscopic lymphadenectomy in patients with localized prostatic cancer.[2] Childers and colleagues reported the only published series of patients who underwent laparoscopic pelvic and para-aortic lymphadenectomy.[3] The authors used this technique to stage patients with early and advanced cervical carcinoma. Childers and coworkers have also reported the management of patients with stage-I endometrial cancer and early and advanced ovarian carcinoma by a combined laparoscopic and vaginal approach.[4–6] The patient with early ovarian carcinoma underwent infrarenal para-aortic lymphadenectomy, a technique that was first described by Querleu in two patients with early ovarian carcinoma.[7] All of these investigators used a transperitoneal approach to the retroperitoneal space.[1–7]

Dargent and coworkers reported a series of patients with early cervical cancer whose pelvic lymph nodes were removed by an extraperitoneal endoscopic approach.[8] An average of 13 nodes was obtained. This compares to nine nodes in the Querleu series and 31 nodes in the series by Childers.[1–3,8] Currently the extraperitoneal approach allows access only to the pelvic nodes.

This chapter outlines the technique of and early experience with laparoscopic para-aortic lymphadenectomy for patients with gynecologic malignancies. We have performed more than 60 laparoscopic para-aortic lymphadenectomies using this technique.

Our initial experience with laparoscopic para-aortic lymphadenectomy included patients with cervical, endometrial, and ovarian carcinoma.[6] The patients with cervical cancer were either patients for whom primary radiotherapy was planned and laparoscopy was being used for surgical staging or patients who were considered candidates for radical hysterectomy. The endometrial cancer patients were clinically stage I, and the ovarian cancer patients were those undergoing second-look laparoscopy or patients being staged for presumed stage-I malignancies.

Para-aortic lymphadenectomy could not be performed in 4 of 65 patients considered eligible for it: in 3 cases this was because of obesity and in 1 the difficulty was extensive intraperitoneal adhesions. The obese patients all weighed at least 180 lb. The fourth patient had ovarian carcinoma and was undergoing second-look laparoscopy. Extensive intraperitoneal adhesions prevented adequate exposure to the para-aortic area. Of the remaining 61 patients, 1 had a significant complication: laceration of the vena cava that could not be controlled laparoscopically and required conversion to laparotomy. She received 4 units of packed red blood cells but postoperatively developed right pelvic deep-venous thrombosis. She remained in the hospital until postoperative day 10.

Four patients had nodes with tumor involvement. One had cervical cancer and positive pelvic lymph nodes. The second patient had a stage-III ovarian carcinoma, and her microscopically positive para-aortic lymph node was the only site of persistent disease at her second-look laparoscopy. The third patient had a positive microscopic para-aortic node removed during a second-look procedure. Metastatic disease had been discovered in these nodes during her original debulking, but only the nodes below the inferior mesenteric artery were removed at that time.

The nodes cephalad to her previous lymphadenectomy were removed during the laparoscopic procedure. She was the only patient who had had a previous para-aortic dissection. CT scans did not reveal adenopathy in any of these patients. The fourth patient had a clinical stage-I grade-3 adenocarcinoma of the endometrium. Her tumor was deeply invasive, and the right para-aortic lymph nodes contained metastatic disease, although her left para-aortic nodes were uninvolved.

Thirty-five women had laparoscopic surgery only; they did not require either laparotomy or laparoscopically assisted vaginal hysterectomy. The average blood loss was less than 50 cc for these patients, and there were no significant intraoperative or postoperative complications. The average hospital stay for this group was 1.3 days. Twenty-five of these women were discharged on postoperative day 1, 7 were discharged on postoperative day 2, 2 remained until postoperative day 3, and 1 patient was treated as an outpatient.

Our initial experience established the feasibility of laparoscopic para-aortic lymphadenectomy. In addition, it showed that this is a safe procedure with a conversion rate of only 2%. The advantages of the procedure for the patient include a short hospital stay and, more importantly, a rapid recovery.

Preoperative Considerations

Bowel Preparation

Evacuating the large and small bowel facilitates the laparoscopic approach to the para-aortic nodes. This is easily accomplished by putting the patient on a liquid diet for two days prior to the procedure and administering one bottle (240 cc) of magnesium citrate for each of the two days prior to the procedure. An enema on the morning of admission, routinely performed on our laparoscopic surgery patients, will aid in the evacuation of the lower bowel. In general, we do not use oral erythromycin- or neomycin-based antibiotics.

Anesthesia Considerations

General anesthesia is used. An endotracheal tube is placed and end-tidal CO_2 is monitored. A nasogastric or oral gastric tube is inserted to empty the stomach contents prior to placement of the primary trocar or Veress needle. A pulse oximeter is used, and a Foley catheter is placed. The patient's arms are tucked into her sides with consideration given to padding the ulnar nerve. The supine position is preferred except for patients with stage-I endometrial cancer who are placed in the dorsal lithotomy position (see Special Considerations, page 677).

Since the patient's arms are tucked by her sides to give the surgeon room to maneuver, the anesthesiologist may prefer to place an arterial or a central line. A heating blanket is placed under the patient, and body temperature is monitored. Sequential compression stockings are currently used.

Operating Room Considerations and Instruments

Routine abdominal preparation of the patient is performed. Vaginal preparation is necessary for patients with stage-I endometrial cancer (see Special Considerations, page 677).

Even a well-trained physician will be unable to perform this procedure if proper instruments are lacking or he is unfamiliar with the instruments. It behooves the surgeon to be familiar with all of the instruments available at each institution at which he operates. These include insufflators, light sources, cameras, telescopes, trocars and sleeves, as well as the basic instruments used during the procedure. Lasers are not used.

In general, the procedure can be accomplished with the instruments available on a laparoscopic cholecystectomy tray. It is absolutely necessary, however, to have: (1) *sharp scissors* with monopolar electrocautery capabilities; (2) a large spoon forceps that fits through a 10-mm laparoscopic sleeve; and (3) a suction irrigation apparatus. Endoshears (US Surgical Corporation, Norwalk, CT) are the scissors with which we have the most experience. They have monopolar electrocautery capabilities, and because they are disposable, they are always sharp. The spoon forceps is necessary for extirpation of the lymphatic tissue. A 10-mm laparoscopic telescope with a 0° lens is preferable for most cases.

Special instruments such as needle drivers, knot pushers, pre-tied slipknots, and stapling devices are not absolutely necessary for lymphadenectomy but are very helpful if a laparoscopically assisted vaginal hysterectomy is to be performed (see Special Considerations, page 677). On occasion, a laparoscopic clip-applier may be needed. This is most commonly used to occlude the perforating veins over the vena cava.

Training Considerations

Adequate training is obviously necessary to perform this advanced operative laparoscopic procedure. Although there are many ways to learn the procedures, it behooves the gynecologic oncologic laparoscopist to receive some sort of formalized training. A formal training course will allow the laparoscopist to become familiar with the myriad instruments as well as introduce him or her to critical troubleshooting methods, essential surgical techniques, safety considerations, and the management of laparoscopic complications. Video teaching tapes and hands-on operative sessions in the animal model are invaluable and allow the beginner to avoid many of the errors that are inevitably made when one is mastering a new procedure.

Operative Technique

Instrument Insertion

Gaining access to the intraperitoneal cavity is a procedure well known to most gynecologists. We prefer the technique of direct trocar insertion without the prior establishment of a pneumoperitoneum. This is accomplished by placing a 10-mm or larger laparoscopic trocar and sleeve through an incision made in the umbilicus. Upward traction on the anterior abdominal wall with towel clips placed on either side of the umbilicus reduces the risk of injuring abdominal structures. This technique is safe, saves time, and decreases the incidence of annoying preperitoneal emphysema.

In patients with previous abdominal incisions extending through the umbilicus or in patients with umbilical hernias, another technique is used.[9,10] We begin by placing a Veress needle in the 9th or 10th intercostal space in the left upper quadrant. Once the pneumoperitoneum is established, the primary trocar is placed in the midclavicular line just below the left costal margin (Figure 30.14.1). A 5-mm trocar and sleeve should be used to minimize resistance and downward tenting of the anterior abdominal wall. The telescope is then used to assess the intraperitoneal cavity for adhesions and to locate optimal sites for placement of ancillary trocars for adhesiolysis. If the surgeon prefers, open laparoscopy can be performed with the use of a Hasson cannula.[11] However, our technique allows access to the intraperitoneal cavity lateral to the midline adhesions and offers better visualization during adhesiolysis.[10] The operative laparoscopist should be familiar with more than one technique for obtaining access to the intraperitoneal cavity.

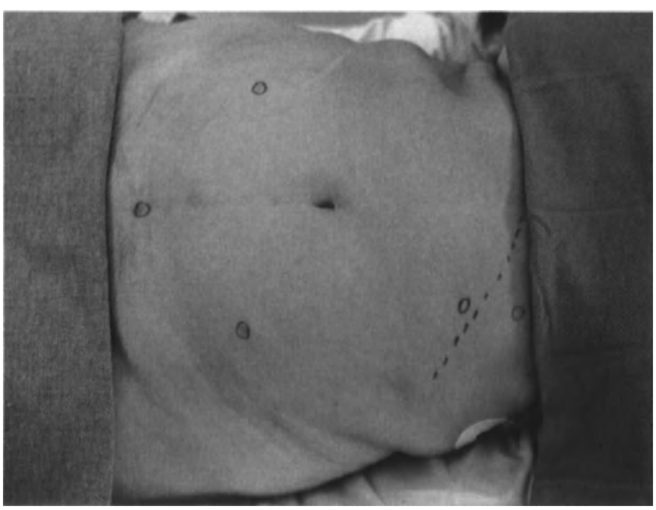

FIGURE 30.14.1. This photograph of the abdomen demonstrates laparoscopic port placement. The dotted line is the left costal margin. The Veress needle is placed intercostally (above the dotted line). The primary trocar is 5 mm in size and placed just below the costal margin. The ancillary port sites are in the lower abdomen. The lateral ports are 5 mm in size and should be placed lateral to the inferior epigastric vessels. The midline port is 10 mm in size or larger.

Four laparoscopic ports are needed to perform this procedure. The primary port is placed in the umbilicus and should be 10 mm in size to allow use of a 10-mm telescope and camera. The three ancillary ports are placed under direct laparoscopic visualization. Five-millimeter trocars and sleeves are placed lateral to the inferior epigastric vessels and the rectus muscle bilaterally (Figure 30.14.1). This is generally approximately midway between the umbilicus and the symphysis. The third ancillary port is placed in the midline above the symphysis, and should be 10 mm in size to allow a large spoon forceps to be used to remove nodal tissue.

Inspection of the Intraperitoneal Cavity

After the laparoscopic ports are in place and before the patient is placed in the Trendelenburg position, it is important to explore the entire intraperitoneal cavity in a systematic fashion. The cecum and appendix should be visualized, as well as the right paracolic gutter. The gallbladder, the surface of the right lobe of the liver, the right hemidiaphragm, the falciform ligament, the greater curvature of the stomach, the anterior wall of the stomach, the left hemidiaphragm and its left ventricular pulsations, the supracolic omentum, the transverse colon, and the infracolic omentum should be carefully inspected. Systematic clockwise inspection continues with evaluation of the descending colon and left paracolic gutter, which leads the surgeon to the pelvis. The pelvis is evaluated after the establishment of Trendelenburg position. It is helpful, when evaluating the pelvic sidewalls, to grasp the utero-ovarian ligament and to lift the ovary so that the ovarian fossa can be adequately visualized. Pelvic washings should be taken (see Special Considerations, page 677).

When the para-aortic area is examined, the root of the small bowel mesentery can be lifted, and often the transverse duodenum can be seen. The area from the third part of the duodenum to the lower pelvis should be inspected for obvious adenopathy.

A peritoneal incision over the aorta between the mesentery of the small bowel and the common iliac arteries will allow access to the para-aortic nodal tissue from the transverse duodenum to the proximal common iliac arteries bilaterally.

On the left side, the nodal tissue over the distal common iliac vessels and their bifurcation can be obtained only through a peritoneal incision in the pelvis. However, on the right side these nodes may be removed through the peritoneal incision over the aorta and right common iliac artery.

Laparoscopic Para-Aortic Lymphadenectomy

The key to removing the para-aortic nodes successfully is proper placement of the small bowel into the upper abdomen. The mesentery of the small bowel should be identified, flipped in a cephalad direction, and splayed out across the abdomen. This will place the small bowel into the upper abdomen, exposing the para-aortic area. The Trendelenburg position, a good bowel preparation, and, occasionally, lateral tilt of the operating table assist in keeping the bowel in the upper abdomen. During this process the small bowel can be inspected for metastatic disease. The packing of the bowel is extremely important, and time should be taken to accomplish it correctly, to avoid delays later. Occasionally, additional ports may be required to keep the bowel in the upper abdomen, especially in heavier patients. Depending on its location, the transverse duodenum can often be visualized as it crosses the vena cava and aorta. Lifting the mesentery of the small bowel as it crosses the aorta will aid in visualizing the third portion of the duodenum. The aorta, the right common iliac artery, and the ureter as it crosses the right iliac vessels are landmarks that should be identified prior to beginning the dissection.

Right-Side Para-Aortic Lymphadenectomy

The surgeon, who is on the left side of the patient, performs the procedure with graspers in the lower midline port and scissors in the left lateral port. The assistant holds the camera in the umbilical port and uses graspers in the right lateral port. It is extremely important to rotate the camera so that the aorta and vena cava are horizontal on the monitor, with the patient's head to the right of the monitor.

An incision is made in the peritoneum over the aorta. This incision is extended down the right common iliac artery, to the point where the ureter crosses the iliac vessels, and up the aorta to the mesentery of the small bowel or the transverse duodenum. The peritoneum is lifted with graspers, and blunt dissection is performed laterally toward the psoas muscle. The right ureter is identified and dissected away from the underlying areolar tissue. The grasper in the midline port then retracts the ureter anteriorly, and the dissection is completed laterally until the right psoas and tendon of the psoas are completely identified.

The assistant then places his or her grasper (in the right lateral port) underneath the ureter to retract it anteriorly and laterally out of the operative field. This also creates a small tent, which helps prevent small bowel from falling into the operative field.

The surgeon then dissects the nodal and fatty tissue off the aorta by sharply developing the adventitial plane of the aorta. This dissection is continued in a cephalad and caudad direction, using the scissors and electrocautery as needed. The dissection is then continued laterally toward the psoas muscle, unroofing a portion of the vena cava. Care should be taken to avoid lacerating perforating vessels when unroofing the aorta.

The dissection is continued up the aorta and down the right common iliac artery, taking care to stay in the plane and using blunt and sharp dissection. Small vessels and lymphatic channels are easily coagulated with the scissors. Large perforating vessels from the vena cava or aorta should be clipped. We use Endoclips (US Surgical Corporation, Norwalk, CT) placed through the 10-mm port in the lower midline.

One end of the nodal bundle is then transected. We feel it is better to transect the distal end over the right common iliac artery first, to fully expose the vena cava. One may clip and cut, but it is easier and faster to transect, using short bursts of monopolar electrocautery. Once the nodal package is transected at the caudad end, it is easy to continue the dissection in a cephalad direction. The dissection is extended as far as possible or as far as necessary. The cephalad extent on the right side is usually limited by the mesentery of the small bowel or the transverse duodenum. Transection of the cephalad end is again accomplished by clipping and cutting or coagulating and cutting. The nodal tissue is extracted through the lower midline port using the spoon forceps. The operative field is irrigated, and hemostasis is secured (Figure 30.14.2).

FIGURE 30.14.2. The aorta, right common iliac artery, and vena cava are inspected for hemostasis after a low right-side para-aortic lymphadenectomy has been performed.

If the nodal tissue over the right common iliac artery is to be removed as well, this can be accomplished through the same peritoneal incision. The assistant uses his or her grasper to retract the ureter atraumatically in a caudad direction, exposing the nodal tissue over this artery and beyond its bifurcation. The nodal dissection is then continued down the common iliac vessel to the proximal internal and external iliac vessels.

This maneuver will not allow removal of obturator or distal external iliac nodes. In addition, because of the location of the mesentery of the rectosigmoid, it is not applicable to the left-side pelvic nodes.

Left-Side Para-Aortic Lymphadenectomy

The surgeon, who is on the right side of the patient, performs this procedure using instruments placed through the lower midline and right lateral ports. The assistant holds the telescope and camera through the umbilical port. The camera is rotated so that the aorta and the vena cava are horizontal on the monitor, with the patient's head to the left. The image on the monitor will be upside down for the assistant.

If the peritoneal incision has not already been made, an incision similar to that used for the right-side para-aortic lymphadenectomy is made. This incision over the aorta is extended in the cephalad direction as far as possible. The mesentery of the small bowel or the third portion of the duodenum will limit its cephalad extent. The incision is extended in a caudad direction over the proximal left common iliac artery.

The surgeon dissects in the adventitial plane of the aorta in a cephalad and caudad direction. It is important to extend the adventitial dissection as far as possible in both directions to allow ample room to safely perform the lymphadenectomy. On this side, the cephalad extent will be limited by the inferior mesenteric artery. Care should be taken to avoid injuring this artery because its origin on the abdominal aorta is often difficult to identify. The better the aorta and left common iliac are cleaned off, the more space and visibility the surgeon will have.

Only after the adventitia over the aorta has been adequately dissected free should lateral dissection toward the left psoas muscle be carried out. The surgeon can safely dissect beneath the left ureter and mesentery of the rectosigmoid by staying in this plane. This sequence differs from that of right-side para-aortic lymphadenectomy, where the lateral dissection is done after the peritoneal incision is made but before the aortic adventitia is dissected.

Lateral dissection is performed until the psoas muscle and its tendon are identified. The assistant now places the grasper or irrigator/aspirator into the dissected space beneath the mesentery of the rectosigmoid and the left ureter. This retraction is essential for adequate exposure, and exposure is mandatory because the left-side para-aortic lymph nodes in this area are lateral to the aorta.

Once adequate exposure has been created, the surgeon grasps the nodal bundle near the bifurcation of the aorta and lifts anteriorly while pushing down on the aorta with another instrument. This frees the loose attachments between these two structures and assists in dissecting beneath the nodal chain. A window is created beneath the nodal chain at its caudad end by blunt dissection. We prefer transecting the chain with scissors and electrocautery. The dissection is then extended in a cephalad direction using blunt and sharp dissection and electrocautery with the scissors as needed. The nodal chain is transected at the cephalad end near the inferior mesenteric artery. The specimen is removed through the lower midline 10-mm port, and the operative field is irrigated and inspected to confirm hemostasis (Figure 30.14.3).

Infrarenal Para-Aortic Lymphadenectomy

The vena cava and the aorta are separated from the transverse duodenum by blunt and sharp dissection. This dissection is continued in a cephalad direction, but lateral dissection is also accomplished by sweeping the laparoscopic instruments bluntly toward the psoas muscles. The assistant repositions the retroperitoneal-retracting instrument to maintain upward traction on the transverse duodenum. It is best to place a fifth port in the left upper

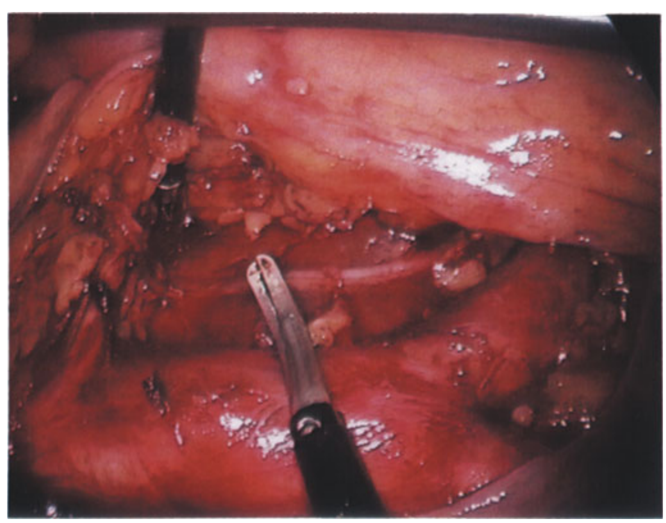

FIGURE 30.14.3. The aorta, left common iliac artery, and tissue over the psoas muscle are inspected for hemostasis after a low left-side para-aortic lymphadenectomy has been performed. Note the inferior mesenteric artery being retracted by the grasper.

quadrant through which instruments can be advanced to assist in elevation of the duodenum. With anterior retraction accomplished through the right lower quadrant and the left upper quadrant, the surgeon and assistant surgeon now face cephalad, and the monitors are moved toward the patient's head. As with the pelvic and lower para-aortic procedures, we prefer that the surgeon stand on the side contralateral to the nodes to be removed; however, this is not absolutely necessary.

After additional cephalad exposure is obtained, the nodal dissection is continued. On the right, this was simply a matter of continuing the previously performed lymphadenectomy up to the origin of the ovarian vein, which may enter the vena cava distal to or very near the left renal vein (Figures 30.14.4 and 30.14.5). On the left, the nodal chain is located laterally, and the surgeon must work around the inferior mesenteric artery. By continuing the nodal dissection caudad to the inferior mesenteric artery, enough of the nodal chain can be freed to allow completion of the dissection by working cephalad to the inferior mesenteric artery. To gain the necessary exposure, transection of the left ovarian artery is required. We accomplish this by clipping the artery with the Endoclip (US Surgical Corporation, Norwalk, CT), which we place through the midline suprapubic port. After the artery is clipped, it is cut, and the lymphadenectomy continued up to the renal vessels. The nodal bundle is transected near the left renal vein as it enters the vena cava (Figures 30.14.4 and 30.14.5).

The peritoneum is not closed, and no retroperitoneal drains are placed. The mesentery of the small bowel is

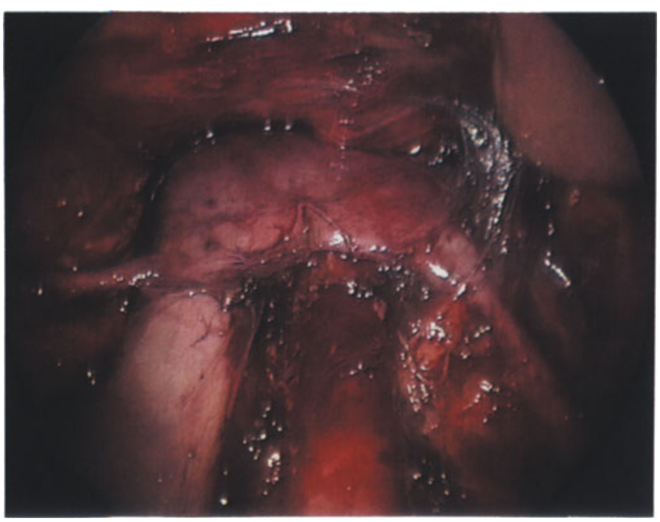

FIGURE 30.14.4. The infrarenal area is inspected after a high right-side para-aortic lymphadenectomy. Note the left renal vein crossing the aorta and entering the vena cava and the left ovarian vein entering the left renal vein. The right ovarian vein enters the vena cava near the left renal vein.

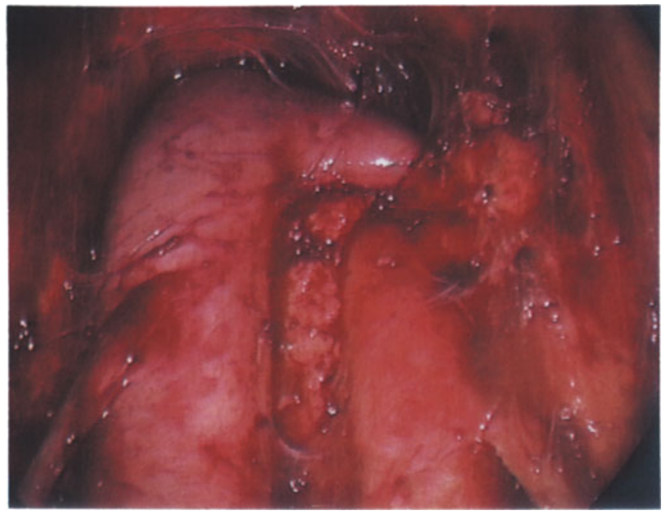

FIGURE 30.14.5. The infrarenal area is inspected after a high right-side para-aortic lymphadenectomy has been performed. Note the right ovarian vein entering the vena cava below the left renal vein. The inferior mesenteric artery can be seen exiting the aorta in the lower right portion of the picture.

repositioned over the para-aortic incision site at the end of the dissection. Patients undergoing laparoscopic surgery only are given a regular diet on the day of the procedure.

Special Considerations

Cervical Cancer

In our practice, patients with cervical cancer who are undergoing this procedure fall into two categories. First, are those patients with early or advanced cervical cancer who are to be primarily treated with radiotherapy. Their radiation fields are based on the findings at surgical staging. The second group consists of patients who have received external radiotherapy to the whole pelvis and are now being admitted for transperineal interstitial needle implant. In this group of patients, we perform a laparoscopic right and left para-aortic node dissection and then assist laparoscopically in the transperineal needle placement. Following this, using the laparoscope, we create an omental carpet for the protection of pelvic organs.

In both groups of patients we remove the proximal common and low para-aortic nodes. In addition, many of these patients require simultaneous cystoscopy, proctoscopy, and examination under anesthesia. These procedures should be performed prior to the lymphadenectomy, but care should be taken to evacuate as much of the air placed in the rectosigmoid as possible. An air-filled rectosigmoid can make the lymphadenectomy difficult.

Second-Look Laparoscopy for Ovarian Cancer

Prior to performing lymphadenectomy on patients with ovarian cancer, the intraperitoneal cavity should be carefully evaluated. Adhesiolysis may be required after surgical debulking for adequate evaluation of areas of known prior or residual disease. This may be extensive in some patients. If there is no obvious evidence of disease, then washings are taken from the pelvis, the right and left paracolic gutters, and the right hemidiaphragm, and multiple intraperitoneal biopsies are taken as well. Any remaining omentum is removed or biopsied. Special attention is devoted to evaluation of the right hemidiaphragm. The optics and magnification of modern cameras offer a unique opportunity to evaluate this high-risk site. If the liver is pushed down with the telescope and the table is placed in left lateral tilt with the patient's feet down, the view of the diaphragm is quite different from that obtained during laparotomy. We have found that laryngeal biopsy forceps work quite nicely to biopsy the diaphragm.

If all intraperitoneal specimens prove to be negative, then we perform a lymphadenectomy. The lysis of adhesions previously performed to evaluate the intraperitoneal cavity now allows proper placement of the bowel into the upper abdomen. There will be patients in whom adhesions prevent an adequate second look. On the other hand, in our first 30 patients, positive nodes were found in more than 50%.

Primary Staging of Ovarian Carcinoma

In patients with presumed stage-I ovarian carcinoma, primary staging of the disease is possible. Multiple washings should be taken from the intraperitoneal cavity as well as multiple biopsies from the pelvis and upper abdomen. As when performing second-look laparoscopy, careful attention is paid to the right and left hemidiaphragms. In addition, omentectomy and pelvic and para-aortic lymphadenectomy are performed. Thus far, our patients have had unilateral tumors, and therefore unilateral pelvic and para-aortic lymphadenectomy has been performed. In these instances we perform an infrarenal para-aortic node dissection (Figures 30.14.4 and 30.14.5).

Endometrial Cancer

Patients with stage-I endometrial cancer may be managed with a combined laparoscopic and vaginal approach. The laparoscopically assisted surgical staging procedure (LASS) includes intraperitoneal washings, lymphadenectomy, and a laparoscopically assisted vaginal hysterectomy. Preoperatively these patients receive intravenous prophylactic antibiotic therapy. They are placed in a dorsal lithotomy position with their knees out of the laparoscopist's way. A uterine manipulator is placed to facilitate the laparoscopically assisted vaginal hysterectomy. Hemoclips are placed across the fallopian tubes to prevent tumor spill during the procedure. Pelvic washings are taken, and the entire peritoneal cavity is carefully inspected in the systematic fashion previously described. We found evidence of extrauterine disease in 8 of our first 61 patients, or 35% (8/23) of those patients with grade-2 and grade-3 lesions.[9] We ligate and transect the infundibulopelvic ligament prior to the lymphadenectomy in these patients. This is particularly helpful for gaining access to the common iliac nodes, especially on the left side. The surgeon must be familiar with the suturing and stapling techniques discussed in Chapters 4 and 5.

Whether we perform lymphadenectomy on these patients depends on the grade of the tumor and the depth of invasion. Patients with well-differentiated tumors with less than 50% myometrial invasion do not have lymphadenectomies. Obesity prevented para-aortic lymphadenectomy in only two patients who met these criteria.

Conclusion

Operative laparoscopy in the subspecialty of gynecologic oncology is still in its infancy, but the ability to perform laparoscopic para-aortic lymphadenectomy will undoubtedly entice many gynecologic oncologists to consider an operative laparoscopic approach for some of their patients. The role laparoscopic lymphadenectomy will play in managing patients with gynecologic malignancies has yet to be determined. The Gynecologic Oncology Group (GOG) has initiated pilot studies of the laparoscopic approach in patients with cervical and endometrial malignancies. These studies and others may assist in determining the role of this technique in our armamentarium. Our initial work demonstrates the feasibility, limitations, and safety of laparoscopic para-aortic lymphadenectomy even for nodes above the inferior mesenteric artery. We are concerned that our low complication rate may not be equalled when this technique is used in group-wide studies if the surgery is not performed by two experienced gynecologic-oncology laparoscopists. This issue and many others remain to be resolved.

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31
Urology

31.1 Urinary Tract Stones

Gary C. Bellman and Arthur D. Smith

Introduction

Laparoscopy has had a significant impact on urologic surgery over the last several years, as it has expanded from diagnostic applications to extirpative ones and, most recently, to reconstructive procedures. It is routinely used in the management of children with nonpalpable testes.[1] The finding of a blind-ending vas deferens and spermatic vessel is pathognomonic for absence of the testis, thus making surgical exploration unnecessary. Laparoscopic sampling of the lymph nodes can be very useful in the staging of selected patients with genitourinary cancer.[2] Many renal procedures have been performed laparoscopically as well, including both partial and total nephrectomy[3,4] and excision or marsupialization of renal cysts and collecting system diverticula.[5] More challenging reconstructive procedures, such as ureteroureterostomy,[6] ileal conduit construction,[7] bladder neck suspension,[8] and dismembered pyeloplasty[9] have also been accomplished. Most recently, laparoscopy has proved to be helpful in the management of complex stones of the urinary tract.

Historical Perspective

A technologic revolution in the management of urinary stones occurred with the advent of percutaneous stone extraction, which allowed removal of large stone fragments through a small flank incision. Ultrasonic lithotripsy has proved to be most effective in fragmenting stones to a size that permits extraction. This procedure is associated with dramatically lower morbidity than the open counterpart, anatrophic nephrolithotomy,[10] which involves splitting the kidney in two to remove the stones and is rarely performed today. The next important technologic breakthrough in the management of urinary tract stones was extracorporeal shock wave lithotripsy (ESWL), which uses focused shock waves generated outside the body to pulverize urinary tract stones. Since ESWL was introduced in the United States in 1984, various new machines have appeared, including some that offer both fluoroscopy and ultrasonography for stone localization and others that have a variable-power generator that allows stones of different hardnesses to be fragmented.[11] The most recent advance is ureterorenoscopic stone removal. These small-caliber semirigid instruments equipped with fiberoptic imaging and laser or electrohydraulic lithotripsy have proved extremely useful in managing ureteral and even renal stones.[12,13]

Nearly all patients with stone disease can be successfully treated with one or a combination of these methods. Those few patients whose stones are refractory to contemporary forms of management are treated by open surgery. It is this group of patients who may be offered laparoscopic stone surgery as a minimally invasive alternative.

Laparoscopic Ureterolithotomy

The concept of laparoscopic ureterolithotomy is not entirely new. In 1979, Wickham performed retroperitoneoscopy for a ureteral stone.[14] In 1985, Clayman and associates described a percutaneous ureterolithotomy for the management of a stone in a diverticulum located in the proximal ureter.[15] With the aid of a C-arm fluoroscope, a translumbar aortography needle was positioned adjacent to the stone, and dilation of the needle tract was accomplished with the Amplatz system. This was also retroperitoneoscopy, but a nephroscope was used instead of a laparoscope and irrigating fluid instead of CO_2 insufflation.

Several other laparoscopic procedures for the ureter have also been described. These include: ureterolysis for the management of retroperitoneal fibrosis;[16] the ureterectomy portion of a nephroureterectomy;[17] and ureteroureterostomy for relief of obstruction by pelvic endometriosis.[6]

The most frequent indication for laparoscopic stone surgery of the urinary tract is a recalcitrant ureteral stone: a very hard impacted stone that cannot be fragmented by ESWL or removed by ureteroscopy. As is true of all laparoscopic procedures of the urinary tract, two approaches exist: transabdominal and retroperitoneal. Much of the initial experience with laparoscopic surgery of the ureter was gained transabdominally. A pneumoperitoneum was established, the colon was reflected, and the involved retroperitoneal area and ureter were exposed. There are, however, distinct advantages to a retroperitoneal approach: (1) it avoids intra-abdominal maneuvers, with their inherent risk of visceral injury; and (2) there is less dissection, because incision of the peritoneum and mobilization of the intra-abdominal organs are not necessary.

Several technical points about laparoscopic ureterolithotomy warrant emphasis. First, a radiolucent table is necessary. Second, the best position for the patient depends on the location of the stone. For stones in the proximal ureter, the flank position is recommended. During ureterotomy for such stones, there is a greater risk that the upper coil of the double-pigtail stent will buckle out of the ureteral incision because the guidewire above it is too short. A stiff guidewire should be coiled in the renal pelvis and kept taut to avoid this disastrous complication. In managing stones in the middle or distal ureter, the dorsal lithotomy position is preferable. However, if a flexible cystoscope is available, adequate access to the bladder can be obtained with the patient in the supine position. Tilting the table laterally will cause the intra-abdominal contents to fall away from the side of interest. Third, for distal stones, the peritoneal reflection should be incised just medial to the medial umbilical ligament. Finally, stones lodged in the intramural ureter should be dealt with transcystoscopically, with an adjunctive ureteral meatotomy if necessary, because they are difficult to approach laparoscopically.

Gaur has developed a novel method of establishing an effective CO_2 pneumoretroperitoneum that allows access to the ureter and other retroperitoneal structures.[18] The patient is placed in a prone position, a 2-cm incision is made superior to the iliac crest in the midaxillary line, and the retroperitoneal space is bluntly entered. Gaur then inserts a dissecting-balloon device he has developed to detach the dense retroperitoneal areolar tissue that normally limits insufflation of this space. The device is composed of a latex surgeon's glove attached to the pneumatic pump of a standard hand-operated sphygmomanometer by an 8F red rubber Robinson catheter; it is inflated in the retroperitoneum until an abdominal bulge is apparent. The balloon is deflated after five minutes, and a 10-mm trocar is placed in the enlarged retroperitoneal space. Carbon dioxide is insufflated, keeping the retroperitoneal infusion pressure below 10 mm Hg. The laparoscope is inserted through the trocar, and working trocars are placed just below the posterior aspect of the twelfth rib and in the area of the anterior axillary line. Gaur finds that this technique provides excellent exposure of the ureter and reports impressive results for several laparoscopic ureterolithotomies. His operations were performed at a medical center in India, however, where most patients have a lean body habitus and less areolar tissue in the retroperitoneal space. Investigators in the United States have found the Gaur technique challenging in obese patients.

What follows is a description of the authors' techniques for transabdominal laparoscopic ureterolithotomy in cases of distal and proximal stones.[19]

Removal of a Distal Ureteral Stone

Caphazolin (1 g) was given intravenously 30 minutes before the procedure. The guidewire was secured to a Foley catheter, and the patient was placed in the dorsal lithotomy position on a radiolucent table with the stirrups slightly lower than usual. Pneumatic compression stockings were applied, and the entire abdomen, as well as the guidewire and Foley catheter, was prepared with povidone iodine.

Through a 5-mm incision in the inferior crease of the umbilicus, the Veress needle was inserted into the peritoneal cavity, and a pneumoperitoneum of 15 mm Hg was created by CO_2 insufflation. A 10-mm trocar was placed in the umbilical site for the camera, and a second 10-mm trocar was inserted suprapubically. Two additional 5-mm trocars were positioned lateral to the epigastric vessels on the left, all trocars except the first being placed under direct laparoscopic monitoring. The patient was then moved to the Trendelenburg position in lateral rotation with the left (operative) side up, and the video screen was arranged at the foot of the operating table.

A ureterolithotomy procedure has three parts: (1) reflection of the colon; (2) dissection of the ureter; and (3) extraction of the stone followed by insertion of a ureteral stent. In the present case, the left colon was retracted medially, and an incision was made along the white line of Toldt. The dissection was continued to just below the splenic flexure. The spermatic vessels were then seen crossing the ureter and could be followed into the internal inguinal ring (Figure 31.1.1). These vessels were retracted laterally, and the ureter was identified.

The stone made an obvious bulge in the ureter, and its presence was confirmed by the gritty texture when an instrument was rubbed over it. A longitudinal 8-mm ureterotomy was made with scissors, and the stone was extracted, the instrument blades being used to life the stone out while forceps prevented it from moving away from the incision (Figure 31.1.2). The guidewire, which was still sterile, was used to pass a double-pigtail stent into the

FIGURE 31.1.1. Spermatic vessels are seen coursing anterior to ureter after medial reflection of left colon.

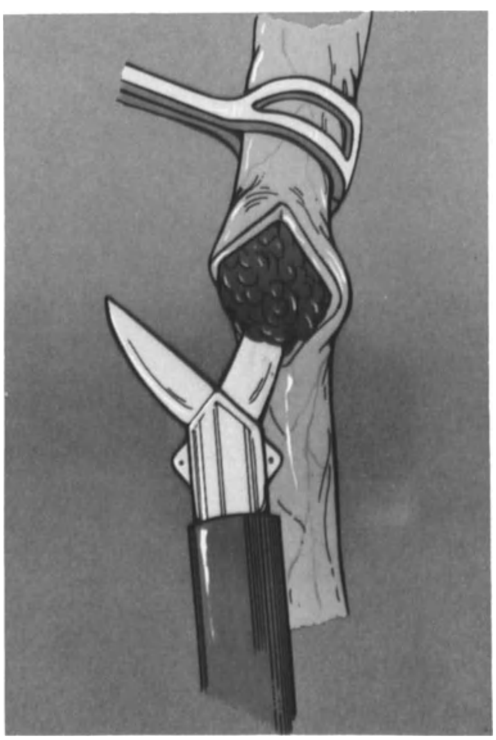

FIGURE 31.1.2. Blades of scissors lifting stone out of ureterotomy.

kidney. Because the ureterotomy was so short, we elected not to suture it.

Removal of a Proximal Ureteral Stone

With the patient in the lithotomy position, a guidewire was maneuvered past the stone into the renal pelvis and secured to a Foley catheter below. The patient was positioned in the lateral oblique position, the same used for laparoscopic nephrectomy as in reference 20. To obtain the oblique aspect of the position, the patient was rolled while in the lateral position. The beanbag was used to maintain this orientation. The patient was positioned on the beanbag and when the desired position was achieved, air was aspirated from the bag, "locking" the position of the patient. The patient was then placed in the lateral position and rolled backward slightly, onto the support of a beanbag, with his abdomen near the edge of the radiolucent operating table. This position provides room to manipulate the camera and instruments. We use the same position for laparoscopic nephrectomy.[20] The patient's ipsilateral arm was fixed to an ether screen, and an axillary roll was placed under the contralateral arm. The contralateral knee was flexed 30°, and the ipsilateral leg was straight. A pillow was placed under the knees. The video screen was at the head of the operating table.

A Veress needle was inserted just lateral to the ipsilateral rectus sheath at the level of the umbilicus. After an adequate pneumoperitoneum had been established, a 10-mm trocar was positioned at the umbilicus, and another was positioned subcostally in the anterior axillary line. Two 5-mm trocars were placed over the kidney laterally in the posterior axillary line.

The right colon was retracted medially, and the peritoneum was incised as far as the hepatic flexure. The duodenum was kocherized, revealing the kidney. Gerota's fascia was incised, and the perinephric fat was dissected off the lower pole of the kidney. The lower pole could then be lifted anteriorly to reveal the proximal ureter. The surrounding tissue was dissected off the ureter, a 9-mm longitudinal incision was made, and the stone was removed. The guidewire became visible coursing upward in the ureter. The patient was returned to the lithotomy position in order to pass a double-pigtail stent, which was left in place for four weeks. Again, we elected not to close the ureterotomy, because we thought that the internal stent would allow the defect to close spontaneously.

To Close or Not to Close?

Even in open ureterolithotomy, a watertight closure is not always required, and placement of interrupted adventitial sutures is adequate. As noted, we did not suture the ureterotomies. However, when Raboy and coworkers performed laparoscopic ureterolithotomy, they placed a few intracorporeal sutures in the ureteral incision.[21]

An argument can be made for closing the peritoneum; this could have been accomplished easily with a hernia stapler. Both of our patients had sterile urine preoperatively, and the small amount of urine that may have leaked out with the stent in place would have been resorbed quickly with little, if any, peritoneal irritation. Thus, we elected not to leave any drains. However, if an extended ureterotomy were necessary, or if the tissues were friable, it would be prudent to leave a drain and close the peritoneum. Our approach was satisfactory; both of our patients did well and showed no evidence of ureteral stricture or leak at six-month follow-up.

Additional Technical Points

The ureterotomy should be longitudinal; Cohen and Persky[22] showed there is less risk of disrupting the ureteral blood supply if the incision is longitudinal rather than transverse. The same consideration makes it preferable to avoid cautery in the ureter.

At present, a laparoscopic ureterolithotomy should not be attempted unless a guidewire or catheter is in place beyond the stone. It is essential to maintain control of the ureter so that an internal stent can be passed after the procedure, and if the ureterotomy is very large, placing a wire laparoscopically is too challenging. As the ease and precision of intracorporeal suturing improve, the indications for laparoscopic ureterolithotomy may expand to include stones that do not permit a guidewire to pass.

Laparoscopic ureterolithotomy is an important advance in urologic surgery. It is a challenging procedure, and should be attempted only by urologists with considerable laparoscopic experience. Although the indications for it are limited, it can spare some patients with a ureteral stone that fails to respond to other forms of treatment an open operation. Laparoscopic ureterolithotomy may also be indicated when laparoscopy is to be performed for another reason, such as decorticating a complex renal cyst. As further experience is gained, new applications can be expected to emerge.

Laparoscopic Surgery for Renal Calculi

Three types of laparoscopic surgery have been described for renal calculi: (1) percutaneous stone extraction from pelvic kidneys; (2) nephrectomy for a staghorn calculus in a nonfunctioning kidney; and (3) partial nephrectomy for a stone in a caliceal diverticulum of an atrophic lower pole. At present, these techniques are experimental rather than standard, but that can be expected to change.

Percutaneous Transperitoneal Approach to the Pelvic Kidney

The retroperitoneal pelvic kidney has always presented a special challenge. These kidneys are prone to stone formation, but removing the stones with contemporary lithotomy methods is often difficult or inappropriate. Bowel loops intervene between the abdominal wall and the kidney, interfering with percutaneous access, and although ESWL will fragment most of the stones, the anatomic peculiarities of the kidney often prevent discharge of the fragments.

We have used a laparoscopically assisted percutaneous approach to remove stones in three patients with pelvic kidneys, succeeding in two cases.[23] The patients were given a complete bowel preparation and intravenous antibiotics. After induction of general endotracheal anesthesia, they were placed in the dorsal position. A cystoscopic examination was performed, and the ureteral orifice on the affected side was identified. Under fluoroscopy, a preshaped guidewire and long 5F open-ended catheter sheathed in a preshaped 9F Teflon catheter was passed into a middle calix. The 5F catheter and guidewire were then removed, and in their place, a long 5F catheter carrying a hollow 160-cm 20-gauge needle (a Hunter-Hawkins retrograde percutaneous nephrostomy needle) intubated with a thin rocket guidewire was inserted. This needle tends to position itself in one of the fornices; when advanced, it will exit from the middle of the papilla. It was advanced into but not through the parenchyma of the kidney.

At this point, the anterior abdominal wall was prepared and draped, and the patient was placed in the Trendelenburg position to displace the bowel loops cephalad. An incision was made in the lower border of the umbilicus for insertion of an 11-mm trocar. A CO_2 pneumoperitoneum was created using either a Hasson-Eder cannula or a Veress needle, and an 11-mm trocar was inserted, through which a laparoscope was introduced into the abdominal cavity. Under direct vision, a separate stab wound was created to allow the passage of a 5-mm trocar into the lower quadrant on the affected side. This was followed by the passage of a probe through the 5-mm trocar cannula, which was used to manipulate the intestinal loops until the kidney became visible.

Under laparoscopic observation, the Hunter-Hawkins needle was advanced through the kidney until the needle exited from the surface of the renal parenchyma. The needle was then grasped by forceps inserted through the 5-mm cannula and pulled out of the abdominal cavity (Figure 31.1.3). The rocket guidewire and 5F catheter followed the Hunter-Hawkins needle naturally as it surfaced through the anterior abdominal wall. The 9F catheter could then be advanced over the 5F catheter. The needle

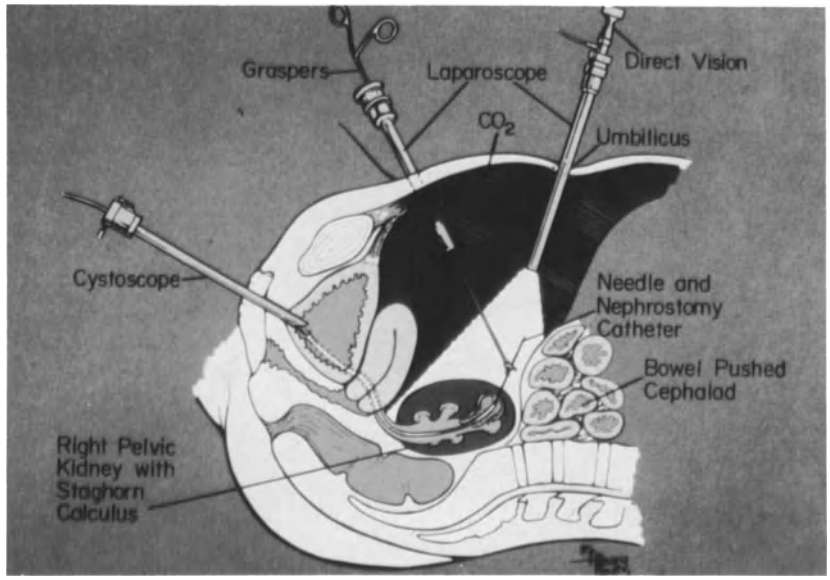

FIGURE 31.1.3. Percutaneous access to pelvic kidney using a combination of retrograde and laparoscopic techniques.

and rocket guidewire were then removed, leaving a tract from the urethral meatus to the anterior abdominal wall that was bridged by the 5F and 9F catheters. A working guidewire was inserted through the 5F catheter, and a second (safety) guidewire was inserted through the 9F catheter. The two catheters were then removed.

Over the working guidewire, the nephrostomy tract was dilated under fluoroscopic guidance using the Amplatz system until the tract admitted a 34F sheath. A nephroscope was introduced into the renal pelvis through this sheath, and the stones were located and removed with a combination of ultrasonic lithotripsy and mechanical extraction. A 24F re-entry nephrostomy tube was inserted over the working guidewire and positioned with its distal segment in the ureter and its open flanges in the renal pelvis. Proper positioning was confirmed with a nephrostogram. Free fluid in the peritoneal cavity was suctioned out with the laparoscope, and a Jackson-Pratt drain was placed intraperitoneally through the umbilical incision.

Nephrostograms were performed two days postoperatively. The Jackson-Pratt drain was removed on day 2, and the nephrostomy tube on day 3. Both patients in whom the procedure could be completed were free of stones.

Schichman and associates have also described laparoscopic pyelolithotomy in a patient with a 1.5-cm renal calculus in a pelvic kidney.[24]

Total or Partial Nephrectomy for Stone Disease

Clayman and associates did much of the work that refined the technique of laparoscopic nephrectomy.[3,25–27] The benefits for the patient are less postoperative pain and a more rapid return to regular activity. The authors have successfully performed laparoscopic total nephrectomy for symptomatic kidney stones in a poorly functioning or nonfunctioning kidney.

Winfield and associates performed a laparoscopic partial nephrectomy in a patient with calculi in a caliceal diverticulum of an atrophic lower renal pole.[4] This patient had undergone nephrostolithotomy and fulguration of the diverticulum three years earlier, but the problem had returned. Vascular control was not obtained for dissection of the renal hilum. A specially designed tourniquet was placed around the lower pole, the parenchyma was cut with electrocautery, and the argon-beam laser was used for further hemostasis. Perirenal fat and renal capsule were used to cover the denuded renal surface. The colon was reperitonealized after a Penrose drain had been placed in the retroperitoneum. An intravenous urogram two months later demonstrated a satisfactory result.

Laparoscopic Approach to Bladder Stones

Laparoscopic surgery has limited use for bladder calculi, largely because lithotripsy for transurethral use is highly effective. However, a bladder diverticulum with a narrow neck has been dealt with laparoscopically.[28]

Conclusion

New indications for laparoscopy continue to be described, and the instrument has certainly altered the manner in which we approach urologic problems. Laparoscopic procedures are appropriate in some patients with particularly complex stone disease. Because such procedures are generally lengthy and technically demanding, they should be attempted only by those surgeons with particular facility in laparoscopy. As new techniques are described, their cost-effectiveness and benefit to the patient should be critically assessed.

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31.2 Laparoscopic Varicocele Ligation

Greg O. Lund, James F. Donovan, Jr., and Howard N. Winfield

Varicocele, an abnormal dilation and tortuosity of the veins composing the pampiniform plexus, affects approximately 15% of adult men.[1] We will present the etiology of varicoceles, the indications and options for repair, and a review of laparoscopic varicocele ligation.

The cause of varicocele is not fully understood, but it may be due in part to anatomic differences between the testicular (internal spermatic) venous drainage of the right and left gonadal veins. The left testicular vein typically drains into the left renal vein, whereas the right testicular vein empties directly into the inferior vena cava. This results in a hydrostatic pressure difference; the pressure in the left testicular vein is typically 8 to 10 cm H_2O greater than that in the right.[2]

Additional anatomic factors that may contribute to the formation of a varicocele include the absence of venous valves, and external compression of the left renal vein between the aorta and the superior mesenteric artery—the so-called nutcracker syndrome—which leads to increased pressures within the left spermatic vein.[2–4]

Unilateral right-sided varicocele is rare (2%), and its presence should prompt further investigation to rule out inferior vena caval obstruction or situs inversus.[5,6]

Above the level of the internal inguinal ring, the increased hydrostatic venous pressure is transmitted through two or three major testicular venous trunks, which can be complex and which communicate with other venous systems, including the renal capsule, sigmoid colon, and iliac veins.[7] These are also complex and have myriad intercommunications to other intermediate veins.[8] Distal to the internal ring, four or more venous channels may be present, and the internal spermatic vein may communicate with the cremasteric, deferential, hypogastric, and external iliac veins.[8] Within the scrotum, the venous system exists as the pampiniform plexus, which, when a varicocele is present, may take on the tactile quality of a bag of worms.[9]

The relation between varicocele and subfertility has been recognized for many years.[10] Clearly, the majority of men with a varicocele are not infertile, but 30 to 40% of men evaluated at infertility clinics demonstrate a varicocele, and it is the most common surgically correctable cause of male infertility.[11] Varicocele is associated with decreased sperm motility, which is found in 90% of patients. Sperm densities of less than 20×10^6 sperm/mL are seen in 65% of patients and of less than 9×10^6 sperm/mL in 42% of patients. Additionally, increased numbers of amorphous cells, immature germ cells, and tapered forms are seen, findings called the stress pattern.[12] These findings are nonspecific, however, and are also associated with other types of male infertility.

The pathophysiology of infertility in men with varicocele is not fully understood. Possible mechanisms include reflux of venous blood (with renal and adrenal metabolites) back toward the testicle, increased testicular temperature due to blood pooling, and decreased arterial inflow secondary to increased venous pressure.[13,14] In experimental models, ligation of the spermatic veins results in the return of normal blood flow and temperature.[10] The basis for subfertility in these patients may be Leydig cell dysfunction.[15]

Clinical varicoceles are detected by means of scrotal examination in the standing position. The valsalva maneuver will accentuate the dilation of the pampiniform plexus. Some suggest confirmatory radiologic studies, such as spermatic vein venography, real-time ultrasonography, isotope scans, or high-resolution color Doppler ultrasound, and others use scrotal thermography.[16] There is currently no strong evidence in favor of treatment of subclinical varicoceles, that is, those diagnosed only by imaging techniques such as spermatic venography or color Doppler ultrasound.

Treatment of varicoceles is indicated when subfertility exists and no other cause can be identified. Treatment in adolescence may be indicated when there is ipsilateral testicular growth retardation.[10,17] Symptomatic varicoceles manifested by testicular pain and aching may require intervention when conservative measures fail.

Treatment of varicocele for infertility is often rewarding. Ultimate success, as measured by pregnancy rates, varies from 24 to 53%.[1] In a review of several series by Marks and colleagues, 71% of patients had an improvement in semen parameters, and the average pregnancy rate was 37%.[18] Nearly all patients had an improvement in sperm motility and about half had an increase in sperm density.[19,20] To date it is difficult to predict which patients will respond to varicocelectomy. Neither large nor bilateral varicoceles seem to predict low pregnancy rates, but patients with higher preoperative sperm density or sperm motility have higher subsequent pregnancy rates.[18] Thus, although not all infertile patients will benefit from treatment of a varicocele, assuming other causes of infertility have been ruled out, correction of the varicocele appears to be the most reasonable approach.

Treatment Options

Once the decision to treat a varicocele has been made, a number of options are available (Table 31.2.1). The goal of all procedures is to ablate the dilated pampiniform plexus by interrupting the hydrostatic column within the internal spermatic vein. Both the surgical and percutaneous techniques reflect the venous anatomy of the testis. Surgical interruption can be accomplished by inguinal (Ivanissevich and Gregorini), retroperitoneal (Palomo), and subinguinal (Marmar) approaches.[21–23]

The inguinal approach is the preferred method of most urologists in the United States, because this anatomy is quite familiar.[24] Fewer venous tributaries are encountered at this level than more distally. Unfortunately, this dissection requires division of the cremasteric muscle and mobilization of the vas deferens, risking injury to the collateral arteries supplying the testis: the cremasteric and deferential arteries. Most surgeons using this approach also attempt to spare the testicular artery, which should be isolated prior to the ligation of any veins.

The retroperitoneal approach is also popular. At this level one encounters only two or three major veins coursing parallel to the testicular artery. The vas deferens, cremasteric muscle, and their associated arteries all lie caudal to the level of this dissection and are in no danger of injury. At this level, the testicular artery is usually readily identified and preserved.

TABLE 31.2.1. Treatment options for varicoceles.

Percutaneous transvenous radiological
Embolization coils or balloons
Sclerosing agents
Open surgical
Inguinal (Ivanissevich and Gregorini)
Retroperitoneal (Palomo)
Subinguinal (Marmar)
Laparoscopic surgical

The subinguinal approach to varicocele involves a high scrotal incision followed by ligation of all branches of the pampiniform plexus. Magnification is required for the dissection of this "bag of worms" to identify the testicular artery and to ensure interruption of all venous tributaries. The failure to interrupt the tributaries may result in varicocele recurrence.

Percutaneous occlusion of the testicular veins is typically performed via the femoral or internal jugular vein.[8,25] This procedure requires the skill of a radiologist knowledgeable in the use of detachable balloons, coils, or sclerosing agents. In the five largest published series on percutaneous occlusion, embolization succeeded in only 78% of cases (1,469 of 1,894).[8] Success rates for right-sided varicoceles were much lower, primarily due to difficulties in cannulating the right testicular vein. Disadvantages of the radiologic approach include possible coil migration and exposing a subfertile individual to radiation. More importantly, not all medical centers have interventional radiologists skilled in these techniques. Percutaneous treatment of varicoceles is a viable option that should be discussed with the patient, but it is probably best reserved for those few patients who have a recurrent or persistent varicocele after surgery.

Laparoscopic Treatment of Varicocele

The indications for laparoscopic varicocele ligation are identical to those for the open surgical or percutaneous approaches. They are a clinically evident varicocele and one of the following: male factor infertility; adolescent testicular growth retardation; or testicular pain refractory to conservative management.

The anatomy of laparoscopic varicocelectomy is similar to that of the retroperitoneal approach, where the testicular veins are ligated above the level of the internal ring. At this level the cremasteric and deferential arteries are out of the field of dissection, and the internal spermatic artery can be spared in the majority of cases.

A thorough history is taken and all patients undergo a physical examination, with particular attention to previous abdominal surgery that may increase the difficulty of the laparoscopic procedure and the risk of complications. Patients are informed of the different surgical and percutaneous treatment options, including their risks and benefits. They are also informed of the possibility of conversion to an open procedure if technical difficulties occur. Formal bowel prep is not required. The operation is performed as an outpatient procedure.

All patients receive a general anesthetic and the abdomen and genitalia are prepared and draped aseptically. The patient is secured to the operating table with wide adhesive tape, and the arms are tucked to the side to allow more room for the surgeon to maneuver. The table is placed in a 10 to 15° Trendelenburg position. The bladder is decompressed with a Foley catheter, and a nasogastric tube is placed if gastric distension is noted.

Pneumoperitoneum is established using either the Veress needle or an open Hasson cannula at the level of the umbilicus. The latter method is especially useful in patients who have undergone previous intraperitoneal procedures, because it avoids the risk of visceral or vascular injury associated with blind needle placement. After an adequate pneumoperitoneum is established and the laparoscope is advanced into the peritoneal cavity, additional trocar-sheath units are placed under direct laparoscopic vision. An initial insufflation pressure of 20 mm Hg allows introduction of trocar-sheath units through a more rigid abdominal wall, decreasing the chance of injury to underlying structures. After the trocars are in place, the insufflation pressure can be lowered to 12 to 15 mm Hg without compromising the exposure of the spermatic vessels. For a unilateral left varicocele, the first working port is established in the left lower quadrant lateral to the rectus sheath and above the iliac crest. A second 10-mm port may be placed in the midline, two to three fingerbreadths above the pubis; alternatively, this second port may be placed in the right lower quadrant in the mirror position to the port in the left lower quadrant. The latter configuration is ideal for bilateral varicoceles. The primary surgeon stands on the side of the patient contralateral to the varicocele (Figure 31.2.1).

The next step is to identify anatomic landmarks. The internal ring is identified; the vas deferens and spermatic vessels are visible under the translucent posterior peritoneum. Occasionally the sigmoid colon overlies the left internal ring or the testicular vessels and must be deflected. The vas deferens exits the internal ring and courses medially and posteriorly to join the seminal vesicles behind the bladder. The spermatic vessels course cephalad from the ring (Figure 31.2.2). Manual traction on the testicles may aid in the identification of these vessels.

A 3- to 4-cm incision is made in the peritoneum lateral to the spermatic vessels, 3 to 5 cm cephalad to the internal ring. This incision is made into a T by incising a cross bar medially toward the iliac vessels (Figure 31.2.3). The entire vascular bundle is gently isolated from the underlying psoas muscle. The bundle, which now contains the testicular artery and veins, is divided into a medial and a lateral portion. The most demanding and time-consuming aspect of this procedure is isolation and preservation of the spermatic artery. Identification of this thick-walled, pulsatile structure is aided by application of 1 to 2% lidocaine or papaverine solution, which relieves spasm of the artery. We always use a 5-mm laparoscopic Doppler probe, which allows the artery to be identified even in spasm.

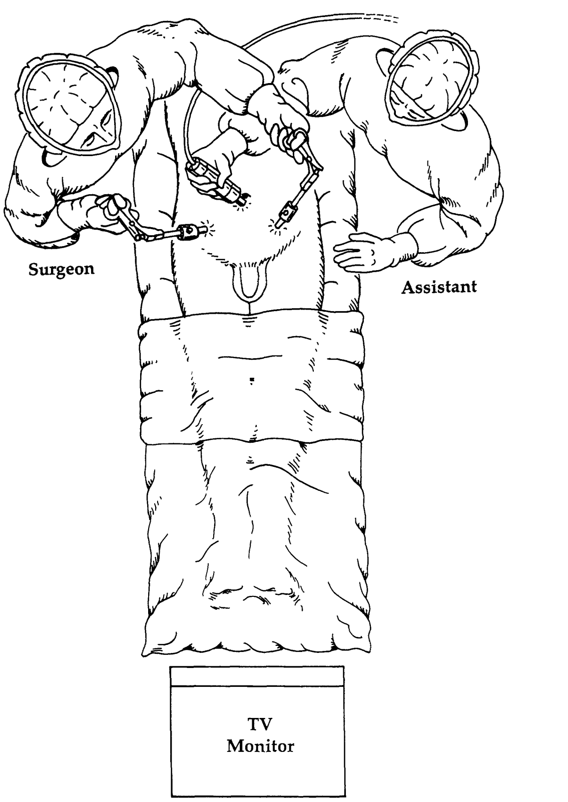

FIGURE 31.2.1. Lateral position of working ports (5- and 10-mm) and umbilical port for laparoscope. The surgeon stands on the side contralateral to the varicocele.

Once the location of the artery has been confirmed, the nonpulsatile bundle is clip-ligated and divided. Larger veins in the remaining bundle are carefully dissected away from the artery and clip-ligated as well.

Initially, we found the Nd:YAG contact laser probe well suited to carefully dissecting and ablating the small venules that frequently course along the artery.[26] Failure to divide these small vessels is thought to be a cause of varicocele recurrence. However, one patient developed a bleed 21 days postoperatively. On exploration, he was found to have pulsatile bleeding from a hole on the lateral aspect of the testicular artery. Because of the delayed onset of bleeding we felt it may have been due to thermal injury of the arterial sidewall by the laser probe. Thermal injuries to bowel or vessels may not be evident at operation. Their delayed presentation presumably follows protein denaturation, and, during the repair phase, an inflammatory response that further weakens the tissue.

All veins are divided, until the testicular artery alone remains (Figure 31.2.4). Completion may be confirmed by applying gentle traction on the testicle while observing the area of the vessels laparoscopically. If bilateral varicoceles exist, the procedure is repeated on the contralateral side.

Upon completion of the procedure, the abdominal con-

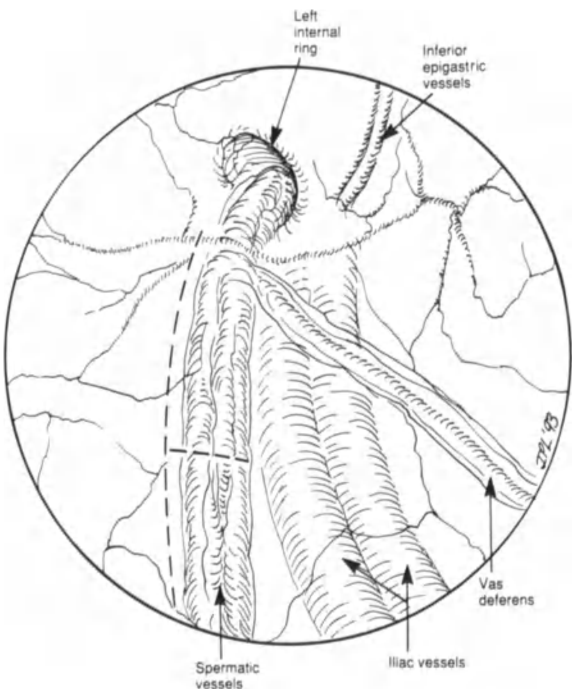

FIGURE 31.2.2. Anatomic landmarks for left laparoscopic varicocele ligation. Dotted lines represent the site of incision in the posterior peritoneum. (By permission of JF Donovan, *Atlas of the Urologic Clinics of North America* 1:2, W.B. Saunders, 1993.)

FIGURE 31.2.3. With the spermatic vessels exposed, a T incision is made in the posterior peritoneum. (By permission of JF Donovan, *Atlas of the Urologic Clinics of North America* 1:2, W.B. Saunders, 1993.)

FIGURE 31.2.4. All spermatic veins are clipped and divided, leaving only the internal spermatic artery. (By permission of JF Donovan, *Atlas of the Urologic Clinics of North America* 1:2, W.B. Saunders, 1993.)

tents are inspected for injury and to ensure hemostasis has been achieved. Trocar sites are individually inspected during withdrawal. The 10-mm sites are closed with absorbable suture after desufflation of the pneumoperitoneum. The Hasson site is close with previously placed stay sutures. The Foley catheter is removed during reversal of the anesthetic.

Diets are advanced as tolerated and most patients are discharged on the day of surgery. Pain is typically minimal and easily managed with acetaminophen and codeine. Patients are allowed to resume regular activity as tolerated.

Results

As of February 1994, 93 laparoscopic varicocele ligations had been performed on 66 patients. Of these, 27 patients (41%) had bilateral varicoceles. The indications for repair were male factor infertility in 57 patients (86%), pain in 7 patients (11%), and adolescent testicular growth retardation in 2 patients (3%). The average age of the patients was 34 years (range 16 to 48). The average operative times were 103 and 157 minutes for unilateral and bilateral laparoscopic varicocele ligation, respectively. The average time to full recovery and return to work was 4.7 days (the range was 1 to 21 days) and average total analgesic requirements were 11 tablets of acetaminophen (325 mg)/codeine (30 mg) (the range was 0 to 23 tablets).

Fifty of the infertile patients underwent surgery at least six months ago, and of these, 37 (74%) have provided at least two semen samples for analysis. The average follow-up time for these patients is 10.1 months. Preoperative and postoperative semen analysis results are shown in

Table 31.2.2. The average sperm density increased from 10.1×10^6 sperm/mL to 19.4×10^6 sperm/mL. The percentage of motile sperm increased from 33.5 to 36.7%, and the average number of motile sperm per ejaculate increased from 13.4×10^6 to 26.0×10^6. Twenty-five patients (68%) have improved sperm density, 22 patients (59%) have improved motility, and 26 patients (70%) have an increased number of motile sperm per ejaculate.

Forty-five of the 50 patients who had surgery at least six months ago were contacted by telephone and asked about impregnation of their partner. Pregnancies had occurred in 23 couples, which means the impregnation rate is at least 46%. This includes two patients whose partners underwent intrauterine insemination.

A total of three complications have occurred: the previously mentioned arterial bleed and two superficial wound infections at the umbilical site. Three postoperative hydroceles have been diagnosed, none requiring repair. Two (2.2%) patients have had recurrences. Seven of 93 arteries were lost, which means that the preservation rate was 92%.

Discussion

Many aspects of varicocele management are still controversial and poorly understood. It is not clear which surgical or radiological approach is most effective or most beneficial for the patient. At this point, laparoscopic varicocele ligation cannot be advocated as a superior method, because the data to support this position do not exist. However, it is clear that the laparoscopic approach has distinct advantages and disadvantages.

Laparoscopic magnification allows meticulous dissection of the testicular artery. Ninety-two percent of the testicular arteries were spared in our series, which compares favorably to the percentage spared during open surgical series. Improved visualization also allows the dissection and division of the small periarterial venules that may cause varicocele recurrence or persistence.

Our series confirms earlier reports of decreased recuperation time.[27] In our series, patients returned to full work and normal physical activity after a mean of 4.7 days. This is particularly meaningful because the majority of these patients are young and employed in vocations that require heavy labor. Our experience with traditional open surgery is that return to regular activity before seven days after surgery is uncommon, and complete recovery (including ability to undertake strenuous activity) typically occurs between 10 and 14 days postoperatively.[26]

TABLE 31.2.2. Pre- and postoperative semen analysis results in 37 patients.

	Preop	Postop
Sperm density (million/mL)	10.1	19.4*
Motility (%)	33.5	36.7**
Motile sperm per ejaculate (million)	13.4	26*

*$p < 0.01$.
**Not significant ($p = 0.054$).

Recurrence (persistence) rates following traditional open surgical procedures range from 5 to 20% and recurrence after percutaneous procedures ranges from 4 to 11%.[28,29] The recurrence rate in this series (2.2%) compares favorably to those of other techniques.

The laparoscopic approach seems particularly well suited for patients who have bilateral varicoceles, or a persistent or recurrent varicocele following a standard open surgical or percutaneous attempt at ablation. Additionally, and this is particularly important in the pediatric age group, there is no manipulation of and hence possible injury to the vas deferens in this procedure.

At this time laparoscopic varicocele ligation is best performed by an intraperitoneal approach. This requires the use of general anesthesia, whereas the traditional procedures may be accomplished using local anesthesia. The intraperitoneal route also places at risk intra-abdominal structures, damage to which could lead to catastrophic complications. These risks can be lessened by use of the open Hasson cannula technique rather than the blind Veress needle technique of establishing pneumoperitoneum.

In an initial study comparing the overall cost of laparoscopic and open varicocele ligation, the laparoscopic approach costs at least $3,000 more than its open counterpart.[30] However, there is a steep learning curve for this and other laparoscopic procedures. Decreased use of expensive disposable instruments and further experience, which will decrease the operative time and complication rate, will lower these costs.

The overall success rate, as determined by semen analysis and the pregnancy rate, is similar to those reported for open procedures. The pregnancy rate of 46% is similar to the 24 to 53% pregnancy rates reported in the literature for open ligation.[1] Improvements in sperm density and in motile sperm per ejaculate are also similar to those reported for the open operation.

In conclusion, laparoscopic varicocelectomy is a relatively new procedure, but it is clearly an effective means of treating varicoceles, and its results compare well with those of traditional procedures. The potential advantages include better visualization, decreased pain and recovery time, and a lower recurrence rate. With time and experience, this procedure will find its place as a treatment option for this common cause of male factor infertility.

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31.3
Laparoscopic Nephrectomy

Kevin R. Anderson and Ralph V. Clayman

Introduction

We are witnessing a conceptual and technical revolution in the art of surgery. As few as five years ago, transperitoneal surgical intervention usually required an incision large enough for the surgeon to get his hands into the belly. Although the first application of laparoscopy in humans was in 1910,[1] it has been used in general surgery and urology only recently. Since the description of celioscopic cholecystectomy by Dubois in 1990,[2] laparoscopic surgery has been widely accepted. Now, at most centers, laparoscopic cholecystectomy is the treatment of choice, replacing open cholecystectomy.[3,4] Minimally invasive surgery has also become desirable to many patients, who wish to avoid lengthy hospital stays and convalescence. This has spurred increased interest in using laparoscopic technology for many procedures traditionally done through an open incision.

Initially, laparoscopy in urology was limited to diagnostic procedures, such as the evaluation of the cryptorchid child,[5] or to tissue-ablative procedures during which only small pieces of tissue were removed such as laparoscopic pelvic lymph node dissection.[6]

Large solid organ removal, such as laparoscopic nephrectomy, was not feasible until 1990. The technical advances needed for successful laparoscopic nephrectomy were twofold: first, an impermeable sack that allowed a large solid organ to be entrapped (Lapsac, Cook Urological) and second, a high-speed electrical tissue morcellator capable of rapidly fragmenting and evacuating tissue isolated in the impermeable sack. These developments, together with improved imaging technology and instruments, allowed laparoscopic surgery to advance beyond the level of diagnostic procedures or removal of small amounts of solid tissue or hollow organs.[7]

The first laparoscopic nephrectomy was performed at Barnes Hospital of Washington University in St. Louis by Clayman and colleagues in June 1990. The approach was transperitoneal, and the entire specimen was fragmented and evacuated via one of the 12-mm port sites. Since then, over 100 laparoscopic nephrectomies have been performed worldwide.[8–19]

Historical Review

The first successful human nephrectomy was performed in 1869 by Gustav Simon.[20] Since that time, nephrectomy has become a standard procedure for urologists. Approaches to the kidney have included transperitoneal, retroperitoneal, and combined pleural routes using a variety of incisions: subcostal, flank, thoracoabdominal, and dorsal lumbotomy. All require a large incision and are accompanied by the attendant wound-related morbidity, incisional pain, prolonged recovery time, and potential for infection and herniation. The type of incision depends on the exposure required to treat the specific pathologic process as well as the preference and training of the surgeon. For benign renal disease, a simple nephrectomy suffices; for malignant renal disease, a total (kidney plus Gerota's fascia)[21] or radical (kidney, Gerota's fascia, and ipsilateral adrenal) nephrectomy is indicated. In all cases (except for dorsal lumbotomy), transmuscular incisions are necessary, and in some cases of radical nephrectomy, one or more ribs may need to be resected.

The percutaneous removal of renal tissue was initiated by Smith and colleagues in 1988; they attempted to ultrasonically aspirate a pig kidney, the arteries and veins of which had been embolized, using a single-port percutaneous retroperitoneal endoscopic approach.[22] Although much of the kidney was removed, a colonic injury also occurred. In early 1990, Ikari, Netto, and coworkers reported a single-port percutaneous partial resection of renal tissue using grasping instruments advanced through a nephrostomy tract to avulse pieces of a previously embolized kidney.[23] In this case, a total of 16 g of tissue were removed; a postoperative sonogram revealed approximately 17 g of renal tissue remaining. In mid-1990

Clayman, Kavoussi, and coworkers began studies of the laparoscopic removal of porcine kidneys using a transperitoneal route, organ entrapment, and a high-speed tissue morcellator; they were successful in six of seven animals.[7] Subsequently on June 25, 1990, Clayman, Kavoussi, and colleagues laparoscopically removed a right kidney from an elderly woman with an oncocytoma using five ports, none larger than 12 mm.[8]

Indications

Laparoscopic simple nephrectomy is indicated in patients where nephrectomy is warranted for benign disease. Indications include end-stage reflux nephropathy, renal vascular hypertension, a poorly functioning kidney secondary to long-term obstruction, recurrent pyelonephritis, and calculus disease. Laparoscopic total or radical nephrectomy for malignant disease may be performed in patients with small (< 5 cm) renal tumors. In the case of middle- or lower-pole tumors, a total nephrectomy is performed, whereas in the case of upper-pole tumors, a radical nephrectomy, including removal of the ipsilateral adrenal, is completed. In cases of malignant disease, the intact specimen entrapped in the impermeable sack is removed through a 5- or 7-cm lower-midline or flank incision. This allows proper staging of the renal tumor and limits the possibility of seeding of the abdomen or port sites by malignant cells.[24]

Current Laparoscopic Technique for Nephrectomy

Preoperative Preparation

The patient undergoes antibiotic and mechanical bowel preparation prior to the procedure. Intravenous antibiotics are given immediately preoperatively. A nasogastric tube and urethral catheter are inserted. To facilitate ureteral identification, a 7F occlusion balloon (11.5 mm) or a 7.1F pigtail catheter are placed in the ipsilateral renal pelvis. The ureteral catheter is stiffened with a 0.035-in Amplatz super-stiff guidewire; it is secured to the bladder catheter with a 0 silk suture. Intraoperative manipulation of the ureteral catheter assists in identification and dissection of the ureter. Those relatively inexperienced in laparoscopic nephrectomy should consider performing renal arterial embolization immediately before the procedure.

Positioning

After general endotracheal anesthesia is administered, the patient is positioned in a lateral decubitus position on a beanbag; the iliac crest is at the level of the kidney rest. Pneumatic stockings are used to prevent deep venous thrombosis. An axillary roll is used beneath the dependent arm, and both arms are padded; the arms can be left extended on upper and lower armboards or they can be bent at the elbow in a prayer position. In either case, the arms must be well padded. The lower leg is bent approximately 25° and well padded; the upper leg is kept straight. Pillows are placed between the legs at the levels of the knees and ankles. The field is prepared horizontally from the vertebral column to the midline of the anterior abdominal wall and vertically from the nipples to the knees, thereby including the urethral and ureteral catheters.

Procedural Outline for Laparoscopic Nephrectomy

The performance of transabdominal laparoscopic nephrectomy follows nine basic steps:

1. Creation of the pneumoperitoneum
2. Trocar placement
3. Incision of the line of Toldt
4. Dissection of the ureter
5. Dissection of the lateral upper and lower poles of the kidney
6. Securing the renal hilum: renal artery, renal vein, and ureter
7. Organ entrapment
8. Specimen removal: morcellated or intact
9. Exiting the abdomen

Creation of the Pneumoperitoneum: Lateral Insufflation

With the patient in a lateral decubitus position, the table is flexed and the kidney rest is raised. A 12-mm incision is made at the junction of the midclavicular and umbilical lines, just lateral to the ipsilateral rectus muscle. The Veress needle[25] is then passed perpendicular to the abdominal wall; there are two pops as the blunt tip of the needle enters the preperitoneal fat and then the peritoneal cavity. At this point, tests are performed to ensure proper placement of the Veress needle in the peritoneal cavity. Aspiration is done to ensure that no blood or bowel contents return. The cavity is then irrigated with sterile saline and aspirated again. Upon removal of the syringe the irrigant in the clear plastic hub of the needle should flow freely into the peritoneal cavity. When the Veress needle is advanced 1 or 2 cm, there should be no retraction of the blunt tip, indicating that the needle is free within the peritoneal cavity. If, for any reason, the surgeon is unsure of the needle placement, the needle should be removed and passed again.

Once the surgeon is certain the Veress needle is intraperitoneal, insufflation may begin. Carbon dioxide insufflation is begun at 1 L/min. If the Veress needle has been correctly placed, the intra-abdominal pressure should remain low ($\leq$ 10 mm Hg). After 1 L of CO_2 is instilled, the pressure limit is increased to 15 mm Hg, and the flow is increased to > 3 L/min.

Trocar Placement

Immediately prior to trocar placement, the insufflation pressure limit is raised to 25 mm Hg. This allows the surgeon to insufflate an additional 1 to 2 L of gas, thereby further increasing the distance between the anterior abdominal wall and the underlying viscera. In addition, the increased pressure may push the peritoneum more tightly against the anterior abdominal wall, facilitating trocar penetration of the peritoneum. As soon as the first trocar is passed, the insufflation pressure limit is dropped to 15 mm Hg. A 12-mm skin incision is made in the midclavicular line (MCL) on the same level as the tip of the 11th rib. The skin on either side of the incision is secured with a towel clip, and the disposable 12-mm trocar, equipped with a safety shield, is passed cephalo-caudal at a 70° angle to the body and towards the pelvis. Once the trocar enters the abdomen, a 10-mm laparoscope is used to inspect the intra-abdominal contents for any injury that might have occurred during the blind passage of the Veress needle or the initial trocar.

All other trocars are placed under direct endoscopic control. Two more trocars are placed in the anterior axillary line (AAL): a 12-mm trocar just below the costal margin; and a 5-mm trocar 3 to 4 cm below the umbilicus. The sheaths of these two trocars are advanced 2 cm into the peritoneal cavity and are then sewn to the skin using a no. 2 Prolene suture. Next, the laparoscope is passed through the upper AAL port to inspect the initial blind peritoneotomy site. The primary trocar is similarly secured to the abdominal wall with a suture. Now two posterior axillary line (PAL) ports are placed: a 12-mm trocar at the level of the tip of the 12th rib and a 5-mm trocar at the level of the umbilicus.

Operating Team

The operating surgeon and camera person stand on the side contralateral to the kidney being removed. The first assistant stands on the ipsilateral side of the table. The endoscope is passed via the MCL port; at times a 30° lens can provide a better view of the renal vessels than the 0° lens. The surgeon works through the two AAL ports while the first assistant retracts tissue via the two PAL ports. A full list of the equipment necessary to perform a laparoscopic transabdominal nephrectomy is presented in Table 31.3.1.

TABLE 31.3.1. Equipment for transabdominal laparoscopic nephrectomy.

Laparoscopes: 5- and 10-mm, 0° lens
10-mm, 30° lens
(2) 10-mm multiloaded clip appliers (one 9-mm and one 11-mm)
(1) Surgical entrapment sack (5 × 8 in.)
(1) 10-mm electrical tissue morcellator or (1) ring forceps and (1) Kelley clamp
(4) 5-mm traumatic, locking grasping forceps
(3) 5-mm atraumatic dissecting forceps
(1) 10-mm right-angle forceps
Light cord
Xenon light source
(1) Suture scissors
(1) Needle holder
(1) Pair of army/navy retractors
(2) Kocher clamps
(1) Pair of Sinn retractors
0 Vicryl to close fascia of 12-mm port sites
4–0 Absorbable suture to close the skin at the 12-mm port sites
Steristrips
(1) Laparotomy tray (unopened but in operating room)
Laparoscopic camera
(2) 19-in. monitors
(1) Curved electrosurgical scissors
(1) Right-angle electrosurgical probe
(2) Jarit-Peer retractors (one 5-mm and one 10-mm)
(1) 5-mm Babcock clamp
(1) 4-in. length of umbilical tape
(2) 12-mm trocars
(3) 5-mm trocars
(5) #2 Prolene to suture trocar sheath to abdominal wall
(1) Aspirator/irrigator (1 L saline with 5,000 units heparin and 500 mg of cefazolin added)
Insufflator (high flow with automatic pressure control)
(2) CO_2 tanks

Incision of the Line of Toldt

Incision of the line of Toldt (colonic peritoneal reflection) is done with a curved electrosurgical scissors (Endoshears, US Surgical Corporation); the incision extends from the iliac vessels up to the splenic flexure on the left or the hepatic flexure on the right. The peritoneum is then reflected medially—exposing the aorta on the left or the vena cava on the right; in the latter case, the duodenum is rolled medially (Kocher maneuver). Both the surgeon and assistants must be aware at all times of the respective locations of the spleen, stomach, pancreas, liver, duodenum, and colon to avoid inadvertently injuring them when passing instruments through laparoscopic ports or by overly aggressive retraction.

Dissection of the Ureter

The assistant holds the ureteral catheter at the meatus and gently moves the catheter back and forth; the surgeon simultaneously inspects the retroperitoneum medial to the psoas muscle, just above the level of the iliac vessels. The movement of the ureter can usually be seen. Alternatively, the surgeon can drag a closed blunt-tip grasping instrument from medial to lateral across the retroperitoneum, beginning at the medial edge of the psoas muscle. The ureter, which has been stiffened by the ureteral catheter and the super-stiff Amplatz guidewire, can be located by feel.

The ureter is dissected. Once a 360° window has been created around the ureter, either a Babcock clamp or a 4-in. length of umbilical tape is passed around the ureter to retract it during the procedure. The tape is grasped with a locking grasping forceps.

On the right side, the dissection crosses the right gonadal vessel lying anterior to the ureter; two pairs of 9-mm clips are applied proximally and distally to the vein, and it is transected. On the left side, the gonadal vessel can be followed to its insertion in the left renal vein; two pairs of 9-mm clips are then applied, and the left gonadal vein is transected. With the assistant applying lateral traction to the ureter, dissection of the ureter is continued up to the renal hilum; the renal vein may be encountered during this part of the dissection.

Dissection of the Upper and Lower Poles

Nephrectomy for benign disease continues with the incision of Gerota's fascia, exposure of the renal capsule, and dissection of first the lower lateral and then the upper lateral portions of the kidney. The dissection is continued medially until the anterior medial edge of the upper and lower pole is cleared of tissue; the assistant can then place a pair of closed, blunt-tip grasping forceps via the upper and lower PAL 5-mm ports until the tips lie over the medial edge of the upper and lower pole of the kidney, respectively. The assistant displaces the kidney laterally, thereby placing the renal hilum on stretch.

It is important to note, however, that there are often vascularized attachments (lienorenal "ligament") connecting the upper pole of the left kidney to the splenic flexure. These can be secured with 9-mm clips and divided as necessary. Also, the surgeon must be aware of the proximity of the adrenal gland and pancreas to the upper pole and endeavor not to injure either.

If there is a tumor in the middle or lower portion of the kidney, then Gerota's fascia is left intact along the lower and middle portion of the kidney (in the case of a total nephrectomy). At the upper pole Gerota's fascia is incised, and the adrenal gland is preserved.

However, if the tumor resides in the upper pole, then Gerota's fascia is not opened, and the ipsilateral adrenal gland is removed with the specimen. On the left side, the adrenal vein can be traced from its origin at the main renal vein up to the adrenal gland. The left adrenal gland can be dissected medially and then rolled laterally to include it with the perirenal fat and Gerota's fascia. On the right side, it is necessary to continue the dissection cephalad along the lateral edge of the inferior vena cava. The short right adrenal vein is secured with three 9-mm clips and incised in such a way that two clips remain on the caval side of the vein. The medial edge of the adrenal gland is then dissected and moved laterally so that it is included with the *en bloc* specimen of the kidney and Gerota's fascia.

Securing the Renal Hilum

Gentle dissection at the level of the renal hilum is done to expose the renal vein. This dissection can be facilitated by use of a hook electrode as well as a right-angle dissector. A 360° window is created around the renal vein, and the renal artery is then identified and dissected. A 360° window is created around the artery. The renal artery is occluded with three 9-mm clips placed proximally and two 9-mm clips placed distally; it is then sharply divided between the second and third clip; thereby leaving three 9-mm clips on the aortic stump of the renal artery. The renal vein, if hypoplastic, can be secured in a similar fashion with 9- or 11-mm clips (Figure 31.3.1). However, in most cases, because of the breadth of the renal vein, a 3-cm-long 12-mm vascular Endo GIA stapler (US Surgical Corporation) is used to divide it. In the case of the right kidney, the renal vein is usually solitary and without tributaries; in contrast, in the case of the left kidney, the

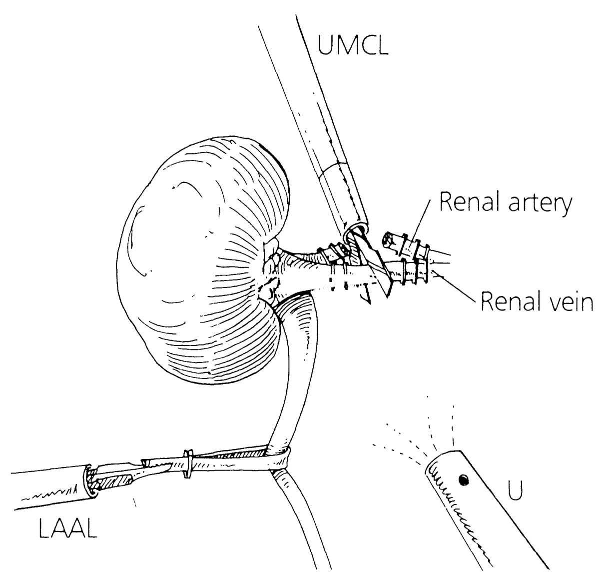

FIGURE 31.3.1. The renal artery and vein are individually secured with clips and transected. (By permission of Clayman, R.V. and McDougall, E.M.: "Laparoscopic Renal Surgery" in *Laparoscopic Urology* (ed. R.V. Clayman and E.M. McDougall) Quality Medical Publishing, Inc., St. Louis, pp. 272–309, 1993.)

adrenal vein, gonadal vein, and ascending lumbar vein usually need to be secured in turn with four, 9-mm clips and incised between the two pairs of clips before the main renal vein is secured.

In all patients the surgeon should endeavor to identify the renal vessels close to the lateral edge of the aorta (left side) or inferior vena cava (right side). If the hilar dissection proceeds too far laterally, it will be necessary to separately dissect and ligate each of the segmental renal arteries and veins, thereby greatly increasing the difficulty and length of the procedure.

After the renal artery and renal vein are separately secured, the ureteral catheter is removed, and the ureter is secured with two 9-mm clips approximately 4 to 5 cm below the renal hilum and divided between the clips. The ureter is then grasped by the assistant with a traumatic, locking, grasping forceps via the upper PAL port. The kidney is retracted, and any remaining attachments between the kidney and the retroperitoneum are sharply divided. The kidney is then moved out of the area of dissection: on the right side, it is moved above the liver; and on the left side; it is moved beside the spleen. The intra-abdominal pressure is lowered to 5 mm Hg, and the renal fossa is inspected for any previously unrecognized bleeding.

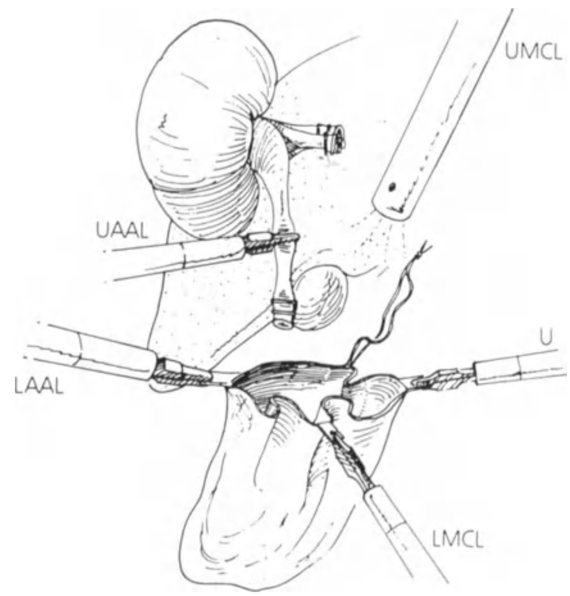

FIGURE 31.3.2. The kidney is pulled toward the open sack by the grasper on the proximal ureter. (By permission of Clayman, R.V. and McDougall, E.M.: "Laparoscopic Renal Surgery" in *Laparoscopic Urology* (ed. R.V. Clayman and E.M. McDougall) Quality Medical Publishing, Inc., St. Louis, pp. 272–309, 1993.)

Organ Entrapment

A 5 × 8-in. impermeable entrapment sack (Lapsac, Cook Urological) is rolled onto a metal introducer device; care is taken to place the drawstrings within the fold of the sack so that they do not become entangled in the flap valve of the port. The sack-bearing introducer is passed into the 12-mm AAL sheath. Using *atraumatic* graspers, the bottom of the sack is pulled into the lower abdomen until the drawstrings have cleared the tip of the 12-mm AAL port. The laparoscope is moved to the upper 12-mm AAL port, and three atraumatic graspers are passed via the MCL, lower AAL, and lower PAL ports. The sack is completely unfurled. The three graspers are removed. Now three traumatic, locking grasping forceps are passed via the MCL, lower AAL, and lower PAL ports. The three tabs along the mouth of the sack are then secured. By moving the graspers in three different directions, the mouth of the sack is opened (the MCL grasper moves anterior, the lower AAL grasper moves upward, and the lower PAL grasper moves laterally). The laparoscope is advanced into the sack, and the sack is opened further by moving the shaft of the laparoscope in an ever-widening circle. Once the sack is expanded, the endoscope is withdrawn from it.

The kidney is placed into the sack using the upper AAL traumatic, locking, grasping forceps affixed to the ureter (Figure 31.3.2), which was previously secured at the ureteopelvic junction. The lower lip of the sack is pulled slightly superiorly and downward, thereby creating a leading edge, or apron. The grasper holding the kidney is pushed deeply into the sack just beneath the upper lip of the sack. As the kidney traverses the lower edge of the sack the assistant can slowly raise the grasper on the lower edge, thereby pushing the kidney deeper into the sack.

The laparoscope is returned to the MCL port and the drawstrings are grasped with a traumatic, locking forceps, passed via the upper 12-mm AAL port. The drawstrings are pulled into the sheath, as is the neck of the sack. The 12-mm sheath is removed, thereby depositing the drawstrings on the abdominal wall. The drawstrings and the mouth of the sack are pulled through the 12-mm abdominal incision. This is all done under continuous laparoscopic monitoring to make sure that the colon or omentum does not get caught in the folds of the sack as it is pulled through the abdominal wall.

Specimen Removal

Tissue morcellation is accomplished with a high-speed electrical tissue morcellator (Cook Urological). This device has a rotating cylindrical blade that is recessed inside the blunt tip of its 10-mm barrel. First, the surgeon, using his left hand, and the assistant, using his right hand, pull the sack up through the skin incision until the kidney is tightly pressed against the underside of the abdominal wall. Next, the morcellator is advanced firmly into the renal tissue; then negative pressure (wall suction) is applied to the handle of the device (Figure 31.3.3). Now the blade is activated, and the resulting cores of tissue are fragmented and aspirated into a wire-mesh filter in the handle of the morcellator. Every three to five minutes the accumulated tissue is removed, so that aspiration remains vigorous. When used correctly, the electronic morcellator will not injure the impermeable nylon entrapment sack. However, throughout the morcellation procedure, the surgeon and assistant must pull on the sack to keep the kidney against the anterior abdominal wall. If they don't, folds in the sack could get into the barrel of the morcellator and be cut. When the sack is empty, it can be pulled from the abdomen.

The morcellation process must be monitored endoscopically. At no time during this phase of the procedure should the sack touch the intra-abdominal viscera; a sudden loss of pneumoperitoneum or adherence of bowel to the sack is a sign that the sack has been perforated. At this point, the morcellation procedure must stop and adherent bowel be examined for injury.

If an electronic tissue morcellator is not available, then under endoscopic control, a large blunt Kelley clamp or ring forceps can be passed into the neck of the sack and used to fragment the kidney. Pieces of tissue are then pulled from the sack and sent to pathology for histologic examination.

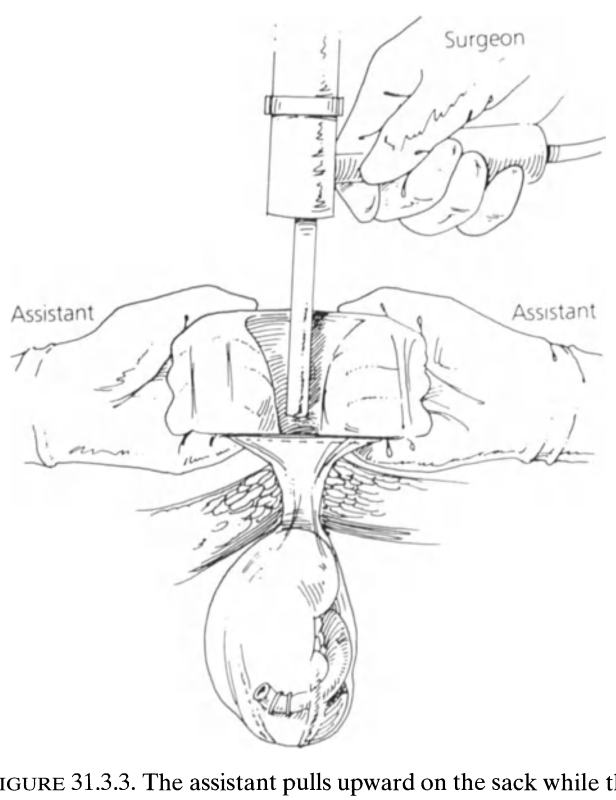

FIGURE 31.3.3. The assistant pulls upward on the sack while the surgeon operates the morcellator. (By permission of Clayman, R.V. and McDougall, E.M.: "Laparoscopic Renal Surgery" in *Laparoscopic Urology* (ed. R.V. Clayman and E.M. McDougall) Quality Medical Publishing, Inc., St. Louis, pp. 272–309, 1993.)

If a malignant tumor is suspected, then the entrapment sack is removed with the kidney intact through a 5- to 7-cm incision at Petit's triangle. With the help of army/navy–type retractors on either side of the incision, the sack and kidney can be slowly delivered. This part of the procedure is also done under endoscopic control.

Exiting the Abdomen

Once the specimen and sack are removed, a 5-mm laparoscope is passed through one of the 5-mm ports. Each port is inspected as it is removed to ensure there is no hemorrhage from any of the port sites. The 12-mm port sites are removed first; these incisions require closure of the fascia (one 0 Vicryl figure-eight stitch) to prevent bowel or omental herniation. Sinn retractors and Kocher clamps are helpful in exposing the fascia. The 5-mm ports do not require fascial closure. The 12-mm skin incisions are closed with an absorbable subcuticular suture. The last 5-mm port is withdrawn with the 5-mm laparoscope protruding from the tip of the 5-mm sheath in order to check for bleeding. The gas in the abdomen is allowed to pass out of the 5-mm port sites. All skin incisions are closed with adhesive strips. The nasogastric tube and Foley catheter are removed, and oral intake is begun within 6 to 12 hours.

Alternative Techniques

Retroperitoneal laparoscopic nephrectomy was first reported by the authors in 1992.[10,11] Since then, others have described their experience with this direct approach to the kidney.[26] In this approach, the retroperitoneum is insufflated directly (by a Veress needle passed at Petit's triangle), and the kidney is removed without ever entering the peritoneum. Trocar placement along the AAL and PAL is similar; however, there is no MCL port. Instead a 12-mm port is placed just below the 12th rib and along the lateral border of the sacrospinalis muscle. The advantage of the retroperitoneal approach is that the intra-abdominal contents do not interfere with visualization and dissection of the kidney, and there is no need for adhesiolysis. This approach also allows a posterior approach to the renal hilum that exposes the renal artery before the renal vein.

To facilitate retroperitoneoscopy, we have used a device devised for the balloon dissection technique first described by Gaur.[26] After a 12-mm port is placed into the retroperitoneum (outside Gerota's fascia), the middle finger of a size-8 surgical glove is transected at its base and tied to the end of a 16F red rubber Robinson catheter. The balloon is backloaded into a 30F Amplatz sheath; the Amplatz sheath is passed into a 12-mm port sheath, and the balloon catheter assembly is then pushed out of the Amplatz sheath into the retroperitoneum. The balloon is expanded in the retroperitoneum with 1,000 cc of sterile saline. The balloon is then deflated and removed. The psoas muscle, genital femoral nerve, and Gerota's fascia can usually be seen. According to Gaur, in particularly thin individuals, Gerota's fascia can be entered, and the balloon placed *within* Gerota's fascia; following expansion of the perirenal space, the kidney and ureter can usually be seen.

The limitations of the retroperitoneal approach are that the renal anatomy is less familiar, especially the appearance of the left renal vein, and there is less space in which to work than in the peritoneal cavity. At present, this approach is better suited to a simple than a total or radical nephrectomy, but it is possible that in the future the majority, if not all, renal and ureteral procedures will be performed via the more direct retroperitoneal approach.

Intraoperative Monitoring

During a prolonged laparoscopic procedure, the surgeon must be aware of two potential problems. One is the risk of hypercarbia with attendant hypertension, tachycardia, and acidosis. To prevent this, P_{CO_2} should not be allowed to exceed 45 mm Hg, and arterial blood gases should be checked every 30 to 60 minutes. If hypercarbia develops, the abdomen should be desufflated and the patient hyperventilated until the P_{CO_2} falls within a normal range and the acidosis is corrected. The pneumoperitoneum can then be re-established at a lower pressure (10 to 12 mm Hg).

The second problem is that after the first hour of a lengthy procedure, the urine output drops precipitously. Ten to 30 minutes after the pneumoperitoneum is released, diuresis occurs. This oliguric state may be due to renal vein compression from the pneumoperitoneum but the exact mechanism is unknown. It cannot be readily reversed by the use of diuretics or by delivery of a fluid challenge; indeed, if this is done, fluid overload and congestive failure may result. Also the insensible loss during laparoscopic surgery appears to be less than during open surgery. For both reasons, fluid delivery should be carefully monitored during the procedure. For patients at risk of developing congestive failure, a pulmonary arterial line is necessary to monitor fluid status; a central venous pressure line is often unreliable because it registers the pressure of the pneumoperitoneum.

Clinical Results

Since our initial laparoscopic nephrectomy in June 1990, the authors have performed 32 laparoscopic nephrectomies in 33 attempts: 28 for benign disease and 4 for malignant disease. To date, we have assessed the outcome for the first 20 patients who underwent laparoscopic nephrectomy for benign disease.[27] The patients ranged in age from 16 to 91 years; there were 13 females and 7 males. The right kidney was removed in 14 patients, and the left kidney was removed in 6 patients. The mean operative time was 340 minutes, and the estimated blood loss averaged 211 cc. Postoperative complications occurred in 37% of our patients. In one patient, a laparoscopic approach to the left kidney was converted to an open approach because of our inability to properly secure the renal artery; this patient also had a postoperative brachial plexus palsy that resolved over 12 months. Two patients had a low-grade fever for two days postoperatively, which resolved spontaneously. Blood and urine cultures were negative in both patients. One patient developed a postoperative retroperitoneal hematoma that was verified by CT scan; 2 units of packed red blood cells were given. This patient also experienced mild congestive heart failure, which responded to diuretic therapy. One patient developed a pneumothorax after a retroperitoneal approach; a chest tube was placed. One patient developed a small pulmonary embolus on postoperative day 4; she was anticoagulated and discharged from the hospital on postoperative day 11. In a young muscular male, a vastus lateralis compartment syndrome occurred postoperatively in the dependent thigh; this resolved within one week with conservative measures.

Interestingly, this complication rate is quite similar to the morbidity noted in open donor nephrectomy, which also involves removal of a benign kidney. In four large series, encompassing between 100 and 247 patients each, the morbidity rate among these young healthy patients was between 14 and 30%.[28–31] Wound-related problems occurred in 5 to 13% of these patients, 8% complained of chronic incisional pain, and 0.8% developed an incisional hernia.[31] Also, laparoscopic nephrectomy is a very new procedure. As we crest our learning curve, the morbidity of the procedure will probably decrease.

The real benefit of laparoscopic nephrectomy for benign disease is seen in the postoperative course: pain requiring narcotic therapy is minimal; the hospital stay is shorter; and convalescence is briefer. In our series, the average amount of postoperative parenteral narcotics was 54 mg (the range was 0 to 363 mg). Several patients received no parenteral analgesics; the higher levels of narcotic use were associated with a postoperative complication (pulmonary embolus in one patient and pneumothorax in another). The average hospital stay was 3.7 days.[27] The mean time for return to normal activity (work or usual activities at home) was 3.43 weeks, and full recovery (complete return to preoperative status) was seen at an average of 6.6 weeks.

The four patients who underwent laparoscopic radical nephrectomy for malignant disease had a mean operative time of 437 minutes. In the two cases where the tumor was located in the lower pole region, the adrenal gland was left *in situ,* whereas in the two cases of upper-pole tumors, the adrenal gland was removed with the specimen (one tumor was in the right and the other was in the left). Complications were noted in two patients. An 85-year-old patient developed postoperative congestive heart failure and associated anemia; this was corrected with a 1-unit blood transfusion and diuretic therapy. A 91-year-old woman developed atrial fibrillation on postoperative day 2; this was converted medically. She also developed mild congestive heart failure and anemia, which responded to 1 unit of packed red blood cells and diuresis. In both patients there was no evidence of a retroperitoneal hematoma on CT scan.

Literature Review

Laparoscopic nephrectomy has now been successfully performed in many centers around the world.[8–19] The combined experience of Coptcoat and Rassweiler encompasses 27 patients, including 21 patients who underwent nephrectomy for benign disease and 6 who underwent nephrectomy for a renal malignancy. They began laparoscopic nephrectomy with the patient in the lateral rather than the supine position and used a transperitoneal approach. Twenty-five of 27 cases were successfully completed laparoscopically; the mean operating time was 270 minutes. The inpatient stay averaged 4.8 days, and return to normal activity occurred in an average of 12 days. In two cases the laparoscopic approach failed—one patient had a large staghorn calculus and dense perirenal fibrosis and another had intraoperative hemorrhage.

Conclusion

Whether a kidney should be removed laparoscopically really depends on the surgeon's level of comfort with laparoscopic techniques. Relative contraindications for a laparoscopic nephrectomy that are currently cited include renal tumors larger than 5 cm, multiple abdominal surgical procedures, morbid obesity, or any other condition that would eliminate a patient as a candidate for an open surgical procedure. Early in a surgeon's experience with laparoscopic nephrectomy, it is wise to limit patients to those without a history of inflammatory renal disease, such as patients with a hypotrophic kidney from renovascular hypertension, dysplasia, or reflex nephropathy.

The patient demand for minimally invasive surgery continues to increase. Although laparoscopic nephrectomy is admittedly time-consuming and technically demanding, it is both feasible and reproducible. Laparoscopic nephrectomy is already our primary method of removing kidneys with benign renal disease. For removing smaller renal malignancies, continued studies are needed to assess whether this approach is as effective yet less morbid than current open surgical techniques.

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31.4
Laparoscopic Pelvic Lymphadenectomy to Diagnose Metastatic Prostate Cancer

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Introduction

Urological laparoscopy, while still in its infancy, is gaining acceptance not only in the academic community but also in the private practice of medicine. Although the long-term benefits of laparoscopy are not known, it is already widely used in urologic surgery. Laparoscopy was first applied in urology in the diagnosis of impalpable testes,[1–3] but its most common use is to diagnose the metastatic spread of prostate cancer during staging pelvic lymphadenectomy.[4–28]

Historical Review

Principles Behind Open Technique

There are many treatments for prostate cancer, each of which has its place in the treatment protocol. In 1905, Young proposed that a cancer confined to the prostate by the capsule could be cured by surgical removal of the prostate.[29] Today, that argument still holds; however, improvements in medical technology have made it easier to recognize metastatic spread past the capsule and thus to differentiate surgically curable from surgically incurable cancers.

Numerous techniques have been developed for determining whether a cancer is metastatic.[6,8,10,14,17,30–32] Gleason scores, which indicate the grade of differentiation of the tumor, and serum prostate-specific antigen (PSA) levels offer considerable insight. The most accurate test for metastasis from the prostatic capsule, however, is evaluation of regional lymph nodes.[4–6,8,14,32]

If lymph nodes are found to be positive for metastatic prostate adenocarcinoma during staging pelvic lymphadenectomy, the patient generally cannot be cured by surgery or radiation therapy. In this instance, if further treatment is instituted, it is generally palliative in nature, since surgery and radiation are associated with significant mortality. Until recently, the only way to perform staging pelvic lymphadenectomy was by open surgery, which again put the already compromised patient at increased risk. For all these reasons there was a need for a minimally invasive procedure with relatively low morbidity that could be used to remove intact lymph nodes to assay metastatic spread of prostate cancer. Laparoscopy lymphadenectomy has proven to be that procedure.

Schuessler and colleagues[21] introduced the use of laparoscopic pelvic lymphadenectomy for the management of prostate cancer in 1991. In subsequent years, use of this procedure for the staging of prostate cancer has increased.[1–20,22–28]

Rationale for the Laparoscopic Approach

As stated earlier, definitive treatment of prostate cancer is usually warranted only when the cancer is limited by the prostatic capsule. In general, if the morbidity of the procedure is greater than the chance of providing benefit to the patient, the operation should not be performed. The question then becomes: What factors are indicative of localized prostate cancer? Several studies have suggested that patients with clinically well-defined prostate cancer, who also have low Gleason scores and low serum PSAs have small risk of metastatic spread to regional lymph nodes. On such a case the type of treatment planned, in conjunction with clinical, pathologic, and laboratory findings, would determine whether staging lymphadenectomy was warranted. If the surgeon is contemplating a nerve-sparing radical perineal prostatectomy or radiation therapy, surgical exploration of the patient's lymph nodes prior to treatment is not warranted. If, however, the surgeon is planning a radical retropubic prostatectomy, staging pelvic lymphadenectomy is suggested.

Unfortunately, there are no threshold Gleason scores or PSA values that dictate when staging pelvic lymphadenectomy should be performed. In our practice, we have found that the incidence of metastatic spread increases with increasing Gleason scores and PSA values (Figure 31.4.1). In addition, we have found that clinical staging correlates with metastatic spread as would be expected. Other investigators have reported similar findings.[6,8,14,17] In general, the Gleason score is more significant than the PSA value and patients with a Gleason score higher than seven have a significant chance of having positive lymph nodes. Schuessler[10] also suggests that patients with tumors detected by ultrasound only do not need lymphadenectomy because he found no lymph node metastasis in this set of patients.

Based on available knowledge, our recommendation is that in the case of surgical candidates for prostatectomy or radiation therapy, laparoscopic pelvic lymphadenectomy be performed in the following situations: (1) the serum PSA level is higher than 20.0 ng/mL; (2) the serum prostatic acid phosphatase is elevated; (3) upon physical examination, the lesion is of significant size to make the clinician suspect the cancer extends outside the prostate; or (4) the tumor is a high-grade lesion having a combined Gleason score higher than seven.

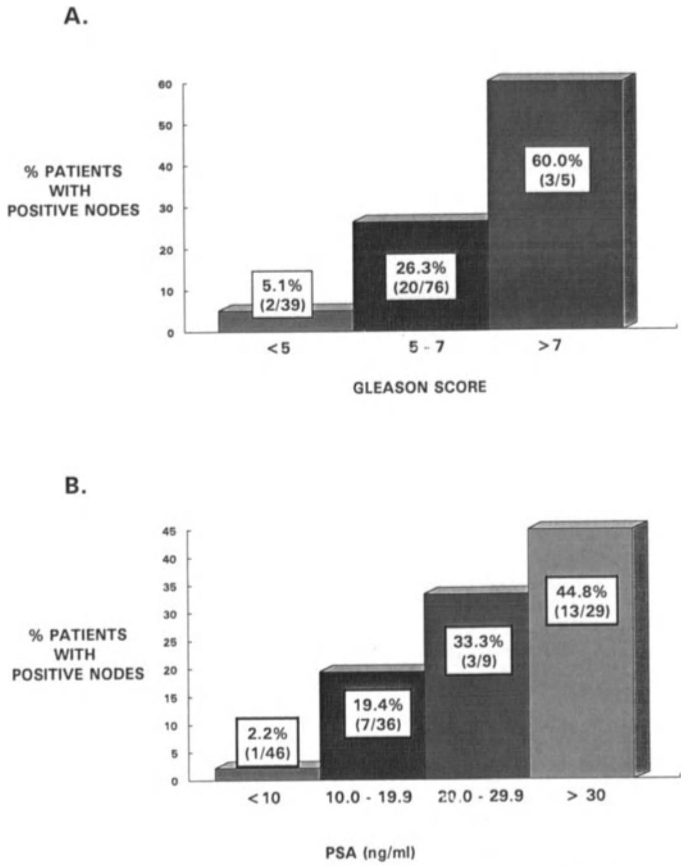

FIGURE 31.4.1. Relation of Gleason scores or serum PSA levels and finding of positive lymph nodes. (A) Gleason scores and percent positive lymph nodes; (B) PSA levels and percent positive lymph nodes.

Laparoscopic Technique

Equipment

For the urologist, laparoscopy is merely a new technique for performing familiar open procedures. In general, the following basic equipment is needed: scissors, graspers, cautery, retractors, surgical clips, and an instrument to remove the nodal package. Additionally, if laparoscopic pelvic lymphadenectomy is being performed with gas distension, a Veress needle or Hasson port should be available for initial penetration of the abdominal cavity. Also needed are: a laparoscope, a camera, CO_2 gas, an insufflator, and ports to allow the passage of instruments into the abdomen. The following are useful to have at hand: a smoke-evacuation device, an irrigation and suction device, defogging solutions for the camera, a metal rod for exchanging ports if necessary, extra ports, a soluble hemostatic agent such as Surgicel, appendix extractors, and a powered operating-room table that allows the patient to be easily rotated to 45°. It is also wise to prepare an instrument set for open intra-abdominal surgery in case a problem arises that cannot be corrected laparoscopically. Finally, an experienced operating room laparoscopic team is essential for optimal performance.

Procedure

The day prior to surgery, the patient is given a mild laxative to decompress the bowels. The patient is informed that although the operation will be attempted laparoscopically, open surgery may be required. It should be emphasized that laparoscopy is a sound surgical technique and that conversion to open surgery does not necessarily mean that a complication has occurred.

Prior to surgery, the patient is fitted with either thigh-high TED stockings or compression boots. The patient is intubated to allow maintenance of an airway. General anesthesia is administered, and a nasogastric tube is placed to decompress the stomach. A Foley catheter is then placed to empty the bladder and to prevent its perforation with a port. Both of the patient's arms are placed at his sides and secured to provide the surgeon easier access to the pelvis. The patient's chest and hips are taped securely but not tightly to the table so that the patient will maintain position when the table is rotated 45°. Rotation of the table causes the bowels to drop below the line of dissection. A towel is then rolled and placed under the patient's lower back to raise the pelvis. If a long procedure is anticipated, we request that the anesthesiologist not use nitrous oxide, since it tends to cause some bowel distention.

The patient is then prepped and draped in a sterile fashion. A curvilinear incision is made around the umbilicus. If the patient has significant risk factors for bowel or vascular injury (such as previous surgery or an aneurysm), a minilaparotomy[34] is performed: a Hasson's port is placed through the curvilinear incision and secured with stitches. Alternatively, a Veress needle is placed through the incision. If the distance between the patient's umbilicus and symphysis pubis is short, the incision is made above the umbilicus. If the distance between the umbilicus and symphysis pubis is relatively long, the incision is made below the umbilicus. The vicinity of the umbilicus is preferred, since this is where all layers of the abdomen coalesce, making it the easiest place to blindly place a Veress needle.

A towel clip is next placed on either side of the incision, and the abdominal wall is lifted. Some surgeons feel that it is easier to lift the lower abdominal wall; however, we have had little experience with this technique. The needle is then placed through the abdominal layers into the abdominal cavity. Usually, two pops are felt before the needle is in the abdominal cavity. It is important not to use the depth of needle insertion to ascertain whether the needle is in the abdominal cavity, because the peritoneum can be pushed away from the abdominal wall without being punctured.

Once the needle is placed, saline is injected into the needle and the needle is then aspirated. If the saline returns to the syringe, indicating that the needle is not in the peritoneal cavity, the needle should be removed and the procedure repeated. If there is little or no yield, a CO_2 insufflator is connected to the Veress needle, and the intra-abdominal pressure is measured. The pressure should be less than 5 mm Hg. Once the pressure is felt to be appropriate, the insufflator is turned to high flow. The abdomen should distend fully in all four quadrants and there should be tympany over the liver in the right upper quadrant. Once the abdomen is insufflated to 15 mm Hg, the needle is removed. Typically a port is placed at the same location as the needle. The laparoscope is then defogged and advanced through the port into the patient's abdominal cavity. The bowels and abdominal contents are examined for signs of injury. The intraperitoneal anatomy is shown in Figure 31.4.2.

Next, the number, size, and location of the ports is determined (Figure 31.4.3). All ports are placed under laparoscopic guidance in order to ensure safe passage into the abdominal cavity. Routinely, the initial port is an 11-mm port for the camera. The CO_2 tubing may have to be moved to another port to prevent fogging of the camera. Next, 5-mm ports are placed just lateral to the epigastric vessels on either side. These vessels can often be seen through the laparoscope. An 11-mm port is then placed three fingerwidths above the supraphysis pubis. Once the ports are in place, the smoke evacuators may be placed in the two large ports and the CO_2 connected to the 5-mm "up port." The patient is then rotated 45° with the operative side elevated. Flowers and colleagues[7] report occasional use of a fourth port for retractors, but we do not find this is necessary.

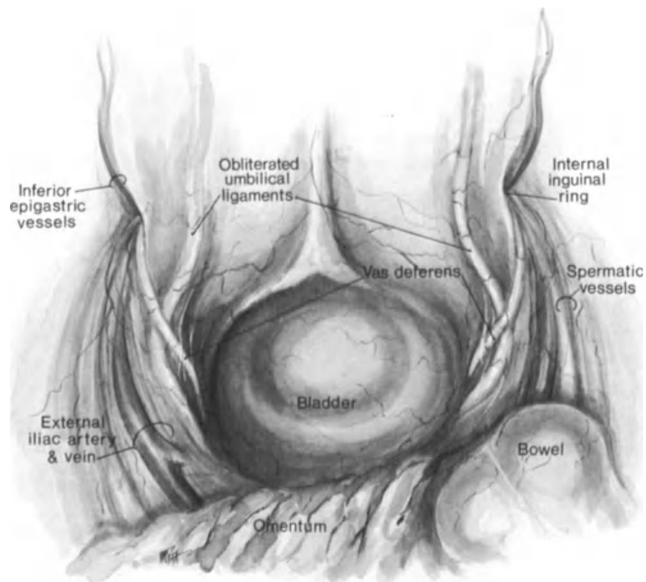

FIGURE 31.4.2. Intraperitoneal pelvic anatomy.

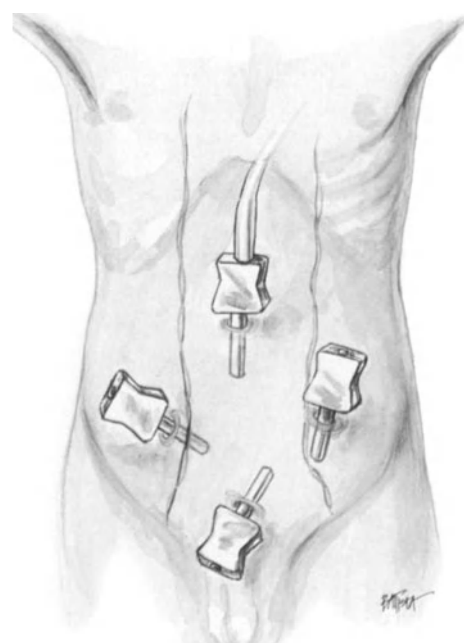

FIGURE 31.4.3. Four ports are often placed for laparoscopic pelvic lymph node dissection. The two 5-mm ports are placed lateral to the epigastric vessels at the level of McBurney's point. Two 11-mm ports are located in the midline. One is placed adjacent to the umbilicus, and the other is three fingerbreadths above the symphysis pubis.

Patient anatomy determines the procedure actually employed at this point (Figure 31.4.4). The limits of dissection are defined by the nodal tissue, which is located under the iliac vein above the obturator nerve, lateral to the obliterated umbilical vessel (a branch of the superior vesical artery, which is often patent), and proximally from the iliac bifurcation to the abdominal sidewall. Next, the peritoneum is incised just lateral to the umbilical ligament, from the pelvic sidewall to the bifurcation of the iliac artery (Figure 31.4.5). It has been our experience that there are several branches of the ligament, which may cause bleeding later during the procedure. Thus, it is important that the incision be lateral to the ligament. Fortunately, the only structure that usually crosses the umbilical vessel is the vas deferens (Figures 31.4.6–31.4.9). Rarely, the ureter is near the vessel at the level of the bifurcation of the iliac artery. The simplicity of the anatomy enables one to do a quick lateral dissection of all superficial material here. See and colleagues[33] proposed using an inverted-V peritoneotomy rather than a linear one. They report that this type of incision provides a better nodal yield and decreases operative time without increasing morbidity.

Dissection is usually done from under the iliac vein. Seen through the laparoscope, the edge of this vessel is quite distinct. All tissue from the iliac vein to the umbilical vessel is then mobilized (Figure 31.4.10). Generally, blunt dissection, rather than cutting with scissors, is used. Once the nodal package is mobilized, the obturator struc-

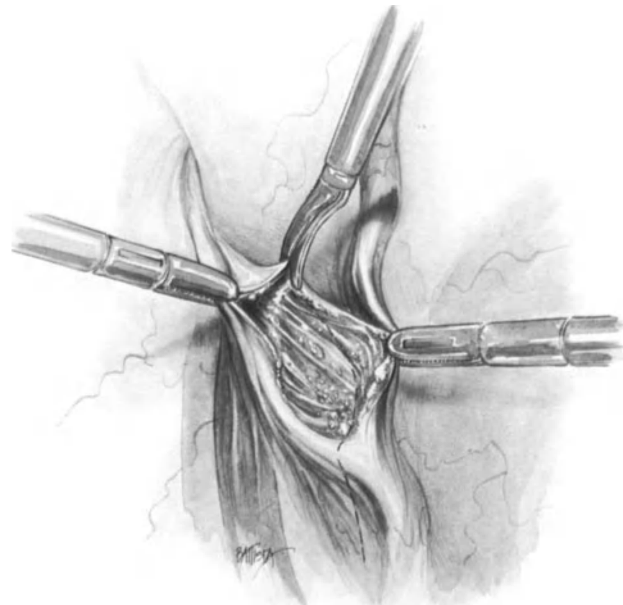

FIGURE 31.4.5. The umbilical vessel is an important anatomic landmark for intraperitoneal pelvic lymph node dissection; it marks the medial margin for node removal. By exposing most of it, one can often prevent unexpected complications. The peritoneum is incised lateral to this vessel, which is often patent.

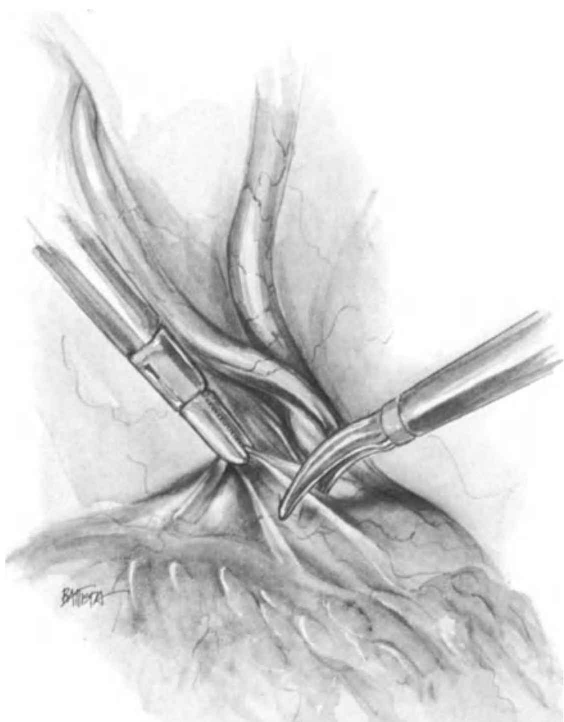

FIGURE 31.4.4. If one begins the bilateral dissection on the left side, the sigmoid colon must be sharply dissected off the peritoneum over the iliac structures, to which it is often adherent.

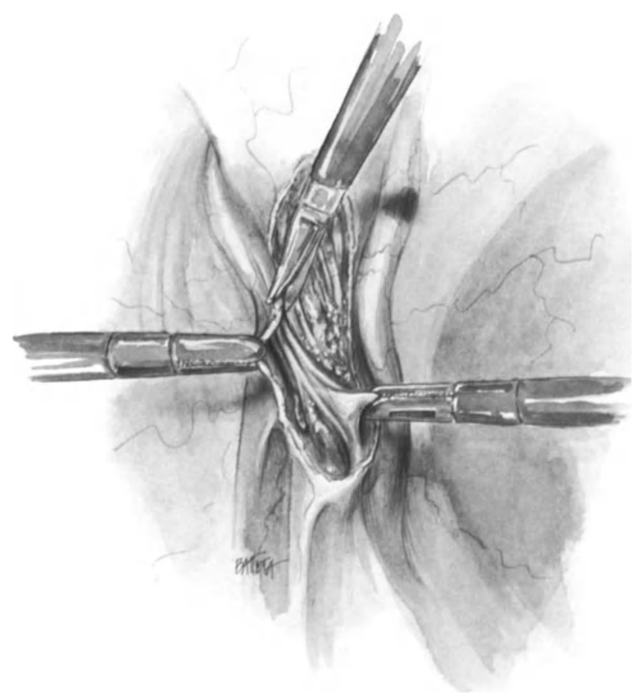

FIGURE 31.4.6. The only structure that usually crosses the umbilical artery is the vas deferens. It is identified and dissected from the medial border of the umbilical vessel to the point where it crosses the external iliac artery.

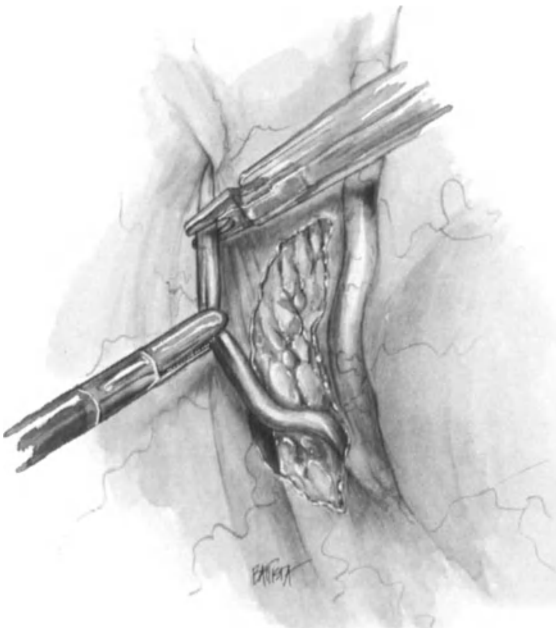

FIGURE 31.4.7. The vas deferens is dissected off of the umbilical vessel up to the medial margin of the external iliac artery.

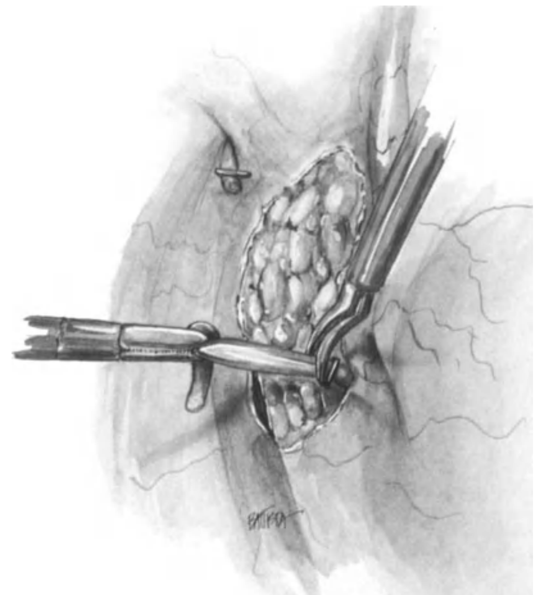

FIGURE 31.4.9. This portion of the vas deferens is then surgically removed.

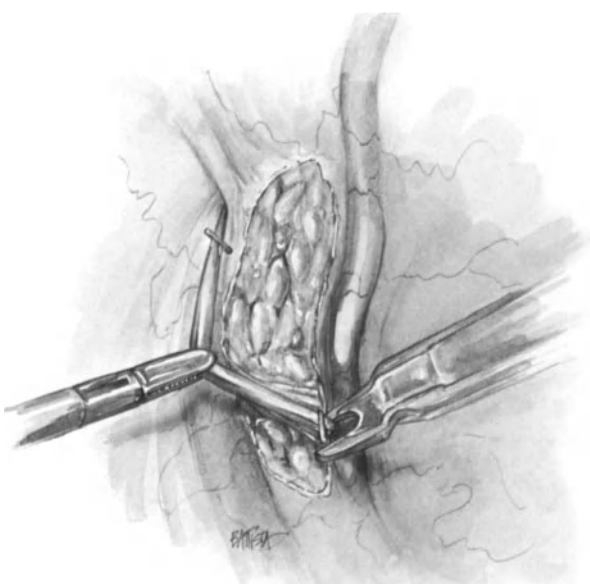

FIGURE 31.4.8. The vas is clipped proximally and distally at the end points of the dissection.

FIGURE 31.4.10. After one dissects the umbilical artery proximally to the level of the bifurcation of the iliac artery, the iliac vein is easily identifiable. The lymphatic material is swept from the posterior margin of this vein toward the umbilical artery.

tures are identified (Figure 31.4.11). The obturator vessels vary in location, and the obturator artery occasionally branches off from the umbilical artery; one has to be careful, but, in general, these structures do not pose a problem. The distal portion of the node package is then double clipped near Cloquet's node (Figure 31.4.12). After an incision is made between the two clips, the nodes are pushed off the nerve, as in the open lymphadenectomy procedure. They are then removed through the middle 11-mm port using a spoon grasper (Figure 31.4.13). If necessary, a clip is placed proximally (Figure 31.4.14). After the node package has been removed, a soluble hemostatic agent, such as Surgicel, is placed in the site to prevent any subsequent bleeding. The ports are then removed under direct vision, watching for bleeding (Figures 31.4.15 and 31.4.16). The fascia of the larger wounds is closed. Simple S retractors are used to hold back the skin, and the fascia is closed with 0 Dexon suture

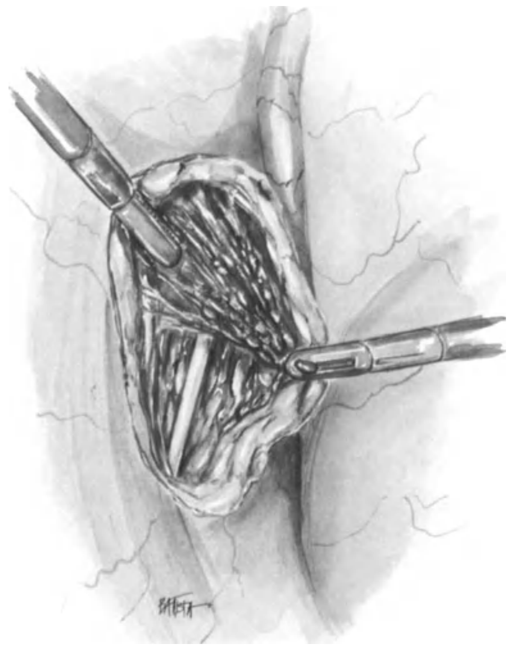

FIGURE 31.4.11. The obturator nerve is next identified posterior to the iliac vein. This is the posterior margin of the lymph node dissection.

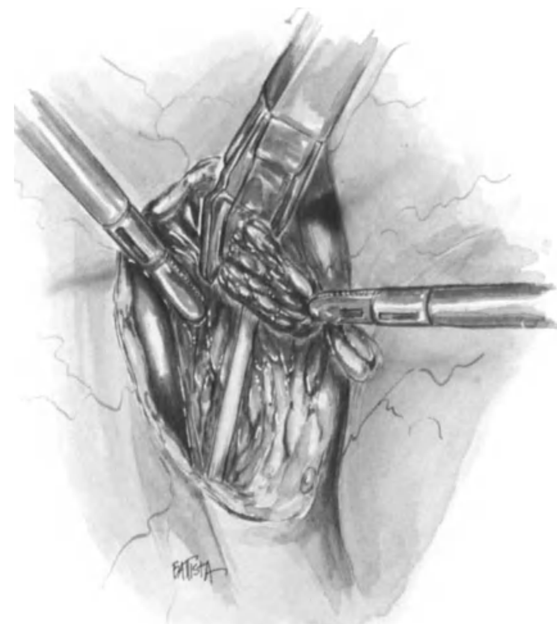

FIGURE 31.4.12. The distal portion of the specimen is clipped to prevent lymphocele formation.

on a GU needle. We use skin staples with Opsite dressing for all the skin wounds.

Clinical Results

Our experience with laparoscopic pelvic lymphadenectomy has been a positive one. We have currently performed over 150 pelvic lymphadenectomies; here we describe our experiences with our first 100 patients. Typically, the procedure can be performed on an outpatient extended-care basis. Initially, our patients spent one or two nights in the hospital for observation, but we have found that hospital admission is usually not necessary. Exceptions are patients who experience complications or who live a considerable distance from the hospital.[28] Operative time decreases significantly with increasing physician experience (Table 31.4.1, Figure 31.4.17). Other investigators have reported operative times ranging from 72 to 270 minutes, with most in the range from 100 to 200 minutes.[4,11,17,18,21,33,36,38]

Approximately 20% of our cases had positive nodes. Other investigators have reported that anywhere from 6 to 50% of their cases had positive nodes.[7,8,12,36] The percentage of positive nodes depends upon the patient population being tested. The majority of the patients in our study were being considered for radioactive implants for treatment of their prostate cancer. Thus, they would be expected to have a lower percentage of metastasis. Danella[12] reported that *routine* laparoscopic node dissection is unnecessary since only 13 of 229 (5.7%) of their patients had metastasis to the lymph nodes. Danella suggests that pelvic lymphadenectomy should be performed only when the clinical signs of cancer are accompanied by some other factor, such as a significantly elevated PSA. Studies that reported a higher percentage of positive nodes followed this rule.

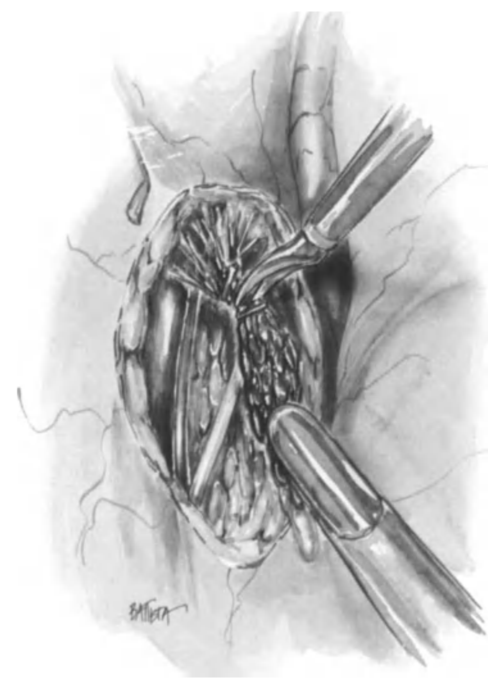

FIGURE 31.4.13. The node package is cut distally and the package is gently teased out with spoon graspers.

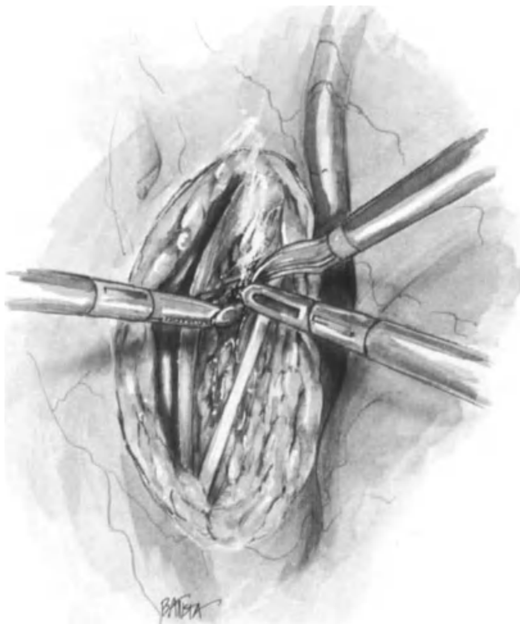

FIGURE 31.4.14. It is sometimes necessary to use cautery as well as clips; but cautery should be used carefully, particularly in the vicinity of the bowel or large vascular structures.

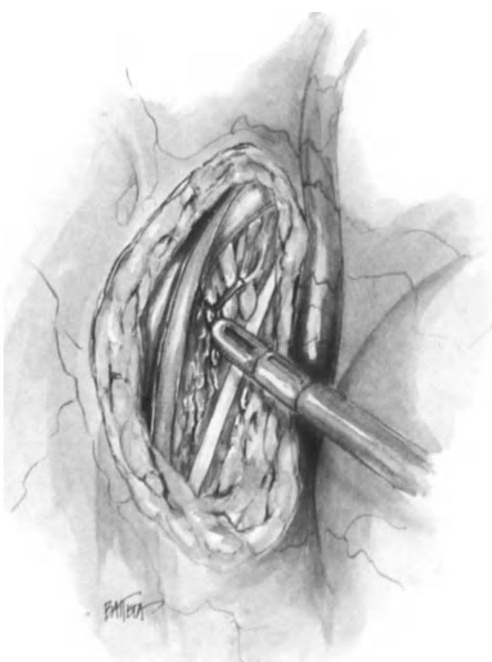

FIGURE 31.4.15. There should be no bleeding in the fossa after the nodes have been removed. It is also important to make sure that all of the nodal tissue has been removed from under the iliac vein. One may elect to remove common iliac nodes after the deep iliac nodes have been taken, but it is not clear whether this is worthwhile.

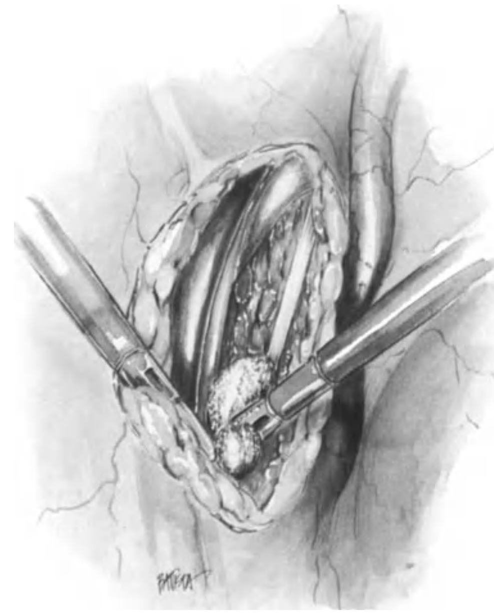

FIGURE 31.4.16. Collagen or antiplatelet products can be placed in the fossa to prevent venous bleeding once the CO_2 has been removed from the abdomen.

TABLE 31.4.1. Operative time decreases with increased surgeon experience.

Patient number	Operative time (min)
1–20	173.6 ± 10.9
21–40	144.4 ± 7.9
41–60	128.5 ± 4.5
61–80	134.8 ± 5.4
81–100	116.6 ± 7.7

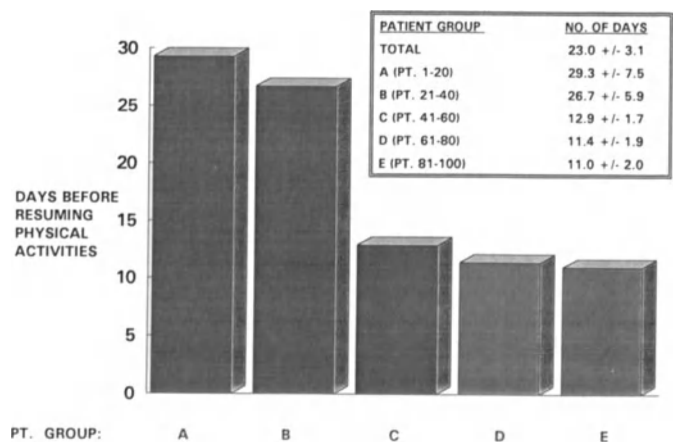

FIGURE 31.4.17. Relation of patient body size and operative time.

In our experience, 10 or 11 nodes were collected per laparoscopic lymphadenectomy. Similar results have been obtained by others, who report average yields of 5 to 15 nodes per dissection.[5,17,18,21,23,33,36] In addition our experience has been that as many, if not more, nodes are harvested during laparoscopic lymphadenectomy as during open lymphadenectomy (Table 31.4.2). Parra and

TABLE 31.4.2. Comparison of number of lymph nodes collected by laparoscopic and open techniques.

Procedure	Metastasis	No metastasis
Open surgery (76 patients)	6.5 ± 0.6	6.2 ± 0.3
Laparoscopy (69 patients)	10.5 ± 0.6	10.3 ± 0.5

colleagues[23] also had similar nodal yields in open and laparoscopic procedures. In addition, Parra reported that when radical retropubic prostatectomy was performed on nine men following laparoscopic lymphadenectomy, no additional nodal tissue was obtained. See and colleagues[33] reported that a twofold increase in nodal yield can be obtained when an inverted-V peritoneotomy rather than a linear peritoneotomy is used to expose the obturator fossa.

Patients were generally quite satisfied with their recovery following laparoscopic surgery. Patients who had had prior open surgery strongly favored laparoscopy. The time required to return to normal daily activities (Table 31.4.3, Figure 31.4.18) depended to some extent on surgeon experience with the procedure. The earliest groups had the longest recovery period, primarily because the physician told them to wait longer before resuming activities. Once the surgeons were more comfortable, patients generally resumed their normal diet one or two days after surgery and were driving and performing normal household activities within a week. Physical activity was resumed 11 or 12 days after surgery. It should be remembered that people undergoing laparoscopic pelvic lymphadenectomy for staging prostate cancer are typically retired. Many patients noted that they could have resumed activities sooner had there been a reason to do so. Patients who were still in the workforce resumed activities sooner (in Table 31.4.3, patient group 21–40 included several patients who were still employed). Similar results have been reported by others.[4,11] Kerbl and colleagues[11] compared recovery after a laparoscopic procedure to that after an open procedure and found that recovery was significantly faster for patients who underwent laparoscopic technique; they returned to normal activities and to preoperative activity levels 3 to 10 times faster than patients who underwent open surgery.

Contraindications

Laparoscopic pelvic lymphadenectomy, although not as invasive as open surgery, still has risks. The abdomen is distended with CO_2 gas, sharp ports are placed in the abdomen, and a pelvic lymphadenectomy is performed in a manner similar to open lymphadenectomy. Thus, if a patient is not a candidate for surgery in general, he is not a candidate for laparoscopic pelvic lymphadenectomy.

TABLE 31.4.3. Days required to return to normal activity after laparoscopic pelvic lymphadenectomy.

Patient group	Normal diet	Driving	Normal activity
1–20	3.0 ± 1.2	7.2 ± 1.9	9.5 ± 2.8
21–40	1.1 ± 0.1	5.0 ± 0.6	9.5 ± 2.6
41–60	1.1 ± 0.1	5.0 ± 0.6	9.5 ± 2.6
61–80	1.6 ± 0.3	5.0 ± 0.9	5.1 ± 0.9
81–100	1.5 ± 0.4	5.7 ± 0.9	6.0 ± 1.3

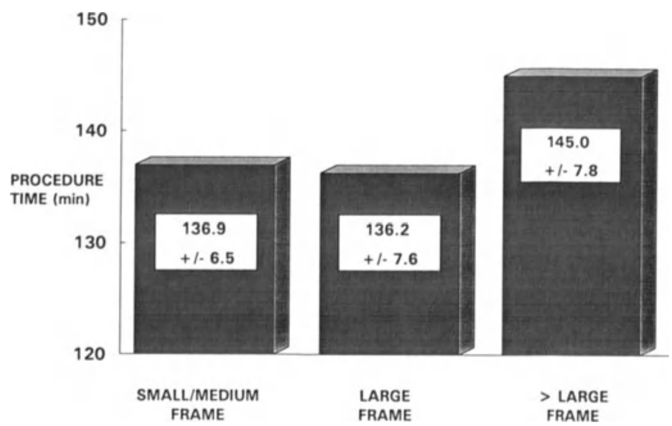

FIGURE 31.4.18. Effect of surgeon's experience with laparoscopic procedure on patient's return to full physical activity.

Absolute contraindications for the laparoscopic approach include sepsis, coagulopathy, and severe cardiopulmonary insufficiency. Another factor to consider in deciding whether to perform laparoscopic pelvic lymphadenectomy is the relative obesity of the patient. In general, the procedure is much more difficult in patients who are very large or obese, as reflected by an increased operative time (Figure 31.4.17). Patient obesity may be an absolute contraindication if the abdominal wall is thicker than the ports are long. Other relative contraindications for the procedure include: abdominal aneurysms; distended bowel or significant chance of dense adhesions of the bowels; severe, chronic, obstructive pulmonary disease (COPD) with hypercarbia (since this procedure may increase CO_2 levels); a history of phlebitis; large, umbilical hernias; and bleeding disorders.

Complications

Complications from laparoscopic pelvic lymphadenectomy tend to decrease as surgeon experience increases. In our experience the majority of significant complications occurred in the first 20 or so patients. Major complications we encountered included: aspiration pneumonia (< 1%); an infected lymphocele (< 1%); and a partial-thickness laser incision of the iliac artery (< 1%), which was repaired laparoscopically during the procedure. Minor complications of note include scrotal or penile swelling (10%), bruising or bleeding around the incision sites (5%), and urinary retention or voiding difficulties (4%). Several other investigators report low morbidity rates for laparoscopic pelvic lymphadenectomy.[4,5,9,10,21,23,36,37] Complications of significance that have been reported include intraoperative bladder laceration[7] and venous injuries,[38] pelvic hematoma,[7] infection,[38] and small bowel obstruction as a consequence of trocar injury to the ileum.[39] Kerbl and colleagues[11] reported a higher complication rate for laparoscopic procedures (13%) than for open procedures (0%) in a study of 30 laparoscopic and 16 open cases. However, the authors noted that all complications occurred in the first 12 patients, which again demonstrates that a learning curve is associated with the technique.

Discussion

Laparoscopic pelvic lymphadenectomy is a viable alternative to the open procedure. The laparoscopic procedure should be considered for high-risk patients who are being considered for a radical retropubic prostatectomy; for the staging of cancer prior to radiation therapy; and for the staging of cancer prior to a radical perineal prostatectomy. Walther[40] has predicted a resurgence of radical perineal prostatectomy to be used in conjunction with laparoscopic pelvic lymphadenectomy.

The open technique is clearly preferable for patients with absolute contraindications to the laparoscopic technique, such as extensive previous abdominal surgeries or morbid obesity. However, in many instances presurgery staging information, such as Gleason scores and PSA values, combined with the patient's health and general medical history, will allow the surgeon to recommend the laparoscopic procedure, avoiding unnecessary open surgery.

Summary

Laparoscopic pelvic lymphadenectomy for the staging of prostate cancer is a useful technique that has a low complication rate and enables the patient to resume normal activity quickly. When variables such as the patient's general health status, the Gleason score from a prostate biopsy, and PSA values are taken into account in patient selection, laparoscopic pelvic lymphadenectomy is a safe alternative to open surgery. Thus patients can avoid potentially unnecessary open surgery and its attendant risks.

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31.5 Techniques of Combined Intracavity Endoscopic and Laparoscopic Therapy

Graham Watson

Laparoscopy now ranks with intracavity endoscopy in importance as a technique for minimally invasive surgery. As we develop minimally invasive surgery we first attempt to replicate open surgery and then to perform procedures that are not possible by open surgery. The combination of laparoscopy and intracavity endoscopy might make endoscopic surgery more effective. This is the possibility this chapter will explore.

Laparoscopy as an Adjunct to Open Surgery

The use of laparoscopy as an adjunctive rather than a primary procedure has been reported sporadically in the literature. One can mobilize the ligaments and ovaries laparoscopically in order to perform a hysterectomy vaginally rather than abdominally. One can use the same principle in urology and general surgery; Bernhard and Hulbert have described the use of laparoscopy to mobilize the seminal vesicles. This made a perineal prostatectomy easier and more controlled in their opinion. The laparoscope has been used by Puppo and colleagues to dissect the bladder and uterus as well as to mobilize the ureters (which were brought out as stented-end ureterostomies) prior to anterior exenteration performed through the vagina. Coptcoat described the similar use of a laparoscope to mobilize a loop of ileum and the ureters before an ileal-loop diversion. He then performed the anastomosis of bowel and the anastomosis of the ureters to the bowel extracorporeally. One can almost consider the extracorporeal component of these procedures to be the adjunct to the laparoscopic surgery. Soon, it may be possible to do the entire procedure laparoscopically.

Combined Ureteroscopy, Cystoscopy, and Laparoscopy for Ureteric Reimplantation

The combination of laparoscopy and endoscopy proved synergistic in the case of a patient with a ureteric tumor. A 75-year-old woman presented with an obstructing lesion seen on intravenous urogram in the right ureter at the level of the bifurcation of the common iliac vessels. There was doubt about the diagnosis, and a ureteroscopy was performed. A tumor was discovered. On biopsy this was shown to be P1B G2. The patient did not want to have open surgery and requested an endoscopic approach. The following is a description of how the procedure was performed.

The patient was anesthetized with muscle paralysis. She was placed in the supine position, slightly head-down, and a pneumoperitoneum was produced. The ports were placed as follows: a 10-mm port subumbilically; a 10-mm port in the right iliac fossa; and a 5-mm port in the left iliac fossa. The laparoscope was introduced via the subumbilical port. The line of Toldt was incised along the right colon, and the cecum was mobilized to gain access to the right ureter. At this point the patient was placed in the lithotomy position, and a 7.2F ureteroscope (Candela Corp.) was introduced into the right ureter. The ureteroscope was passed above the tumor. The presence of the ureteroscope facilitated the procedure in two ways. It allowed easier identification of the ureter (Figure 31.5.1) and, more importantly, it defined the level of the tumor for the laparoscopist (Figure 31.5.2). A metallic clip was placed across the ureter 2 cm above the level of the tumor. A conventional cystoscopy was then performed, and the right ureteric meatus was cannulated with a Bugbee electrode. Diathermy was used to occlude the intravesical ureter. At this point a 24F Storz resectoscope with a Collings knife was introduced into the bladder. The bladder was distended with CO_2 rather than fluid. The right ureteric meatus was then circumscribed (Figure 31.5.3), and the dissection was continued until the ureter was completely free from its attachments to the bladder.

We then reverted to laparoscopic technique. A nylon suture on a cutting needle was introduced by passing the suture through the abdominal wall in the right upper lateral port and grasping it with forceps. The suture was passed through the vault of the bladder and then passed out 2 cm from the initial puncture site. This suture was placed on traction while the bladder was mobilized by dissection of its lateral pedicles (Figure 31.5.4). This brought the bladder up as would a psoas hitch reimplantation. A tunnel through the bladder high on the posterior wall was created using forceps introduced via a cystoscope. The lower end of the ureter was then passed into the jaws of the cystoscopic forceps, and the ureter was drawn into the bladder. Traction on the bladder and further mobilization allowed the ureter to be drawn into the bladder until the ureter above the clip was intravesical (Figure 31.5.5). The ureter was then opened above the clip and a JJ stent was inserted. The adventitia of the

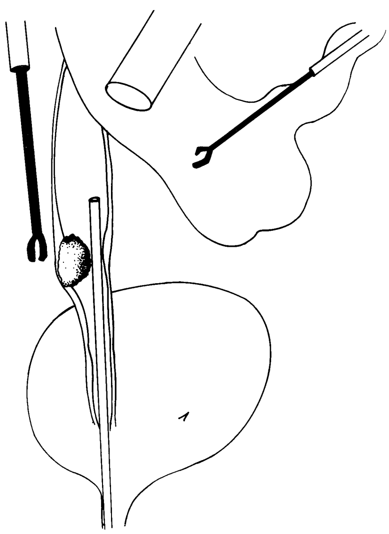

FIGURE 31.5.1. Simultaneous ureteroscopy and laparoscopy facilitates dissection of the ureter and identification of the level of the tumor.

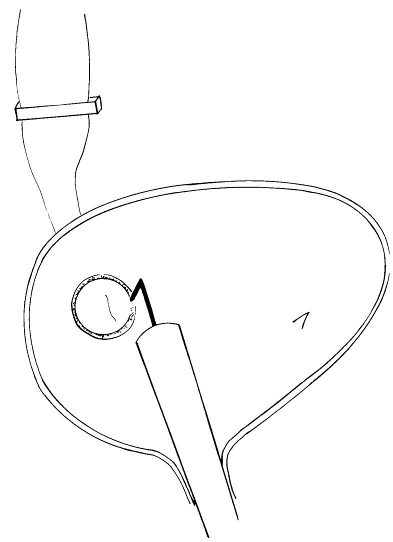

FIGURE 31.5.3. Transurethral fulguration of the intramural ureter followed by circumcision of the ureteric orifice.

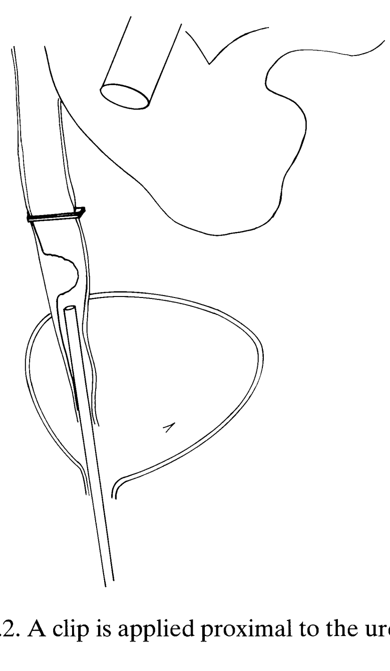

FIGURE 31.5.2. A clip is applied proximal to the ureteric tumor.

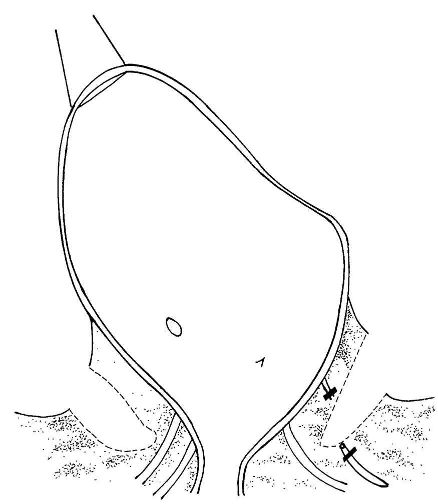

FIGURE 31.5.4. A suture in the bladder dome draws the bladder towards the right loin, while laparoscopic dissection of the vesical pedicles mobilizes the bladder.

ureter was clipped to the peritoneal surface of the bladder laparoscopically. The ureter was then fully divided to create a spatulated end. The suture holding the bladder was secured to a metal stud so that there would be no tension on the ureterovesical anastomosis. No attempt was made to suture the spatulated ureter to the bladder mucosa. Finally the bladder was catheterized and a tube drain was inserted into the peritoneum via the 10-mm port in the right iliac fossa (Figures 31.5.6–31.5.8).

In the early postoperative period the patient needed little analgesia and was ambulatory on the first postoperative day. The tube drain was removed after five days, after insignificant drainage. The urethral catheter was left for 10 days, at which time a cystogram was performed; there was no extravasation and the catheter was removed. The suture secured on the metal stud was removed after 14 days. Finally the JJ stent was removed after three months.

A cystogram performed after the stent was removed

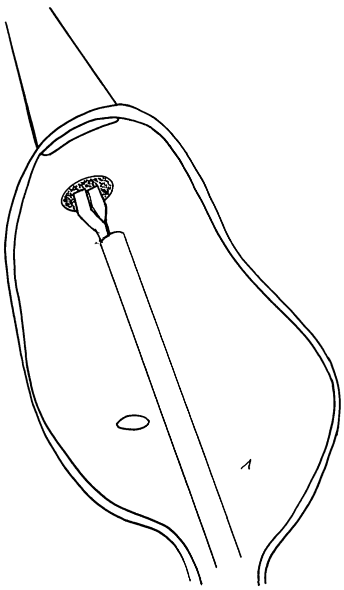

FIGURE 31.5.5. Transurethral dissection of a tunnel obliquely through the bladder wall.

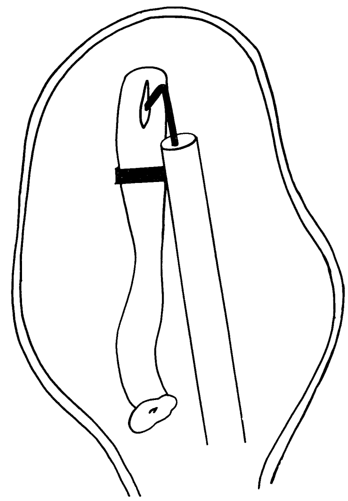

FIGURE 31.5.7. The ureter is incised above the level of the clip and a JJ stent is inserted. The ureter is then completely transected.

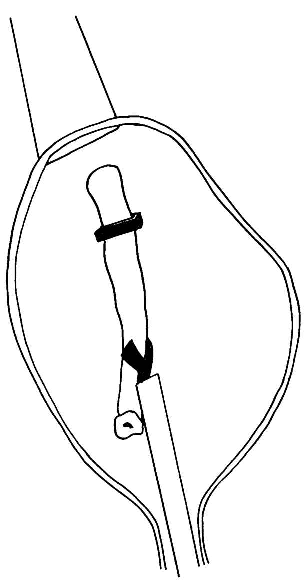

FIGURE 31.5.6. The ureter is pulled through the new tunnel transurethrally.

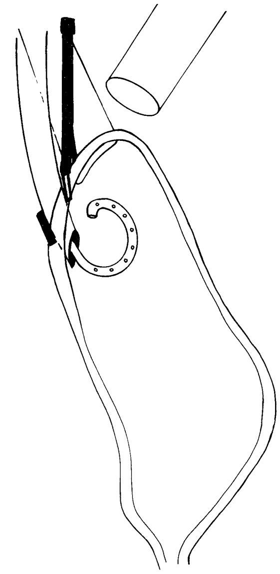

FIGURE 31.5.8. The adventitia of the ureter is clipped to the serosa of the bladder from the peritoneal aspect, and the suture maintaining tension on the bladder is secured to a button at the right loin.

showed no reflux. An intravenous urogram showed poor drainage from a dilated right pelvicalyceal system. At a follow-up cystoscopy, it was possible to pass a ureteric catheter through the neoureterostomy, and there was no significant obstruction.

Combined Laparoscopy and Cystoscopy for Bladder Tumor Work

One of the earliest descriptions of combined laparoscopic and cystoscopic management of invasive bladder cancer was by Rothenberger in 1989. He used a Nd:YAG laser to irradiate tumors on the dome of the bladder and laparoscopy to remove bowel from the serosal aspect of the bladder. The risk of damage to ileum in the peritoneum limits Nd:YAG laser penetration into the bladder wall. By introducing a pneumoperitoneum and separating the bowel from the bladder, this risk was avoided. A logical extension of this technique is to coagulate the serosal aspect of the bladder laparoscopically. This would cause transmural coagulative necrosis at least in the case of T2 bladder tumors. We have used this combination of approaches in three patients with T2 cancer of the bladder vault. They have all had recurrences in other parts of the bladder but have not shown signs of local recurrence after follow-up of 6 to 18 months. Coptcoat has described laparoscopic partial cystectomy for selected cases of bladder cancer. He did not combine the procedure with cystoscopy, although he mentions this as a possibility for the future. Removal of the tumor has the advantage of providing a specimen for histology but the disadvantage of causing malignant cells to spill into the peritoneum. Very occasionally it is possible to perform a total cystectomy laparoscopically. This has been described by Parra and colleagues.

Watson, Ralph, and Wickham have described the use of laparoscopy and cystoscopy to treat bladder instability in three patients. The detrusor was incised from the serosal aspect of the bladder, leaving the epithelium intact. They used a resectoscope with a Collings knife introduced from below the umbilicus in the midline. A cystoscope in the bladder allowed better control of the process. Carter and Coptcoat independently arrived at the same approach to this problem. Instead of performing simultaneous cystoscopy, they introduced methylene blue into the bladder. They divided the detrusor, again leaving the epithelium intact. Instead of using the Collings knife to hook up the muscle, they used forceps and scissors laparoscopically. They describe their results as 60% complete response and 40% partial response in an unspecified number of patients.

Combined Laparoscopy and Endoscopy in General Surgery

Dallemagne and colleagues have described the use of laparoscopy together with thoracoscopy through a small incision in the neck to perform a subtotal esophagectomy for a middle-third esophageal carcinoma. They started by inserting five trocars in the right lateral chest wall, dividing the right inferior pulmonary ligament and freeing the esophagus from the hiatus to the neck. The azygos arch was divided using an Endo GIA stapler (US Surgical Corporation). The stomach was then mobilized using a laparoscopic approach based on the right gastric artery and the greater curvature arcade. The stomach was tubularized from the angle of the lesser curvature proximally, using a succession of staples. Finally the proximal esophagus was anastomosed to the stomach via the small incision in the neck. Kipfmuller and colleagues used a transcervical endoscopic technique to dissect the esophagus and adjacent nodes without recourse to thoracic trocars.

In both cases endoscopic routes were employed to reduce the trauma of thoracoabdominal incisions. However, endoscopy and thoracoscopy were used to gain access to adjacent body spaces rather than to both aspects of an organ simultaneously. Laparoscopy can also be combined with gastroscopy, colonoscopy, and choledochoscopy. The advent of endoscopic techniques further increases the potential of these techniques. For example, a small flexible choledochoscope can be introduced via a port into the common bile duct. A pulsed laser or a small electrohydraulic probe can then be used to fragment a stone in the duct.

Endoscopy and Retroperitoneoscopy

Gaur has published his use of a balloon introduced within Gerota's fascia to create a space for retroperitoneal endoscopic nephrectomy. Provided the peritoneum is not punctured, this technique provides excellent access for endoscopic surgery on the kidney, pelviureteric junction, and upper ureter. This technique causes less pain and is associated with less risk of bowel injury than laparoscopy. Extraperitoneal approaches for lymph node sampling (Hald and Rasmussen) and for bladder neck suspension (Chapple and Osborne) have also been described. Kuenkel and colleagues argue that the retroperitoneal approach is always preferable to the laparoscopic intraperitoneal approach for any part of the genitourinary tract. The advantage of combining endoscopy with retroperitoneoscopy would be that the peritoneum and its contents would be isolated from the surgical field. There would be no risk of intraperitoneal rupture if, for example, an extensive bladder tumor was coagulated from both the intra- and extravesical aspect.

Conclusion

The variety of the examples given in this chapter demonstrates the practical inventiveness of modern laparoscopists. Additional endoscopic access would allow much more extensive procedures to be performed. With the ability to sew, cut, staple, fragment, coagulate, and weld comes increasing effectiveness. Most of the examples given here demonstrate that conventional surgery can be replicated with endoscopic techniques. However, the examples also suggest that endoscopy may eventually allow organs that are now sacrificed to be preserved. The ability to coagulate a tumor from both aspects of an organ will increase the safety of endoscopic procedures for cancer. The combined approach may well encourage surgeons to consider organ preservation.

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32
Angioscopy

32.1
Operative Angioscopy

Malcolm B. Herring

Angioscopy n. (ăn'jē ă skə pē) [Gr. angos—*vessel + skopia—a seeing, an examination] the visual examination of a blood vessel.* Surgeons and physicians have been looking at blood vessels for centuries, but mostly they have seen the outside of the vessel. The development of fiberoptics, irrigation systems, and suitable cameras allows us to have a good look at the inside as well. Most (but not all) of the applications for angioscopy involve *luminal* rather than extraluminal angioscopy. In this chapter, a number of applications for angioscopy will be reviewed. Finally, the chapter will focus on two applications with which the author is experienced.

The first attempts to look into the blood vessels of living animals were frustrating efforts by Rhea and Walker to look into the heart in 1913. They could not displace blood sufficiently to see well. Indeed the displacement of blood is the primary problem of vascular endoscopy and sets it apart from its gastrointestinal and pulmonary counterparts. Angioscopy is now more sophisticated. The angioscopist has a three-dimensional, full-color view of the vessel, and can visualize the vessel repeatedly. These are clear advantages over radiographic techniques. Of course, radiation exposure, contrast-agent toxicity, and the need for a special technician are also avoided.

Experimental Applications

Many of the applications for angioscopy that are now experimental will undoubtedly graduate to clinical use. One intuitive application is to guide the delivery of argon laser energy to vascular occlusions.[1] A somewhat less obvious idea is the use of angioscopy to evaluate luminal thrombus in pelvic veins during venous thrombectomy.[2] Percutaneous techniques for guiding percutaneous transluminal angioplasty, atherectomy, and stent placement procedures on peripheral and coronary arteries are envisioned.[3] Finally, neurosurgeons are experimenting with the use of angioscopy for the evaluation of extracranial vascular occlusions.[4]

Venous Disease

Some applications of angioscopy are now routine. Several German institutions use angioscopy to treat incompetent perforating veins in patients with chronic venous insufficiency.[5–7] In these patients the skin is in poor condition and intolerant of large incisions. Angioscopy permits the ligation of perforating veins through limited incisions. However, unlike most angioscopic procedures, perforating-vein surgery is done with an *extraluminal* approach. An analogous extraluminal approach is used for the sclerotherapy of esophageal varices during esophagoscopy.

Intraluminal angioscopy has been used to facilitate the repair of incompetent venous valves. The angioscope is directed peripherally in the vein, and the vein is gently pressurized with irrigating solution. A competent valve will be driven closed, and incompetent, flaccid leaflets will be readily apparent. Sutures can be placed extraluminally through the cusps to tighten the leaflet and restore the valve. Irrigation is then repeated to check valve competence.

In Situ Vein Grafts

Traditionally, *in situ* vein grafts for lower-extremity arterial reconstruction have required long incisions to expose the vein. The valves must be cut and the branches occluded before the vein can be used as an arterial graft. The angioscope allows these tasks to be done transluminally, reducing the length of incisions, and decreasing the morbidity of the procedure.

The angioscope must be narrow enough to negotiate the vein graft. Relatively small shear stresses applied to the wall of the vein destroy critical endothelial tissue, raising the possibility of neointimal fibrous hyperplasia and subsequent stenosis. Most veins can be served with a 2.3F instrument, but smaller veins that are used often for tibial bypasses will not accommodate an instrument this large. We usually select a 1.5F angioscope for them.

The narrower angioscope has fewer optical fibers and a smaller working channel. Fewer optical fibers results in a smaller image and decreased image resolution. A smaller irrigation channel slows the clearing of blood from the lumen of the vessel. The smallest instruments have no working channel, and irrigation is performed through another catheter placed near the angioscope. While irrigation through a second catheter is usually quite satisfactory, more irrigant is needed because the vein must be cleared from the catheter's insertion site to the angioscope before the image is cleared of blood.

Some angioscopes are sold for one use only. Others are designed for multiple uses. Generally, the multiple-use instruments have more optical fibers and better image resolution but cost more. They require gas sterilization, and are therefore not well suited to hospitals with a high volume of angioscopy. The working channels of all angioscopes are difficult to clear of biologic fluids. The image resolution of the single-use instruments, although lower than that of multiple-use instruments, is adequate.

Irrigation can be performed with any of a number of commercial pumps. A conventional IV fluid such as lactated Ringer's solution with 3,000 units of heparin per liter works well. Omission of the heparin results in clouding of the image because a film of blood products builds up on the tip of the fiberoptic bundle. While pumps are conventional, a very satisfactory irrigation system can be fashioned with a 30-mL syringe and a three-way stopcock. Using this device, an attentive assistant can clear the blood from view with minimal irrigation. An average of 250 mL of irrigant is needed for an entire femoral/popliteal bypass.

One must be careful not to administer too much irrigant. The surgeon's attention is directed to the image and luminal manipulations. Fluid overload can be avoided by assigning someone to notify the surgeon each time 250 mL of irrigant has been used. Once the major branches are occluded, the systemic fluid load can be limited by leaving one or both ends of the vein graft open. Some irrigant will flow into the wound, where it can be aspirated. Finally, less irrigant will be needed if the large proximal branches of the saphenous vein are ligated through a groin incision.

The first mission of the angioscopist during *in situ* bypass is the division of valves. Visual control is useful with some kinds of valvulotomes but not others. The Mill's and Mehigan valvulotomes are hook-shaped, with the cutting surface in the crook. These valvulotomes engage the leaflets of closed valves and the ostia of vein branches equally well. With luminal visualization, the ostia can be spared. On the other hand, there is no advantage to angioscopy during valve division with self-centering valvulotomes, such as the Hall, LeMaitre, and Bush.

Angioscopy is used after valve dissection to ensure complete valvulotomy and to identify vein wall damage. The completeness of valvulotomy is best assessed by directing the angioscope distally and increasing the proximal luminal pressures with irrigation to close the valves. All of the leaflet fragments of an adequately divided valve will fall against the vein wall during irrigation.

To assess the completeness of valvulotomy, the operator must be able to see both of the valve leaflets and their remnants. Since the vein does not generally take a straight course, it may be difficult to see the entire vein. The first 15 cm of the vein in the thigh and the vein near the knee are usually curved. The proximal saphenous vein can be divided before angioscopy and straightened to some degree with gentle traction. A Dacron tape works well, looped around the vessel and retracted. Other segments of vein can be straightened with gentle finger pressure on the skin. Adjusting the flexion of the knee helps when viewing the vein near the knee. Finally, some angioscopes have a flexing tip. Flexion and rotation of the angioscope generally permit good visualization.

The angioscopist's second mission during *in situ* bypass is to control the side branches of the vein. One approach, advanced by Mehigan, is to identify the patent branches angioscopically and to isolate them through an incision using the angioscope light as a homing beacon. (The angioscope light is more easily seen if the ambient light is low.)

Branches that are missed by angiography and Doppler techniques are readily identified by angioscopy. The ostia of the branches are often seen directly, but the most reliable technique is to create a low luminal pressure at the end of the angioscope. The bleeding streamlines then identify the branches. Low luminal pressure is easily created by the attentive assistant, who simply aspirates the 30-mL syringe, but this maneuver is difficult with motorized pumps. Occasionally, the branch ostium is hidden by a valve leaflet. In that case, the ostium may be revealed by reinserting the angioscope in the distal vein and directing it proximally.

To limit the number of incisions, branches can be occluded transluminally. Several occlusion devices have been tried in animals; clinically, however, embolization coils have seen the most use. To deliver embolization coils the operator must: (1) identify the branch; (2) cannulate the branch; (3) estimate the diameter of the branch; (4) determine the distance from the branch ostium to the secondary branch; (5) select an appropriately sized embolization coil; (6) deploy the entire coil into the branch; and (7) test the occlusion and the completeness of coil deployment.

When we first attempted this procedure the angioscope was directed distally from a proximal insertion site and a coil delivery catheter was directed proximally from a distal insertion site (Figures 32.1.1A–C). The vein was

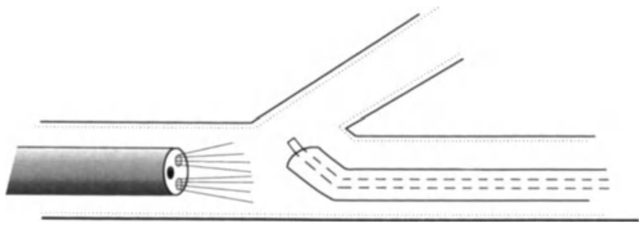

FIGURE 32.1.1A. The angioscope is inserted proximally and the coil delivery catheter is inserted distally.

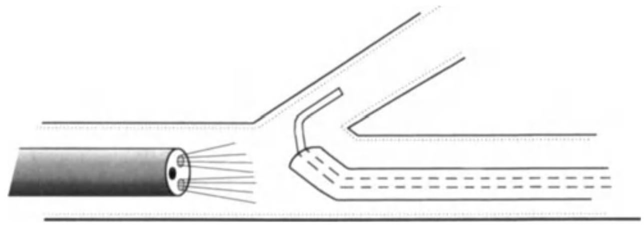

FIGURE 32.1.1B. The nylon tracking catheter is advanced through the delivery catheter until it is well within the branch.

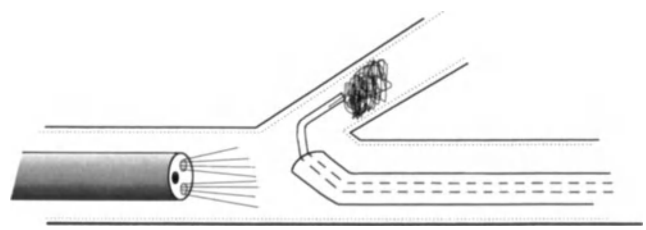

FIGURE 32.1.1C. A coil-occlusion device is deployed through the tracking catheter into the branch. The angioscope allows the tip of the tracking catheter to be monitored and permits the operator to determine if the coil protrudes into the graft lumen.

rendered inflexible by the two luminal instruments, and branch cannulation proved difficult and time-consuming. To avoid this problem, we passed the coil delivery catheter through the working channel of the angioscope. Our ability to cannulate the branches improved greatly. Angioscopy proved an excellent way to test the completeness of vein occlusion and coil deployment, but the remaining steps in the process were better handled fluoroscopically.

In short, angioscopy is an excellent means of controlling the division of venous valves and identifying side branches during *in situ* bypass grafting. Nonetheless, it is not the ideal tool for coil occlusions of branches.

Thromboembolic Disease

Angioscopy is an excellent way to test the completeness of thromboembolectomy (Figure 32.1.2). Arteriograms often fail to reveal residual wall thrombus, and multiple

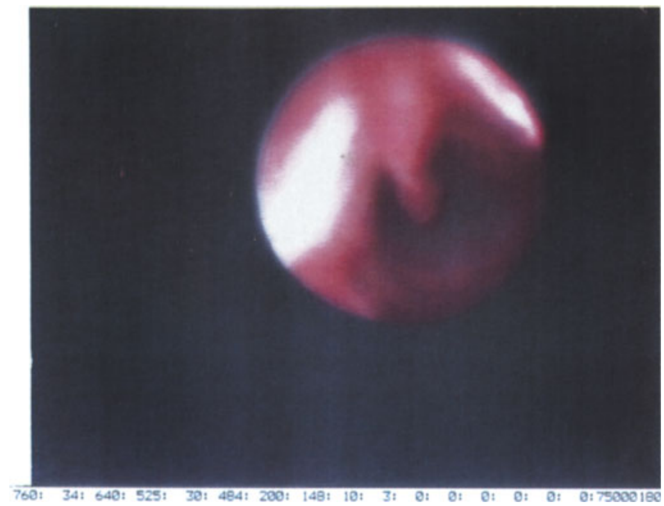

FIGURE 32.1.2. Residual thrombus (pink, uvula-shaped projection over the dark lumen) is often seen after apparently complete thrombectomy.

imaging procedures may require the injection of large doses of radiographic dye.

A 3F 55-cm-long flexing-tip angioscope can be used for most patients. This angioscope has a working channel that will accommodate the *shaft* of a 3F embolectomy catheter. Direct visualization of the balloon is worthwhile in some cases, such as the removal of particularly adherent thrombus. A flexing tip is ideal if the goal is selective balloon cannulation of one branch of a trifurcating vessel and to gain good visualization in aortofemoral graft occlusions. Unfortunately, few other instruments are suitable for use through the working channel. Consequently, the balloon and the angioscope are usually passed independently.

Once the femoral or popliteal lumen is opened, retrograde bleeding can obscure the view. A tourniquet about the calf can reduce the irrigation needed for visualization. An occluding balloon catheter can be used to allow visualization of a newly opened aortofemoral graft. To determine the hemodynamic significance of retained material, the operator must estimate the degree of luminal obstruction. It is helpful to imagine the angioscopic field as a pie divided into quarters or eighths when calculating the residual obstruction.

Conclusion

Angioscopy is a developing technology for visualizing blood vessels. Extraluminal angioscopy is currently used to ablate incompetent perforating veins of the leg and varices of the esophagus. Intraluminal angioscopy can be used to aid in the construction of *in situ* femoropopliteal bypasses and in thromboembolectomy. Other applications await the development of instruments that can be used with angioscopes.

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32.2
Endoscopic Techniques for Percutaneous Transluminal Coronary Procedures: Intravascular Ultrasound and Angioscopy

Zachary I. Hodes and Thomas J. Linnemeier

Introduction

Literally millions of coronary arteriograms will be performed in the United States in 1995. Their purpose is to identify the presence and define the extent of coronary artery disease. The evidence they provide will lead to the performance of hundreds of thousands of intracoronary interventions. Angiography, long the gold standard for coronary imaging, reveals the vessel lumen only as a two-dimensional shadow. From orthogonal projections, the experienced angiographer must estimate the extent of luminal obstruction and reconstruct the three-dimensional appearance of the plaque. Little or nothing is revealed about the nature of the atheroma obstructing the vessel wall.

The new ability to acquire, *in vivo,* real-time ultrasound images of the vessel wall has greatly enhanced our understanding of coronary anatomy and disease. These images are altering our treatment of coronary disease in ways not imaginable just a few years ago. The percutaneous fiberoptic angioscope, which allows direct visualization of the vessel lumen and surface, is also expanding our knowledge of intravascular events and the results of transcatheter interventions. Both imaging modalities, currently in early development, may one day guide the choice of technique for catheter-based percutaneous transluminal coronary interventions and permit the results of these procedures to be more accurately assessed.

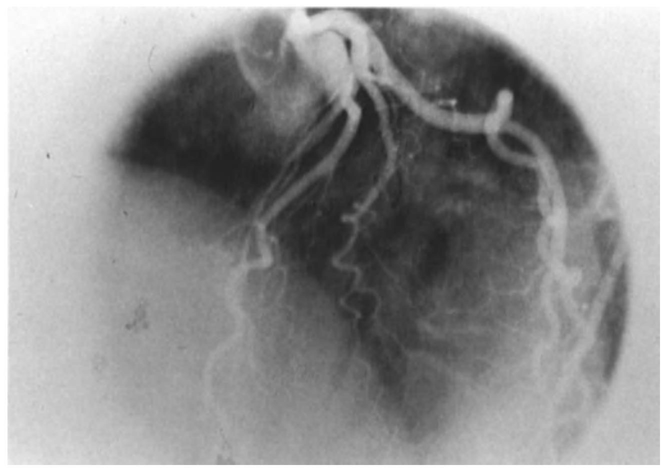

FIGURE 32.2.1. Normal coronary angiogram.

Coronary Angiography

Coronary angiography was first used to assess coronary artery stenoses in 1959 by Dr. Mason Sones.[1] Despite many refinements in x-ray equipment since then, the coronary lumen is still seen as a two-dimensional black and white shadow (Figure 32.2.1). The quality of the images has improved greatly, and most current systems offer digital image processing. Nonetheless, angiography has serious limitations, including imperfect quantification of the degree of luminal encroachment, particularly in the case of eccentric plaques. The inability to discriminate between intraluminal thrombus and intimal ulceration or fracturing is another well-known limitation of coronary angiography.[2] The most serious limitation for the cardiologist, however, is the inability to assess the composition of the plaque.

Better knowledge of the composition of intraluminal coronary lesions would allow better selection of therapeutic devices from the cardiologist's armamentarium, which includes means for directional removal of eccentric soft atheroma (directional coronary atherectomy), means to treat eccentric calcific plaques (directional laser fibers or rotational coronary atherectomy), and devices for long, diffuse narrowings (excimer or holmium lasers or rotational atherectomy).

The development of intravascular imaging techniques has given the cardiologist the ability to visualize the lumen and to obtain cross-sectional images of the vessel wall, placing these objectives within his reach.

Intravascular Ultrasound

Intravascular ultrasonographic imaging relies on the detection of ultra-high-frequency sound waves (20 to 30 MHz) reflected from vessel wall layers. Different tissue layers have different coefficients of reflection, and the layers in the image correspond to the layers of tissue in the normal or diseased vessel wall.

Intravascular ultrasonography developed in parallel with transthoracic echocardiography. Both mechanical (Cardiovascular Imaging Systems Inc.; Boston Scientific; and Intertherapy, Inc.) and solid-state phased-array (Endosonics Corp.) systems have been developed (Figure 32.2.2). Refinements of transducer hardware and computer software allow both systems to produce detailed images of both normal and diseased vessel walls. The cross-sectional diameter of ultrasound probes has been significantly reduced. The original devices had a diameter of 10F (3.3 mm). Current models include rapid-exchange catheters featuring monorail design and 3.5F shafts (1.15 mm) (Visions FX, Endosonics).

In an ultrasound image, a normal vessel appears to have three layers. A thin, reflective inner layer corresponds to the internal elastic lamina. An echo-free space represents the undiseased media. Finally, a reflective outer ring corresponds to the advential layer (Figure 32.2.3). Thickening of the inner layer is considered to be a normal consequence of aging. That the multilayered appearance is normal has recently been challenged, however.[3] It has been suggested that the normal vessel wall in young, morphologically normal arteries is homogeneous. This study used autopsy specimens for the young, normal subjects and transducer frequencies higher than those typically used in vivo. *In vivo* studies of transplant recipients have confirmed the homogeneous appearance of the vessel wall in very young vessels when imaged with high-frequency ultrasound (30 MHz). Separate vessel wall layers were not identified in these studies.[5,6]

Plaques take many forms. Intravascular ultrasound equipment will often detect plaques in vessel walls that appear normal on the coronary angiogram (Figure 32.2.4).[4-6] Ultrasonigraphically, soft lipid-laden plaques may appear relatively sonolucent (Figure 32.2.5). Other plaques have caps of denser fibrous material that is much more echogenic and appears as a brighter area in the image. Calcium is also detected, primarily as a shadowing artifact, because the ultrasound waves are completely reflected by mineralized plaques (Figure 32.2.6).

Reconstruction of the three-dimensional lumen and vessel wall morphology is also possible. Computer hardware and software are available to assemble a montage of 128 serial tomographic images acquired as the transducer is pulled across a segment of vessel wall. These images are often dramatic and reveal eccentric plaques, calcification, and the degree of residual stenosis after percutaneous transluminal coronary angioplasty (PTCA). Calcified areas within plaques can also be detected, as seen in Figure 32.2.7.

FIGURE 32.2.2. Endosonics ultrasound-imaging machine (Endosonics, Pleasanton, CA).

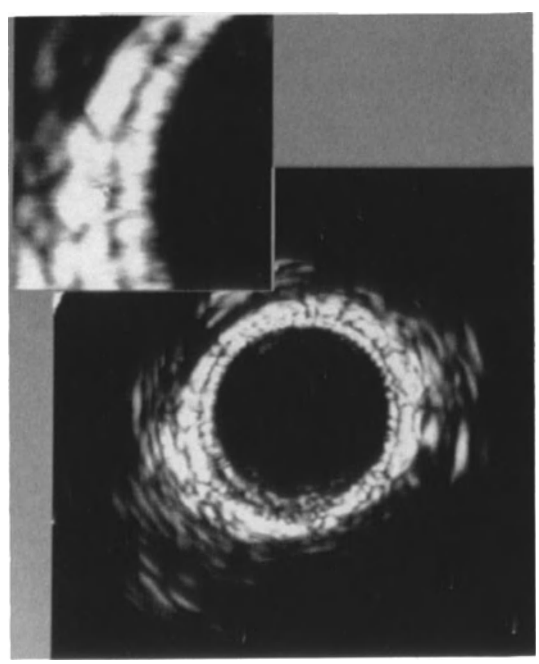

FIGURE 32.2.3. Normal coronary artery.

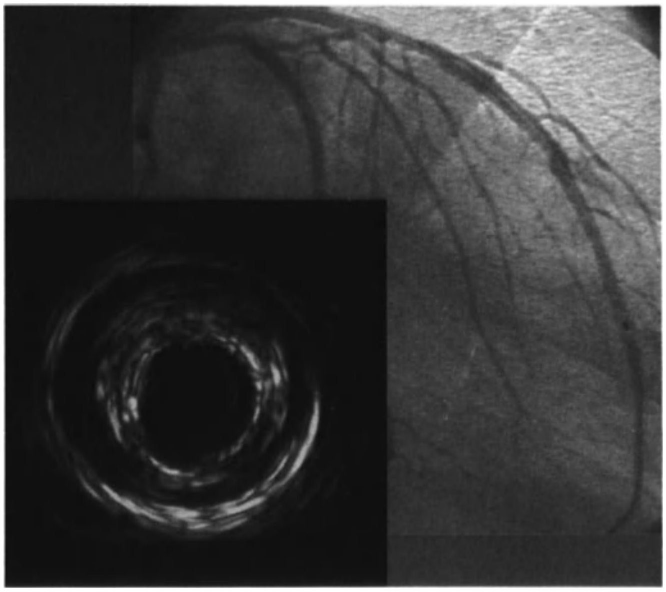

FIGURE 32.2.4. "Normal" angiographic coronary artery. This distal left anterior descending artery is actually quite thickened and diseased (ultrasound inset).

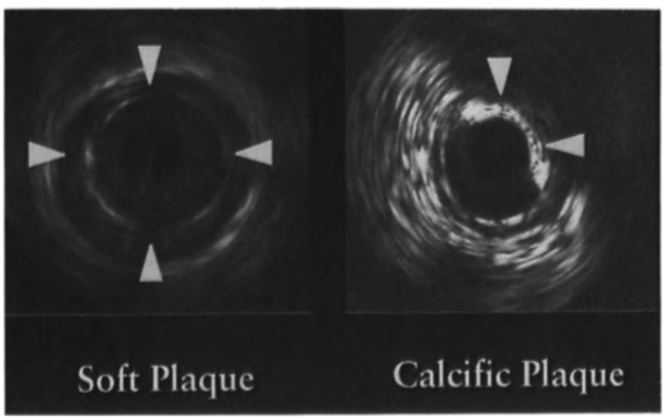

FIGURE 32.2.5. Plaques can be soft or highly calcified.

One of the most exciting recent developments is a combined balloon/ultrasound-imaging device (Oracle Micro, Endosonics) (Figure 32.2.8). The ultrasound transducer is mounted on a 3.5F catheter just proximal to the angioplasty balloon. This allows pre- and postdilatation ultrasound imaging. The studies of the use of intravascular ultrasound to assess coronary artery minimal luminal diameter and evaluate the results of PTCA are studies of procedures done with separate devices for imaging and angioplasty.[7–10] The combined device should reduce the number of catheter exchanges and therefore reduce both fluoroscopy time and blood loss. Combined balloon/ultrasound-imaging catheter systems (BUIC, Boston Scientific) have also been utilized for peripheral vascular procedures.[11]

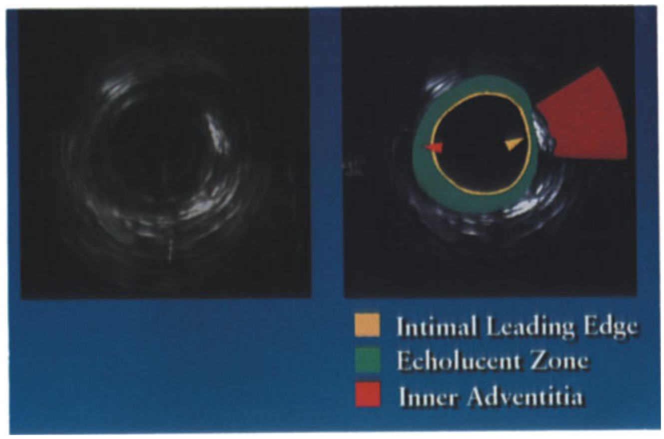

FIGURE 32.2.6. Calcified area is echolucent, a characteristic of a hardened artery.

Ultrasound imaging has been applied to assess the results of directional coronary atherectomy. Ultrasound imaging allows more accurate assessment of lesion morphology (eccentric versus concentric)[12] and former native lumen size (potential lumen)[13] than coronary angiography. This allows the atherectomy device to be matched to the potential lumen of the vessel. Accurate detection of calcium within the vessel wall also aids in sizing the device appropriately.[13] Ultrasound imaging has also confirmed the mechanism by which balloon angioplasty and directional atherectomy achieve larger lumens.[14] Angioplasty was shown to stretch the vessel; the internal elastic lamina was intact but had a significantly larger cross-sectional area. Also, fracturing of the vessel wall was much more common after balloon angioplasty than after atherectomy. Vessel wall stretching was not observed after atherectomy. Rather, the diameter of the vessel lumen increased due to plaque removal.

A recent study from Spain suggests that the composition of the atheroma, as inferred from its echogenicity, may predict the long-term outcome of directional atherectomy.[15] More echolucent plaques, thought to be lipid-rich, were more likely to recur when treated with directional atherectomy, despite more complete removal of plaque with the Atherocath.

Accurate assessment of the degree of left main coronary artery narrowing is important in deciding which therapy is appropriate for patients with disease of this vessel. On occasion, the angiogram may appear to show significant luminal encroachment within the left main artery when no significant narrowing is actually present. Nishimura and colleagues have recently employed intravascular ultrasound imaging to study the left main coronary anatomy in five patients where the coronary arteriogram was equivocal.[16] Useful information was derived in all cases. In one case a persistent intraluminal filling

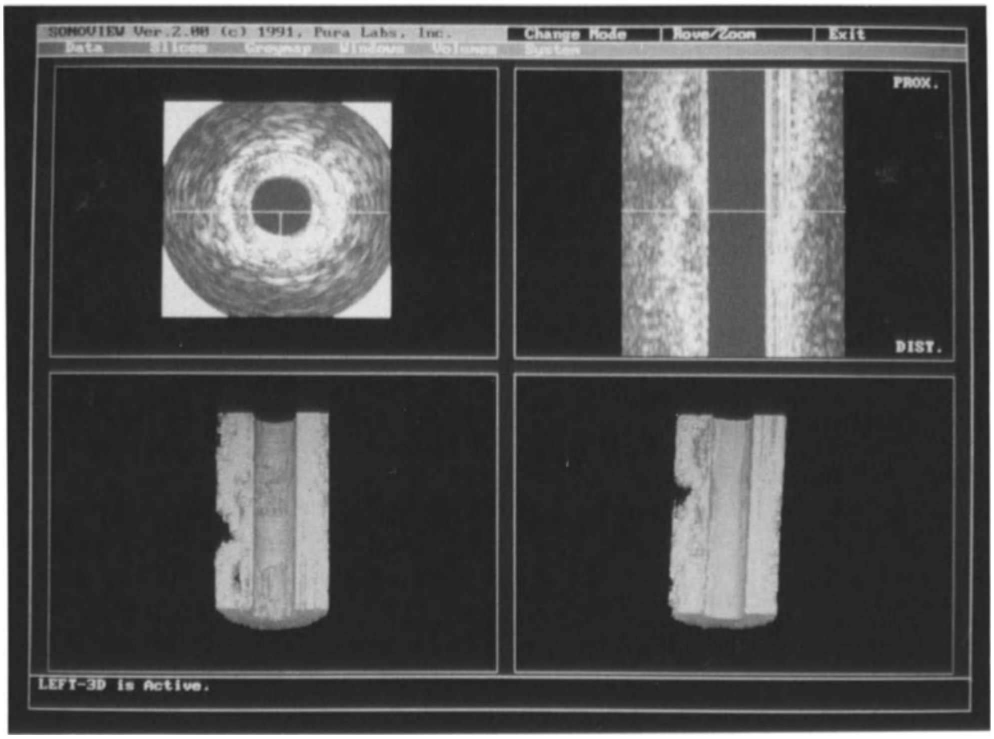

FIGURE 32.2.7. Computer-enhanced three-dimensional reconstruction from two-dimensional ultrasound. (Courtesy of Image-Comm Systems, Incorp., Sunnyvale, CA.)

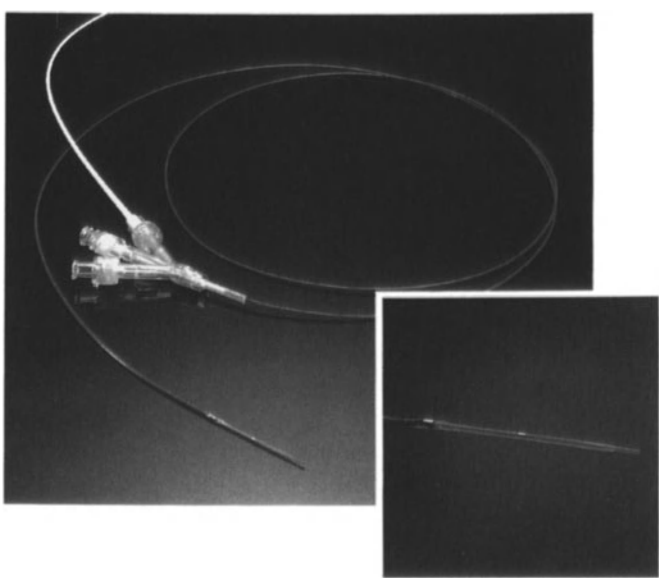

FIGURE 32.2.8. Oracle Micro diagnostic ultrasound catheter within therapeutic coronary angioplasty balloon catheter.

defect was seen on the angiogram after an interventional procedure had been performed on the left anterior descending coronary artery, but no evidence of intimal flap or other luminal encroachment was noted in the left main on the ultrasound images. This patient would probably have been sent for coronary bypass surgery if it were not for the ultrasound images.

Intimal dissection may occur when balloon angioplasty is done on coronary arteries.[17] When extensive dissection occurs, and particularly when spiral dissections develop, angiography often fails to reveal which is the true and which is the false lumen of the vessel. In an extreme case a computer-assisted reconstruction of a three-dimensional image of a chronically dissecting vessel allowed the dissection to be corrected by implantation of a balloon-expandable tubular-slotted stent (Johnson & Johnson Interventional Systems).[18]

Intravascular ultrasound imaging has also been useful in assessing the results of intracoronary stent placement.[19,20] A study of stents placed electively to treat restenotic lesions or lesions whose angiographic appearance suggested balloon angioplasty would have a poor outcome showed marked improvement in luminal diameter after stent implantation.[20] Nonetheless, there appeared to be little change in the morphology of the original plaque and no change in the overall plaque burden. No intimal dissection was noted. It is possible intimal fracturing had occurred, enlarging the lumen, and the dissection plane was sealed by the stent. The radial extent of vessel wall involvement with plaque appeared to increase, which suggests that circumferential redistribution of the plaque burden might also have contributed to luminal enlargement. Deaner and colleagues have employed ultrasound imaging to assess the placement and adequacy of final stent deployment.[19] This is another area where tomographic intravascular images are superior to conventional angiograms, particularly since most intracoronary stents are radiolucent. These studies used ultrasound to image Palmaz-Schatz (Johnson & Johnson Medical) stents. These are slotted-tubular devices with some degree of rigidity that are therefore less likely to embolize when the rigid ultrasound catheter is placed through them. Some feel there is significant risk of embolization when an ultrasound catheter crosses a coil stent, such as the Gianturco-Rubin (Cook Urological) device, but recent unpublished reports suggest these stents can also be imaged.

Coronary Angioscopy

Advances in fiber optics have made possible direct visualization of the vessel interior. Several manufacturers produce angioscopes (Olympus Co.; Advanced Cardiovascular Systems; Baxter Healthcare Corporation, Edwards LIS Division). An angioscope currently in clinical use (Baxter Healthcare Corporation, Edwards LIS Division) consists of a 4.5F (1.5-mm diameter) catheter with a proximal latex occlusion balloon and a 0.6-mm diameter fiberoptic bundle. The bundle is composed of a 3,000-pixel element-fused fiber, 10 120-m light fibers, and a focusing lens. It is possible to advance the fiber bundle 5 cm from the catheter tip. The device can be delivered through standard 8F angioplasty guiding catheters over a 0.014-in.-diameter coronary wire. Imaging is accomplished by occluding the vessel lumen with the balloon and flushing the vessel with crystalloid. The device is connected to a light source and a miniature video camera, and enlarged images are displayed on a video monitor and recorded on standard 3/4-inch videotape. A typical angioscope image of a thrombus within an atheromatous vessel is shown in Figure 32.2.9.

FIGURE 32.2.9. Red thrombus clinging to underlying yellow atheromatous coronary artery in patient with unstable angina.

The use of coronary angioscopy has been reported in patients undergoing bypass graft surgery. A descriptive study showed good correlation between luminal cross-sectional area determined intraoperatively by angioscopy and that calculated from angiography.[21] Sherman and colleagues performed intraoperative angioscopy on patients with unstable angina pectoris and patients who were felt to have stable coronary disease.[22] Intraluminal thrombus was found in all of the patients with rest angina and in none of the patients with stable symptoms. No thrombus was detected in vessels that were not thought to be the cause of the symptomatology in patients with unstable angina. Complex plaque was detected in patients with unstable anginal symptoms and not in patients with chronic stable angina. Coronary arteriography detected only one of four complex plaques and only one of seven thrombi. Angiography, in other words, was very insensitive to the lesions responsible for unstable anginal symptoms.

Coronary angioscopy was subsequently applied percutaneously to examine the vessel interior, both in patients with ischemic heart disease[23] and in patients with unstable angina pectoris and acute myocardial infarction.[24] Thrombi were frequently observed in the latter study. The character of the thrombi seemed to differ between the two groups. Thrombi were primarily grayish-white in patients with unstable angina and reddish in patients suffering acute infarction. The differences in color were thought to represent different compositions; the grayish-white thrombi were thought to be platelet-rich and to occur primarily in areas where blood flow had not been completely interrupted and the red thrombi were thought to contain fibrin mixed with erythrocytes and platelets and to occur in areas of stasis.

Percutaneous angioscopy has been used to observe changes in the coronary lumen brought about by percutaneous transluminal coronary angioplasty.[25,26] Pre-PTCA angioscopic findings in patients with stable and unstable anginal syndromes were similar to those described for patients who underwent angioscopy at the time of coronary bypass graft surgery.[26] Thrombi were not found in patients with stable angina. Thrombi were found on angioscopy in 8 of 10 patients with unstable anginal symptoms. Angiography detected thrombi in only two of these patients. Post-PTCA, mural thrombi were frequently detected, as was intimal dissection. Angioscopy detected thrombi in 75% of patients with stable angina and angiography detected it in none. Angioscopy frequently detected intimal disruption or dissection in patients with unstable angina both before (7 of 16 patients) and after (16 of 16 patients) angioplasty. In contrast, angiography failed to reveal evidence of dissection before angioplasty in any of the 16 patients with unstable symptoms and was interpreted to show dissection in only 7 of the 16 after the procedure.[26] Similar findings had been reported by Uchida and colleagues.[25] They observed intraluminal changes in response to thermal laser angioplasty, including the vaporization of an intraluminal thrombus in a patient with occlusive thrombi and acute myocardial infarction.

Recently, angioscopy has been used to determine the cause of abrupt closure of coronary vessels following intracoronary interventions.[27] Two patients were examined. Intimal dissection with some small areas of platelet thrombi were detected in a case of abrupt postprocedure closure; successful repeat angioplasty was performed. In a case of delayed closure, a white thrombus was seen to overlie ulceration produced by the previous day's dilatation procedure. This lesion, too, was successfully redilated.

Information obtained from coronary angioscopy is complementary to that obtained from intracoronary ultrasound. Angioscopy gives a forward-looking image of the lumen interior. It is superior to ultrasound for detecting intraluminal thrombus, although recent unpublished reports suggest that spectral analysis of ultrasonographic information may identify the composition of atherosclerotic plaques and other intraluminal encroachments. Siegel and colleagues performed angioscopy and intravascular ultrasound on postmortem human arterial segments.[28] They determined that the overall sensitivity of ultrasound was lower than that of angioscopy, primarily because of failure to identify laminar clots in normal vessel segments. Both imaging methods fell short in classifying disrupted atheroma as stable atheroma.

Summary

Intravascular ultrasound and intracoronary angioscopy are two new techniques for imaging the coronary vasculature. They both complement and supplement conventional coronary angiography. They also complement one another. Many potential uses have already been defined for both. Intravascular ultrasound has thus far proven to be the easier technique to employ and appears to have wider application both in diagnostic imaging and in choosing intracoronary interventions and assessing their outcomes. As the technologies evolve, they will undoubtedly find application in laparoscopic procedures as well.

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Section IV
Technological Aspects of Laparoscopy/High Technology

33
Physics of Tissue Ablation

33.1 Electrosurgery in Laparoscopy

Roger C. Odell

Introduction

Electrosurgical energy has been the "gold standard" for surgical dissection and hemostasis in most surgical disciplines for the past several decades. Cardiovascular and general surgeons and urologists have relied on this form of energy during the most demanding applications, such as coronary bypass surgery, hepatic resections, and transurethral resection of the prostate. To date no other energy source has been reduced to practice in such a diverse array of surgical applications. Unfortunately early laparoscopic applications did not have results as favorable as those of open applications.

The use of electrosurgery in laparoscopy dates back to the mid-1960s when gynecologists began to practice operative laparoscopy through a channel within a laparoscope. This single-puncture technique later gave way to multiple-trocar techniques. In the course of these procedures, a number of misadventures occurred, and the investigations of these incidents raised concerns regarding electrosurgery, particularly monopolar electrosurgery. The use of monopolar electrosurgery for laparoscopic procedures has been discouraged for the past two decades, but the medical instrument industry ignored the documented problems.[1] One of the objectives of this chapter is to revisit these problems, to explain their physics, and to discuss ways of minimizing risk as well as the options now available that can eliminate it altogether. Another key objective will be to describe the biophysics of electrosurgical dissection, fulguration, and desiccation because better understanding allows the surgeon to achieve better results with this surgical tool.

History

The use of high-frequency electrical energy in surgical applications dates back nearly a century. Electrosurgery is the generation of radio-frequency current between an active electrode and a dispersive electrode in order to elevate the tissue temperature for the purposes of cutting, fulguration, and desiccation. In contrast to electrocautery, the electric current actually passes through the tissue. In 1927 Harvey W. Cushing was the first to document in depth the art and the biophysics of electrosurgery. The early documents detail Cushing's appreciation and enthusiasm about the versatility of this device developed by William T. Bovie.

Cushing and Bovie did not invent electrosurgery, however. The Germans and French had documented the biophysics of electrosurgical currents in the late 1800s. William L. Clark, a general surgeon in Philadelphia, documented the removal of large benign and malignant growths of the skin, head, neck, and breast with electrosurgery in 1910. But it was Cushing's and Bovie's documentation that changed the course of neurosurgery and other surgeons' views of the potential uses of electrosurgical energy.

Temperature and Tissue

Energy cannot be created nor destroyed, but it can be converted from one form to another. Electrical energy is converted into heat at the active electrode for the purpose of vaporizing or cutting and coagulating the target tissue. The principles are quite similar to those that govern the conversion of laser energy to heat within the tissues.

At or above 44°C tissue necrosis starts. Between 50 and 80°C coagulation occurs, and collagen is converted to glucose. Between 80 and 100°C total desiccation of tissue occurs. At or above 100°C tissue is vaporized. Above 200°C carbonization starts; a visible black eschar is present if fulguration is occurring.

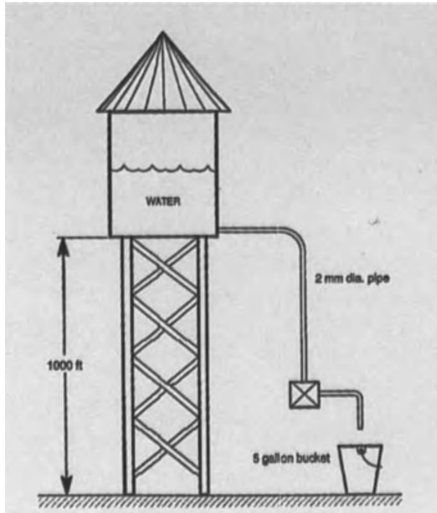

FIGURE 33.1.1

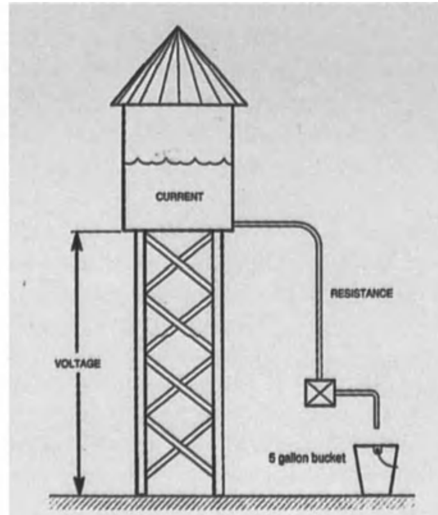

FIGURE 33.1.2

FIGURES 33.1.1 and 33.1.2. Blend nodes in an electrosurgical device is best understood in terms of a hydraulic analogy.

How Electrical Energy Affects Tissue Temperature

The temperature rise can be determined from three electrical variables: current (I); voltage (V); and resistance (R). The conversion of electrical energy to heat can be explained by means of a hydraulic analogy. Figure 33.1.1 presents a water tower, a hydraulic energy source that can be used to perform work. Figure 33.1.2 shows an equivalent electrosurgical tower.

Ohms law ($I = V / R$) gives the relation between the electrical parameters that govern the action of an electrosurgical device.

The power formula ($W = V \times I$, where W is the power in watts) is valuable in understanding how cutting, fulguration, and desiccation compare. The ratio of a waveform's voltage to its current is what primarily determines its effects on tissue, provided exposure time and electrode size are the same.

The power density (current density) squared × resistivity explains how tissue effects at a given energy setting depend on the size of active electrode. In noncontact modalities such as cutting and fulgurating the relevant parameter is the sparking area between the active electrode and the tissue. Only for desiccating is the surface area of the electrode in contact with the tissue of importance. In general the larger the electrode surface area the lower the power density, and the smaller electrode surface area, the higher the power density.

Time is the variable that has the greatest effect on the depth and degree of tissue necrosis achieved at a given energy setting. Many other variables also affect depth and degree of necrosis, but the crucial role of time will be demonstrated in the following sections.

Electrosurgical Modalities

Electrosurgical energy can have three distinct therapeutic effects on tissue: cutting, fulguration and desiccation. Unfortunately most electrosurgical units are labeled for two modes: "cut" and "coag." These terms are not clear enough to allow the surgeon to make optimal use of the energy.

Cutting Mode

The cutting mode makes use of a high-current low-voltage (continuous) waveform, that rapidly elevates the tissue temperature, producing vaporization or division of tissue with little coagulation (hemostasis). Figure 33.1.3 shows cutting waveform with a power of 50 W. During optimal electrosurgical cutting the current travels through a steam bubble between the active electrode and the tissue; electrosurgical cutting, in other words, is a non-

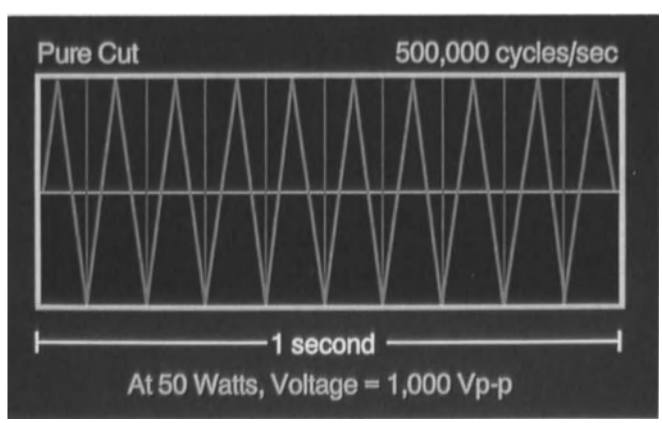

FIGURE 33.1.3. A cutting waveform.

contact means of dissection. The electrode floats through the tissue, and the surgeon receives little tactile feedback. The velocity of the electrode dictates the depth of necrosis. Depths of necrosis of under 100 μm are attainable during dissection. The continuous waveform is analogous to the garden valve shown in Figure 33.1.1 in the sense that it delivers a constant even flow of water. Due to the constant flow of current the voltage can be the lowest one that produces dissection. Because of the low voltage, the width and depth of necrosis are minimal. If the electrode is allowed to remain stationary or is slowed, however, the temperature will rise and the area of thermal damage will increase.

Blend Modes

If the current is interrupted and the voltage increased, the waveform becomes noncontinuous, taking the form of a train of packets. The total energy remains the same, but the ratio of voltage and current is modified in a way that increases hemostasis during dissection. Figure 33.1.4 shows some possible voltage/current ratios, or blends. The blend modes are analogous to water pulsing from a garden valve. The increased height to the water tower makes up for the fact that the water does not always flow. In the blend modes as well, the electrode should float through the tissue. The blend waveforms will require longer to dissect than a cutting waveform at the same power setting, because the current is interrupted. The slower delivery of energy allows thermal spread, improving the coagulation of small vessels during dissection. The blend modes can be a valuable means of controlling bleeding during dissection. On the other hand, if coagulation is not needed, the increased width of necrosis may result in more postoperative infection. Also if the blend modes are used, smoke plume will be thicker. In Figure 33.1.4 blend 1 (A) slightly improves hemostasis, blend 2 (B) moderately improves hemostasis, and blend 3 (C) markedly improves hemostasis during dissection.

When the surgeon is dissecting tissue with an ESU (electrosurgical unit) in a cutting or blend mode, the ESU should be activated before the electrode touches the tissue. The device should be feathered lightly, stroked much as one strokes a paintbrush when doing touch-up or fine-detail work. The maximum power density will be reached as the electrode approaches the tissue, just before contact. This stroking helps initiate vaporization or dissection of tissue. In theory, if the surgeon's technique and control setting are optimal, no force should be required to dissect tissue.

Fulgurating Mode

Fulguration makes use of a high-voltage low-current highly damped noncontinuous waveform that is designed to coagulate by means of sprays of electrical sparks. Figure 33.1.5 shows coagulation (fulguration) waveform at a power setting of 50 W. The most common use of this mode is to coagulate an area that is oozing blood, such as a capillary or arteriole bed. The advantage of this mode is that it can arrest oozing over a large area in a most efficient manner. Cardiovascular, urologic, and general surgeons have relied on fulguration for their most demanding applications, such as hepatic resections, bleeding from a bladder tumor resection, and bleeding on the surface of the heart. Fulguration produces a superficial eschar. Despite the high voltage there is minimal necrosis because the power density is defocused. Since the electrode is at a distance from the tissue, the power density at the tissue surface is decreased, and a great deal of energy is dissipated instead in heating the air between the electrode and the tissue.

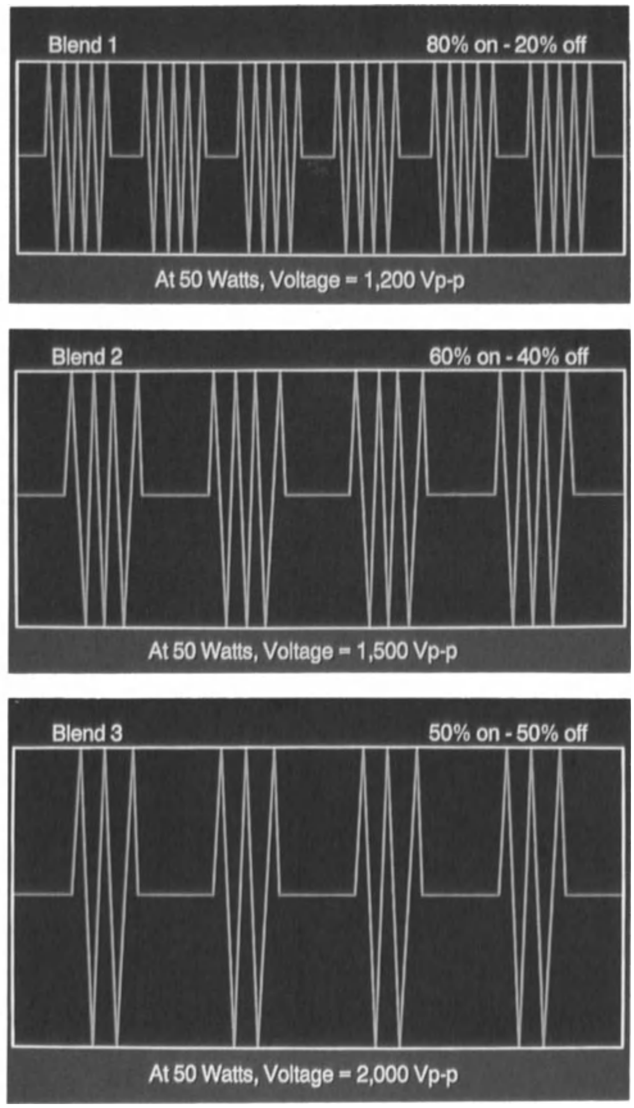

FIGURE 33.1.4. Blend waveforms.

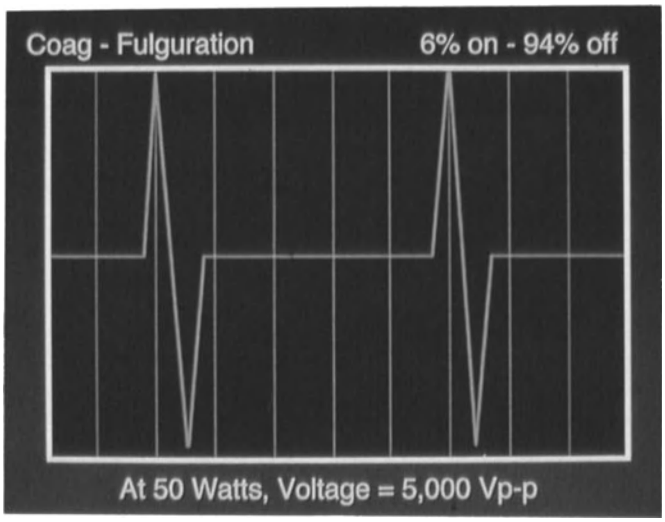

FIGURE 33.1.5. A fulguration waveform.

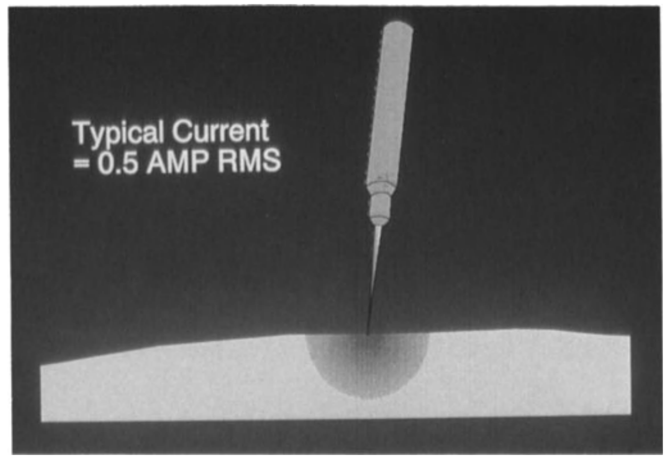

FIGURE 33.1.6. Desiccation can occur with any waveform. The crucial distinction is that the electrode is in contact with the tissue.

Fulguration can be initiated in two ways. One is by approaching the tissue slowly, until a spark jumps to it. Thereafter a rain of sparks will be maintained until the electrode is withdrawn or the tissue is carbonized to the point that the sparks cease. Bouncing the electrode off the tissue will also result in a rain of sparks to the tissue.

Electrosurgical fulguration is the most effective means of arresting capillary or oozing bleeding.

Desiccating Mode

Any waveform will desiccate provided the electrode is in contact with tissue (Figure 33.1.6). If the electrode is in contact, the current/voltage ratio is of less importance than the power in watts. Most surgeons do not make a distinction between fulguration and desiccation but instead refer to both as coagulation. If the electrode is in direct contact with the tissue, all of the energy will be converted into heat within the tissue. By contrast during cutting and fulgurating, a significant amount of the electrical energy converted to heat goes into heating the air or CO_2 between the electrode and the tissue. The increased energy delivered to the tissue by contact desiccation results in an area of necrosis as deep as it is wide (see Figure 33.1.6).

The most common application of desiccation is to control a discrete bleeder. A hemostat is introduced to occlude the vessel by mechanical pressure, and then the electrosurgical energy is applied to the body of the hemostat. The current must pass through the hemostat into the tissue grasped by its jaws and back to the return electrode. With the coaptation of vessels a collagen chain reaction results in a fibrous bonding of the dehydrated denatured cells of the endothelium.[2] In practical applications the cutting or blend waveforms are superior to the fulguration waveform for desiccation. The primary reason is the fulguration waveform tends to spark through the coagulated tissue, resulting in gaps in the bonding of the vessel's cut surfaces. Also when an electrode in contact or nearly in contact with tissue sparks, the metal in the electrode heats up rapidly, and tissue may adhere to it when it is drawn away from the target. Bleeding will resume each time the eschar is pulled off.

The waveform plays a far more important role in bipolar desiccation than in monopolar desiccation. Today, for the most part, manufacturers have incorporated a continuous low-voltage, high-current waveform for bipolar desiccation. In older models, the manufacturer allowed the surgeon to select either a continuous cutting, a blend, or a fulgurating waveform when bipolar desiccation was needed. The physician's lack of understanding of the tissue effects of these waveforms led to a number of problems.[3] Therefore, the author recommends that if bipolar desiccation is critical, a newer model ESU with a dedicated continuous bipolar waveform be utilized. If you must use an ESU that allows you to select a waveform, start with the pure cutting (continuous) waveform for best results. Patience is the key to achieving good results during desiccation. Typically the power density is much lower during desiccating, in part because the contact area of the electrode is larger. Thus longer activation times will be required to attain the desired therapeutic effect. If higher energies are used to speed up the desiccation process, this will be counterproductive. Higher energy levels will increase the temperature of adjacent tissue, potentially allowing the current to spark through areas of necrosis and causing fulguration rather than desiccation. Fulguration, or sparking, immediately stops the deep heating process and starts surface carbonization. When sparking is observed during desiccating, the surgeon should stop and reduce the power or pulse the current by keying the ESU on and off. Sparking is not needed or wanted when desiccating. It causes tissue sticking, creates uneven necrosis, and may compromise vessel occlusion. An ammeter (Model EPM, end-point monitor, Electroscope, Inc.) may be used to control the amount of current during desiccation and assist in determining when the end point of desiccation is reached, confirming the visual evidence. An ammeter shows current flow; when there is no electrolytic fluid left within the tissue, the meter will show no current flow. Total or complete desiccation occurs after dehydration has taken place.

Inherent Risks

Patient burns can occur during electrosurgery in three ways. The active electrode is designed to have a high power density and to heat tissue rapidly. If it is not carefully tended, this electrode can burn the patient severely. Therefore the author strongly recommends that the active electrode be stored in an insulated holster or tray when not in use.

In ground-referenced electrosurgical units, the current can divide and ground through the patient as well as through the return (ground) electrode units. Finally a fault at the return electrode, such as partial detachment, can create a high current density in the return current. The patient may be burned due to this fault. (The return electrode has a surface area of 20 in.^{2} or more when properly applied. Therefore there is little increase in temperature at this site under normal conditions.) Both current division and return-electrode faults have been eliminated by improved design. The two major advances are as follows.

Isolated Electrosurgical Outputs

Isolated electrosurgical units were introduced in the early 1970s. The primary purpose of their introduction was to prevent alternate-ground-site burns caused by current division. Today the number of alternate-site burns resulting from current division is essentially zero. A few hospitals still utilize ground-referenced ESUs, however, and it would therefore be wise to determine the type of ESU that is in service at your hospital.

Contact-Quality Monitors

Contact-quality monitoring circuits were introduced in the early 1980s. The primary purpose of their introduction was to prevent burns at the return electrode. The contact-quality monitor incorporates a dual return electrode and circuit that is used to evaluate the impedance of the return electrode during use. If during the course of surgery the return electrode is compromised, the contact-quality circuit inhibits the electrosurgical generator's output. This feature has essentially eliminated return-electrode burns.

These two technological advances have greatly reduced the potential for patient burns during classical open electrosurgical procedures. These features are now found on the major makes of electrosurgical units, such as Aspen, Birtcher, and Valleylab.

Laparoscopic Issues

As has been mentioned, in the past two decades electrosurgery in laparoscopic surgery was primarily bipolar electrosurgery during laparoscopic gynecologic procedures. The recent development of laparoscopic techniques for general, urologic, and other surgical disciplines has raised the question whether monopolar electrosurgical energy can be safely used in laparoscopy.[6] The purpose of this section is to address the issues pertaining to its safe use in laparoscopy, in a fashion similar to the previous discussion of the general use of electrosurgery in open surgery. Options are available that will minimize or eliminate unintended burns within the peritoneal cavity during laparoscopic surgery.

There are three potential hazards in the use of electrosurgical energy during laparoscopy, all are the result of the use of trocar cannulae and the fact that the laparoscope's field of view includes less than 10% of the electrosurgical probe.

Most laparoscopic accessories are approximately 35 cm long. The images viewed on the monitor show a small portion, typically less than 5 cm, of the distal end of the device. Ninety percent or more of the insulated portion of the active electrode is out of view (Figure 33.1.7). Therefore, if the insulation on the shaft of the electrode breaks down, the bowel or other organs near or touching the electrode may be severely burned (Figure 33.1.7B). These burns may not be noticed during the course of surgery and may result in severe postoperative complications. It is most important to arrange routine inspection of these electrodes. This will minimize, but not eliminate, this hazard, because defects can occur intraoperatively.

The second hazard is that energy can be capacitively coupled from the electrode into other metal laparoscopic instruments or the trocar cannulae. A capacitor is simply two conductors separated by an insulator. Capacitors and their capacitively coupled pathways are commonplace in laparoscopic electrosurgical applications. An insulation-covered active electrode passed through a metal trocar cannula is a capacitor, as is an electrode passed through the operative channel of the laparoscope, or any conductor near an insulated active electrode. The impedance of a capacitively coupled path is given by:

$$Z = \frac{1}{2 + fc}$$

A

B

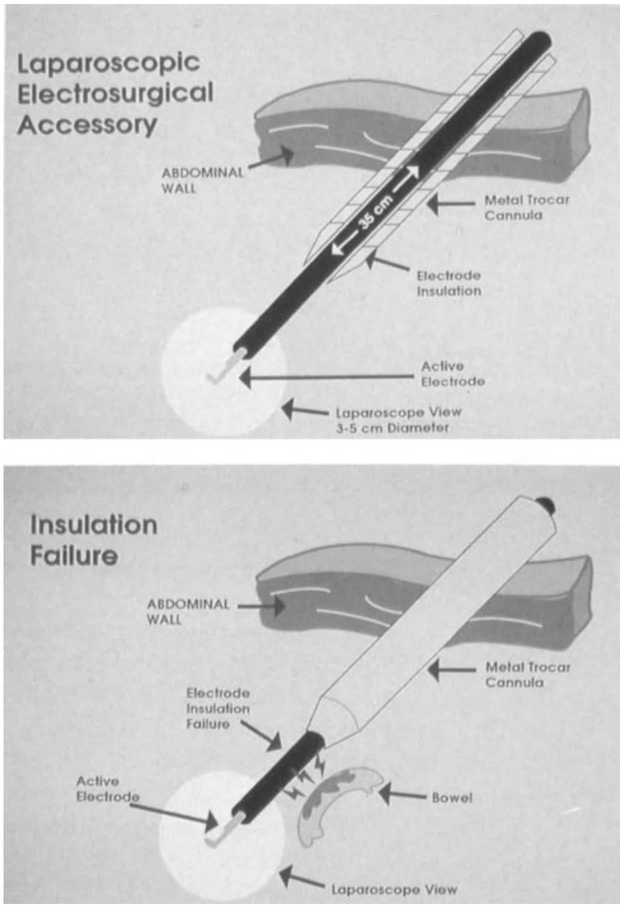

FIGURE 33.1.7. Because much of the active electrode's shaft is out of view, the surgeon may not be aware of insulation failures that can cause serious burns.

A

B

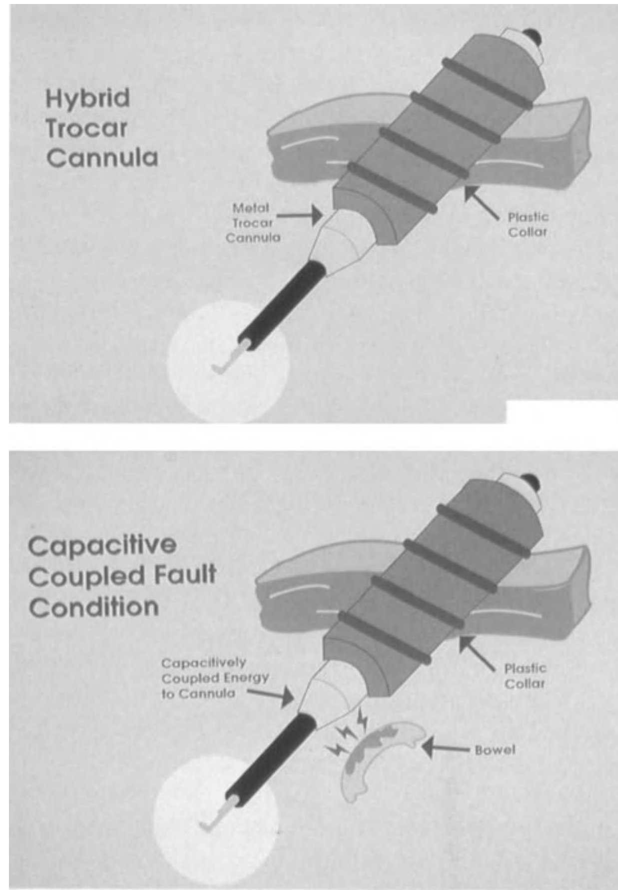

FIGURE 33.1.8. Capacitive coupling to the trocar cannula can also cause serious burns.

where f = the electrosurgical generator's frequency, and c = the capacitance of the path. Most generators work in the range from 400 kHz to 2 MHz and in highly coupled systems, the capacitance can be as high as 100 pf. This means the impedances of these paths are 4 kilohms and 899 ohms for the frequencies of 400 kHz and 2 MHz, respectively. Such low-impedance paths can allow substantial unintended current flow. If the stray currents flow through a small tissue area, the current density there can be extremely high and severe burns will results. These burns are particularly dangerous to hollow organs such as the bowel, because they may lead to unrecognized perforation, with subsequent infection and possibly death.

The bottom line is that 5 to 40% of the power that the electrosurgical unit is set to deliver, can be coupled or transferred into the standard 10-cm-long trocar cannula (Figure 33.1.8). This energy may not be dangerous in itself, providing it is allowed to pass through a low-power-density pathway, such as the all-metal (conductive) trocar cannula inserted through the abdominal wall. This conductive pathway allows the current to return harmlessly to the return electrode.

The problem arises when the energy passes through a high-power-density pathway (Figure 33.1.8B). This can happen, for example, with the part-plastic (nonconductive) part-metal (conductive) trocar cannulae now on the market. Some trocar manufacturers supply a threaded plastic sheath for the metal cannula tube that is intended to help hold the cannula in the abdominal wall when the laparoscopic electrode is moved in and out of it. To avoid this hazard the author strongly recommends that trocar cannulae the active electrode will pass through be all metal or all plastic.

Capacitive coupling can occur to a lesser degree when the electrode touches another laparoscopic instrument within the peritoneal cavity, such as an atraumatic grasper. The energy transfer to these instruments can range from 1 to 10% of the power setting. Care should be taken to avoid this situation, especially when the electrode is being activated for long periods.

Capacitive coupling was detected when single-puncture laparoscopic procedures were first performed.[4,5] These procedures were done by passing instruments through the 30- to 40-cm-long operating channel of a laparoscope. It was observed that when the laparoscope was passed through a plastic 10- or 12-mm cannula, that the distal end of the metal laparoscope could deliver a portion of the power (40 to 80%) set on the ESU, and burns to adjacent tissue were documented. Therefore, during single-puncture operative laparoscopy, an all-metal trocar cannula should be used. The FDA made a strong recommendation in the late 1970s to this effect.[7]

The third hazard with the use of monopolar energy is that the active electrode may accidentally touch the laparoscope. Where does the energy go? A metal trocar cannula will provide a low-power-density pathway that allows this energy to pass safely into the abdominal wall. If a plastic cannula is used, the current may exit through the bowel or other organs touching the laparoscope, out of view of the monitor. Therefore, it is strongly recommended that a metal cannula always be used for the laparoscope port.

To eliminate the first two hazards in the delivery of monopolar energy, Electroscope, Inc., of Boulder, CO has recently released an electrosurgical unit whose Electroshield Monitoring System detects insulation failures and stray capacitive currents and shuts off the unit if they occur.[8] The Electroshield system features a reusable shield used on dissecting and coagulating laparoscopic electrodes (Figure 33.1.9). The Electroshield monitor dynamically detects insulation faults and shields against capacitive coupling outside the view of the surgeon. If an unsafe condition exists, the Electroshield system automatically deactivates the electrosurgical unit and alerts the operating room staff. When a failure occurs, all laparoscopic accessories fail safe. This technological advance allows the surgeon to use monopolar electrosurgical energy in laparoscopic procedures with the same degree of confidence as in open procedures. The shielding system limits the hazard of stray current pathways outside the laparoscope's field of view, which is the fundamental hazard of laparoscopic delivery of this energy.

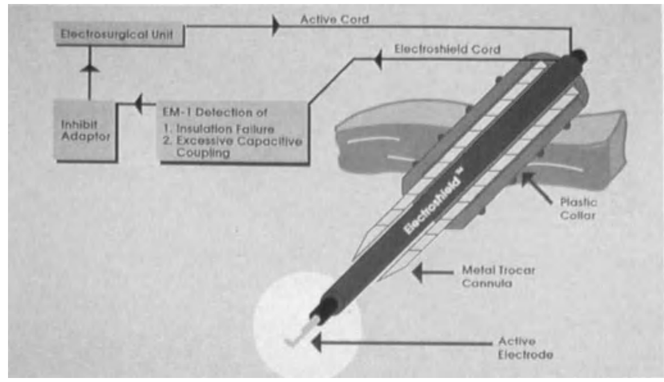

FIGURE 33.1.9. The Electroshield Monitoring System detects insulation faults and capacitive coupling, automatically deactivating the electrosurgical unit if they occur.

Misconceptions

There are two misconceptions about the delivery of monopolar electrosurgical energy during laparoscopy that I believe should be addressed.

The first misconception is that electrosurgical current behaves differently in laparoscopy than in open surgical procedures. Statements are made to the effect that the current, delivered to one site, mysteriously exits from an adjacent site and burns the tissue at the exit or entry point during laparoscopic procedures. The biophysics of laparoscopic and open procedures, however, are identical. In both cases the current takes the path of least resistance from the target site to the return electrode.

On the other hand, burns are a known complication of procedures in which a pedicle of tissue is created by stretching and the current is directed through this narrowing cross section.[5] This complication occurs in both open and laparoscopic procedures, however. Thorough examination of these incidents has indicated that the surgeon could have avoided the complication through technique if he had a better understanding of the biophysics involved. This is as good a point as any at which to mention that medical education currently lacks training in the principles that will lead to efficacious and safe use of electrosurgery. This holds true not only for general surgeons but also for the majority of surgical disciplines. The voltages necessary to perform monopolar (coagulation) electrosurgery are on the order of 3,000 to 5,000 V peak at the maximum power setting (120 W). At a normal operating setting of 20 or 50 W, coagulation mode may produce voltages between 1,500 and 3,000. One sometimes sees statements to the effect that in the closed peritoneal cavity the humidity level and other factors allow uncontrollable sparking to occur. Monopolar coagulation electrosurgery is therefore deemed unsuitable for laparoscopy. Physics textbooks indicate, however, that it takes 30,000 V to arc 1 in. in air under the most favorable environmental conditions.[9,10] In CO_2 it takes roughly 30% more voltage to arc 1 in., or 39,000 V. Humidity levels do not significantly alter these figures. Hence sparking from the active tip of the electrode is actually better controlled in laparoscopy than in open procedures.

Summary

Electrosurgery has been the gold standard for dissection and hemostasis for the past 50 years. It has more diverse capabilities than other energy sources. Medical economics as well have benefited from this device. Technological advances in its performance and safety have made it one of the most useful tools in a surgeon's armamentarium. In the author's opinion, it will again prove itself in laparoscopy. As with any surgical tool or energy source, education and skill are required for its operation. This introduction to biophysical principles of the interaction of electrical energy and tissue and to safety considerations is intended to further understanding of this powerful surgical tool.

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33.2 Laser Physics and the Physics of Tissue Ablation

Gregory R. McArthur

Introduction

Scholars have observed the interaction of light and living tissues since the time of Socrates and Plato. Plato's *Phaedo* contains a passage in which Socrates cautions against looking directly at the sun during an eclipse. He advises the viewer to look instead at the reflection of the eclipse in water or some other medium. A central scotoma following a solar burn of the retina was first reported in the seventeenth century by Thiophilus Bonetus.[1] After the ophthalmoscope came into use, solar burns of the retina were widely described following solar eclipses.[2–4] In the late 1940s, intentional photocoagulation of the human retina was developed concurrently by Moran-Salas[5] and Meyer-Schwickerath.[6] The first instrument for photocoagulation consisted of a complex system of collecting lenses that concentrated sunlight and focused in on the eye. This system worked but it was impractical due to the long exposure times required and its dependence on weather conditions, time of day, and time of year. Other energy sources were adapted for photocoagulation, including carbon arc lamps and high-pressure xenon arc lamps. When Maiman developed the ruby laser in 1960,[7] however, medicine was given an intense light source that could be focused to an extremely small, high-intensity spot that could produce a precise burn of a desired intensity. Zaret began using a ruby-rod optical maser for photocoagulation in animals as early as 1961.[8] The clinical application of the laser for photocoagulation was reported by Campbell[9] and Zweng[10] the following year.

The development of lasers emitting at other wavelengths increased medical interest in them. In 1961, the neodymium:glass laser was developed.[11] The interaction between biological tissue and several early lasers was studied, and it was found that the emission wavelengths (which were primarily in the red and near infrared) did not produce a distinct, predictable tissue effect. The argon laser, developed by Bennett,[12] then replaced the ruby laser for retinal photocoagulation. Light from the argon laser interacts with retinal tissues in a more specific, more predictable manner than does light from a ruby or Nd:YAG laser. The development of the CO_2 laser by Patel[13] put a tool with entirely different properties into the hands of the surgeon. The CO_2 laser produces a beam in the midinfrared portion of the electromagnetic spectrum. Researchers at the American Optical Corporation laboratories used a focused 20-W beam from the CO_2 as a surgical tool to cut tissue in 1965.[14]

These days lasers touch every medical specialty as well as affecting our everyday life. Laser therapy has become the treatment of choice for retinal photocoagulation and vascular lesions. The laser gives surgeons a tool for precise, hemostatic excision. Research is being done in photodynamic therapy, the use of the laser to activate photosensitive drugs.[15] Lasers are used for fiber optic communications systems, grocery store bar-code scanners, and optical-storage devices for data recording and retrieval, including medical record systems and compact discs.

Development

Before World War II quantum physics had no practical application,* but it was the quantum theory that made inventions like the transistor, microcomputer, and laser possible. The development of the laser is a direct result of an effort to improve military radar. Research efforts during and after World War II were focused on making

*The origins of quantum theory arose in connection with a problem of electromagnetic radiation, from which it emerged that such radiation transfers energy in quanta of amount

$$U = hf = \frac{hc}{\lambda}$$

where h is Planck's constant.

a radar system that used shorter wavelengths and had higher power output in an attempt to gain both resolution and range (short wavelengths provide better resolution than long wavelengths). But as researchers developed shorter-wavelength higher-power devices, the range decreased rather than increased. The reason was that water vapor in the air selectively absorbed the short-wavelength energy. Scientists realized that this phenomenon might have practical applications. The application of the knowledge gained during the radar research effort led to the development of the CO_2 medical laser and the microwave oven, devices that exploit the absorption of energy by water.

Quantum Mechanics

Scientists had long used the principles of quantum mechanics to interpret line spectra and identify elements. In 1885 Balmer devised a formula that correctly predicted some of the spectral lines of atomic hydrogen. In 1890, Rydberg devised a generalization of Balmer's equation that predicted even more lines. The Rydberg generalization is:

$$k_n = \frac{1}{\lambda_n} = R\left(\frac{1}{2^2} - \frac{1}{n^2}\right) \; (n = 3, 4, 5 \ldots),$$

where R is Rydberg's constant, k_n and λ_n are the wave number and wavelength corresponding to the n^{th} quantum number.

A further refinement of Rydberg's equation is

$$k_{n',n} = \frac{1}{\lambda_{n',n}} = \mathrm{R}\left(\frac{1}{n'^2} - \frac{1}{n^2}\right) \; (n = n'+1, n'+2, n'+3 \ldots).$$

In 1908, the hydrogen series for $n' = 1$ and $n' = 3$ were discovered by Lyman and Paschen, respectively.

In 1913, Niels Bohr was able to derive the Rydberg formula for the hydrogen spectrum from three basic assumptions about the physics of atoms.

1. Electrons move in circular orbits about the center of mass of the atom.
2. Only orbits with an angular momentum that is an integral multiple of $h/2\pi$ are allowed.
3. Radiation is emitted only when electrons move from one allowed orbit to another allowed orbit. When electrons move from an orbit with higher energy to an orbit with lower energy, the energy difference (ΔE) is radiated as a photon with frequency $f = \frac{\Delta E}{h}$. The reverse process can also occur; that is, an electron can move from a lower energy orbit to a higher energy orbit by absorbing a photon of the proper energy.

The existence of line spectra is proof of the existence of discrete energy levels in atoms. The energy levels of molecules are also quantized. In the case of a molecule, vibrational and rotational energy is quantized as well. For example, ammonia (NH_3) in the ground state is a tetrahedral molecule with a nitrogen atom at one vertex and three hydrogen atoms forming a triangular base. In one excited state of ammonia, the nitrogen atom oscillates through the plane defined by the three hydrogen atoms. The energy difference associated with the transition from the ground state to this excited state corresponds to a microwave photon with a wavelength of 1.25 cm and frequency of 24 billion Hz.*

Stimulated emission, the phenomenon on which the laser is based, was described as early as 1917 by Einstein. If a photon of the proper wavelength collides with a molecule in an excited state, the excited molecule will be stimulated to give up its excess energy by releasing a photon. The emitted photon will have energy of hf, where f is the frequency required to stimulate the emission. The emitted photon, in other words, has the same wavelength as the entering photon. A second property of stimulated emission is that the emitted photon has exactly the same direction and phase as the entering photon. Excitation, spontaneous emission, and stimulated emission are shown graphically in Figure 33.2.1.

Stimulated emission only works when atoms or molecules are in an excited state. Under ordinary conditions, most of the molecules of a given material are in the ground state and only a few are at higher energy levels. This means that any photons released by stimulated emission are absorbed by ground-state molecules and do not stimulate the emission of other photons. To ensure a photon cascade most of the molecules in a system must be excited to higher energy levels, a condition called a population inversion. If there is a population inversion, photons released by stimulated emission cause other emissions rather than being absorbed.

The amplification, or gain, realized by a photon making a single pass through a region of population inversion is fairly weak. Although photons that are released spontaneously can stimulate the release of energy, this process is too rare to be useful. Townes realized the gain could

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*The frequency f of the wave is given by

$$f = \frac{\omega}{2\pi},$$

and its wavelength λ by

$$\lambda = \frac{2\pi c}{\omega},$$

the product of the preceding equations is

$$f\lambda = c.$$

In the above equations, c is the velocity of the wave (3×10^8 m/s), and ω is the radian frequency of the wave.

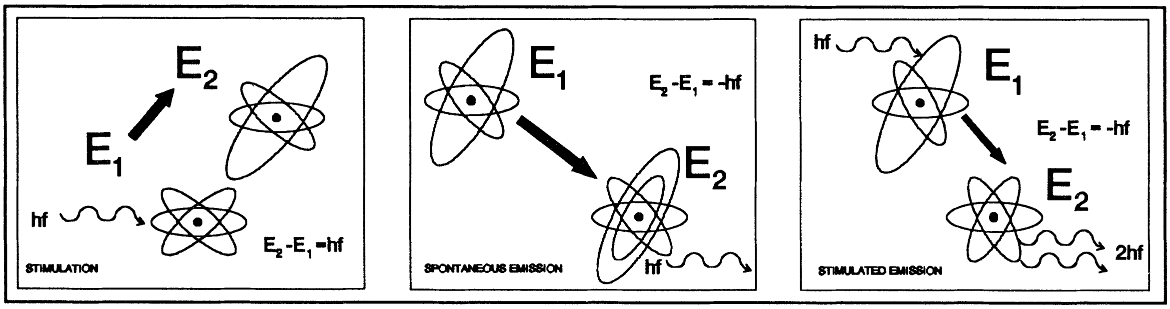

FIGURE 33.2.1. Energy diagrams that show the processes of absorption, spontaneous emission, and stimulated emission.

be increased to usable levels only if a device could be constructed that would reuse emitted photons. A feedback system that amplified the stimulated emission of ammonia molecules was constructed by Townes and his group.[16]

Construction of a device that uses stimulated emission to produce light begins with isolating the medium.* The medium is the group of molecules that are to be excited and will emit photons by stimulated emission. Typically, the medium is contained in a glass or ceramic tube or the molecules that are to be excited are suspended in a crystal lattice. Energy is applied to the medium to create a population inversion. Molecules that have been excited give off energy (in the form of photons with energy *hf*) in a random process of spontaneous emission. These randomly emitted photons then stimulate other excited atoms to release photons by stimulated emission. The system that recycles the emitted photons (the feedback mechanism) is created by adding a mirror to each end of the medium. The mirrors direct emitted photons back through the region of population inversion, where they can stimulate the emission of still more photons. Not all of the photons that are released must be directed back through the region of population inversion to sustain emission. A portion of the photons produced can be allowed to pass through one of the mirrors. Light that passes through the output coupler can then be directed to a delivery device and used as the surgical beam (Figure 33.2.2).

The process just described is called light amplification by stimulated emission of radiation, and devices that use this process to produce electromagnetic radiation in the ultraviolet, visible, and infrared portions of the spectrum are called lasers. Light produced by lasers is collimated, coherent, and monochromatic.* Remember that the photons emitted by stimulated emission travel in the same direction as the photons that caused the emission. This is collimation. All of the stimulated photons are also in phase with one another, both temporally and spatially. Laser light is therefore also coherent.

Most light is what is called blackbody radiation.† Blackbody radiation is multidirectional and polychromatic (the photons have a wide range of energies). The unorganized nature of this light makes it difficult to control. The laser's characteristics of collimation, coherence, and monochromaticity, on the other hand, make it a controllable energy source that is ideal for surgery.

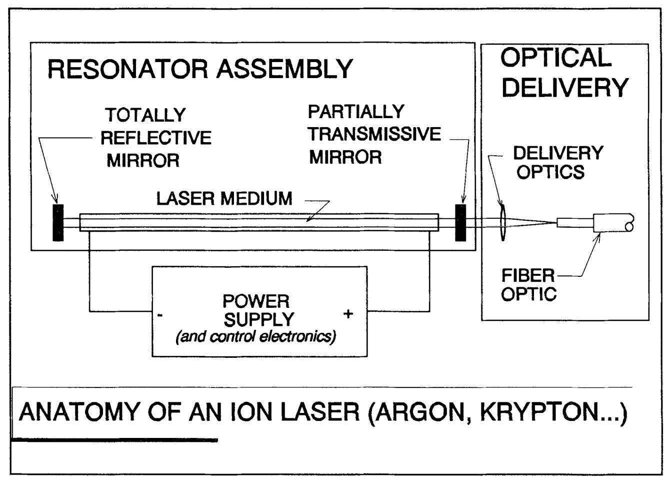

FIGURE 33.2.2. Basic components of a laser. The active medium may be a collection of atoms or of molecules and it may be a solid, liquid, gas, or plasma.

*Lasers are typically named for the element or compound that emits the photon of interest. Examples of lasers that have been used in medicine are the carbon dioxide laser, the argon laser, and the neodymium laser. Usually, the neodymium laser is referred to as a neodymium:YAG laser because the neodymium is contained in a Yttrium Aluminum Garnet or YAG crystal.

*Not all lasers are monochromatic. There may be several "allowed transitions" in an electron's journey from the excited state to the ground state. A photon is emitted for each transition. A laser device can be made to emit any one or all of the wavelengths associated with the allowed transitions and therefore may produce several different "lines."

†An exception is chemoluminescence seen in fireflies, some algae, and some ocean fishes.

Laser/Tissue Interaction

Four mechanisms determine the interaction of light with tissue: light can be reflected, refracted, scattered, or absorbed.

Reflection

Reflection is the directional change that occurs when light is incident on a material but does not enter it. The reflected ray is always in the plane defined by the incident ray and the normal to the surface. The angle of reflection is always equal to the angle of incidence.

Refraction

Refraction is the directional change that occurs when light passes from one material to another with a different refractive index. The refracted ray is always in the plane defined by the incident ray and the normal to the surface. The relation between the angle of incidence and the angle of refraction is defined by Snell's law:

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

Scatter

Photons that collide with molecules without exciting the molecules, are said to be scattered. Scattering is best understood by supposing that photons *really* behave like particles and can bounce off a molecule transferring energy and momentum. In a collision, momentum and energy are conserved, and so any transfer of energy from a photon will result in a change in its wavelength. What is the magnitude of this change? Assume that a photon of energy hf (and therefore of momentum hf/c) that is moving along the x axis strikes an electron (or molecule) at rest. The electron recoils with momentum p along a line at an angle ϕ to the x axis. The photon, which has a new frequency f' departs at an angle θ to the x axis. Since momentum is conserved,

$$\frac{hf}{c} - \frac{hf'}{c} \cos \theta = p \cos \phi, \tag{1}$$

and

$$\frac{hf'}{c} \sin \theta = p \sin \phi. \tag{2}$$

And since energy is also conserved,

$$hf - hf' + mc^2 = \sqrt{m^2c^4 + p^2c^2}. \tag{3}$$

Squaring equations 1 and 2 and adding their corresponding sides eliminates the angle ϕ. Squaring equation 3 removes the radical:

$$h^2(f-f')^2 + 2h(f-f')mc^2 = p^2c^2.$$

It is now a matter of mathematical housekeeping to eliminate p:

$$\left(\frac{hf}{c}\right)^2 + \left(\frac{hf'}{c}\right)^2 - \frac{2h^2ff' \cos \theta}{c^2} = p^2,$$

combine terms, and divide the equation by $mcff'$ to obtain a result in terms of wavelength:

$$\Delta\lambda = \lambda' - \lambda = \frac{h}{mc}(1 - \cos \theta).$$

Notice that the change in wavelength ($\Delta\lambda$) is independent of the original wavelength (λ) and has its maximum value when the photon is scattered directly backwards ($1 - \cos \theta$ has a maximum at $\theta = 180°$). The term $\frac{h}{mc}$ is the Compton wavelength, the wavelength of a photon whose energy is equal to the rest energy of an electron:

$$\lambda = \frac{c}{f} = \frac{hc}{hf} = \frac{hc}{mc^2} = \frac{h}{mc}$$

Since $hc = 1.24 \times 10^4$ eV-Å and the rest energy of an electron is 5.11×10^5 eV, the wavelength change associated with 90° scatter from an electron is 0.024 Å, or 0.0024 nm. The wavelengths of lasers in use today range from about 250 nm (the excimer laser) to 10,600 nm (CO_2 laser). This process, then, does not significantly alter the wavelength of the radiation, although it can significantly change the geometry of the beam.

Absorption

Absorption is the interaction of most interest in surgery. Light energy is absorbed by tissue and is converted to thermal energy on a microscopic level. Bulk absorption of electromagnetic energy causes changes in the vibration and rotation of molecular bonds. This energy is then thermalized by nonradiative decay, that is, the energy stored in the rotational and vibrational states of large molecules is converted to translational kinetic energy by collisions of the excited molecules with other molecules within the target. The geometry of the thermal insult depends on the initial beam geometry and on the changes in beam geometry that result from reflection, refraction, and scatter. Boulnois described the photothermal process as a two-step reaction:

Absorption: $A + hf \rightarrow A^*$ (vibration and rotation)

Deactivation: $A^* + M(E) \rightarrow A + M'(E + \Delta E)$.[17]

In absorption, a macromolecule A absorbs a quantum of energy hf and becomes an excited macromolecule A^*. The whole media then gains this energy when it is thermalized; that is, the system energy $M(E)$ is increased to $M'(E + \Delta E)$ when A^* gives up its energy to the system. Under normal conditions, the average kinetic energy of a molecule is about 0.025 eV. The photon energies of lasers (hf) range from 0.12 eV (the CO_2 laser) to 2.5 eV (the argon laser's blue line). Most biomolecules have a tremendous number of accessible vibrational and rotational states (10^3 to 10^5), and the process of transferring from vibrational and rotational excitations to the kinetic energy of translation is extremely efficient. The biological effects of heating, then, tend to be much less specific than photochemical effects, in which photons of specific energies activate specific chemical reactions.

Because of absorption the intensity of light in tissue is a monotonic function of depth. Absorption is described mathematically by the Lambert-Beers law:

$$I(x) = I_0 e^{-\alpha x}$$

where $I(x)$ is the intensity at a depth x into the tissue, I_0 is the intensity of the laser beam at $x = 0$, and α is the wavelength-specific and tissue-specific absorption coefficient. Scatter has the effect of decreasing the depth of penetration because it increases the distance a photon travels to get to a specific depth within tissue. The Lambert-Beers law can be modified to account for the scatter in tissue by replacing the absorption coefficient with the attenuation coefficient, $\mu = \sqrt{\alpha^2 + 2\alpha\beta}$, where β is the wavelength-specific and tissue-specific scatter coefficient.

Some values for α, β, and μ are given in Table 33.2.1 for several wavelengths and tissue types.

Thermal Laser Selection

The choice of a laser for a specific thermal application is based on *wavelength-specific* properties such as scatter and attenuation depth. Scatter and absorption at a particular wavelength are determined by the composition of the target. Tissue characteristics that determine these properties include the water content, and the concentrations of hemoprotein (oxyhemoglobin and methemoglobin), pigment (melanin, xanthophyll), and other macromolecules (proteins, nucleic acids, aromatics . . .). Material properties must also be considered in the design of delivery systems. For example, electromagnetic radiation with a wavelength longer than about 3,000 nm is absorbed by glass and plastic. Lenses and fiberoptics made from these materials are therefore not usable at these wavelengths.

It should be obvious from the preceding discussion that a laser beam incident on a tissue surface experiences several changes. Its direction is altered by reflection and refraction at boundaries between materials with different optical properties. Heterogeneous materials scatter the beam and alter its spatial distribution. Materials that are not completely transparent to the beam absorb a portion of the energy and are heated. None of these processes are mutually exclusive; laser beams incident on tissue are altered by all of them. The importance of each interaction is determined by the optical characteristics of the target and the choice of wavelength. Knowledge of tissue properties at specific laser wavelengths allows one to select a laser that will achieve the desired effect.

Biophysics of Laser/Tissue Interaction

The interactions of laser energy with tissue can be divided into four classes: photochemical, photothermal, photomechanical, and photoablative. Photochemical interactions are ones in which the laser frequency is precisely matched to the excitation bands of photosensitive molecules in the target tissue. The tissue is usually exposed to low power densities for a comparatively long time. The interaction of light with photoactive drugs has created a new area of medicine called photodynamic therapy.[18–21] Small spot sizes result in high power densities and thus confer the ability to coagulate or vaporize tissue in a precise manner. The photothermal mode of interaction is the basis of most surgical applications of lasers.[22,23] The release of moderate amounts of energy in extremely short pulses results in optically induced dielectric breakdown, the basis of electromechanical interactions.[24] The use of high-energy pulsed ultraviolet lasers to photodecompose tissue is called the photoablative mode.

TABLE 33.2.1. Absorption coefficients, scatter coefficients, attenuation coefficients, and penetration depths for some representative lasers and tissue types.

	Absorption coefficient α [cm^{-1}]			Scatter coefficient β [cm^{-1}]			Attenuation coefficient $(\alpha^2 + 2\alpha\beta)^{1/2} = \mu$ [cm^{-1}]			Depth of penetration $1/\mu$ [μ]		
Tissue	Ar	Nd:YAG	CO_2	Ar	Nd:YAG	CO_2	Ar	Nd:YAG	CO_2	Ar	Nd:YAG	CO_2
Water			1,200						1,200			8
Human Dermis (In Vitro)	8	5		83	20		37.4	15		267	667	
Blood Thrombus	110	6	200	13	3	2	12.3	8.5	202	82	1,276	50
Fibrous Plaque	18	1.4	200	19	2.3	2	31.7	2.9	202	315	3,448	50
Vessel Wall	11	0.9		11	2.8		19.0	2.4		526	4,167	

The four effects described above are elicited by comparable energy densities (energy per unit area). The energy density required for any of these effects is between 1 and 1,000 J/cm^2. The variable that determines which interaction takes place is time. The photoablative effect of the excimer laser occurs in from 10^{-9} to 10^{-6} s. Pulses of from 10 ps (10×10^{-12} s) to 10 ns (10×10^{-9} s) produce electromechanical effects. Photothermal interactions occur in from 1 ms to 10 s, and photochemical interactions typically require more than 10 s. Of course, the local power density must be sufficient to ensure that the power density integrated over time provides adequate energy density for the effect.

Lasers used in general surgery are thermal in nature, and tissue removal is largely by evaporation of interstitial water followed by the combustion of the residue. The temperatures produced by the laser are relatively low—a few hundred °C at most.

Thermal destruction of tissue follows a well-known course. Protein conformational changes and hyperthermic responses such as cell mortality begin at 43 to 45°C. Heating of the tissue from 43 to 50°C may allow collagen helices to uncoil and anneal so that apposed edges of tissues may reform covalent bonds and fuse as the tissue cools. Below 45°C, there is little cell damage. Above 45°C, enzymes degrade, but these changes may be reversible. At about 50°C, there is a marked reduction in enzyme activity. Irreversible protein denaturization and coagulation begin at about 60°C. Near 80°C, collagen begins to denature, membrane permeability is altered, and tissue carbonization begins. The tissue dries out slowly and begins to shrink as temperatures reach 90 to 100°C. Thermal conduction can be rapid at these temperatures and caution should be exercised so that deeper or adjacent structures are not damaged. At 100°C, water boils, and tissue vaporization and ablation occur. Vacuoles are a definite indicator of temperatures over 100°C. As temperatures rise above 125°C, complete oxidation of protein and lipids occurs, leaving behind carbon particles. As tissue turns black, temperatures rise fast because scattering stops and absorption increases. Carbonization, or charring, of the tissue surface suggests a high-temperature process. The surgeon sees the vaporized tissue as a plume of gas and smoke.

Laser heating and ablation of tissue can be described mathematically by the following boundary-value problem. Consider a laser beam of known intensity, normally incident on a semi-infinite, homogeneous tissue sample of density ρ, specific heat c, and diffusivity k. Define a cylindrical coordinate system with the origin at the tissue/laser-beam interface and the positive z axis along the path of the laser beam. The heat equation is

$$k\nabla^2 T(r,z,t) + \frac{1}{\rho c} S(r,z) = \frac{\partial}{\partial t} T(r,z,t)$$
$$r,z,t \geq 0.$$

where $T(r,z,t)$ is the temperature distribution function, and $S(r,z)$ is the (time-independent) source function, which depends on the laser wavelength and the wavelength-specific absorption and scattering coefficients of the target tissue. The boundary conditions imposed on T are

$$T(r,z,0) = 0,$$
$$T(\infty,z,t) = T(r,\infty,t) = 0,$$
$$\left.\frac{\partial}{\partial z} T(r,z,t)\right|_{z=0} = 0$$

The assumptions made in defining these boundary values are that temperatures are measured relative to the ambient tissue temperature, the optical properties of the tissue do not change during the ablation process, and no heat is lost from the surface. Solving this equation yields a family of tissue isotherms (Figure 33.2.3). If the incident power is constant, the ablation velocity will be constant $\left(\frac{d^2T}{dt^2} = 0\right)$, and the isotherms will remain stationary with respect to the ablation front.

The shape and spacing of the isotherms depend on the choice of laser wavelength, the tissue characteristics at the chosen wavelength, and the incident power density. Light that is not well absorbed and is strongly scattered (large α and large β) creates a flat thermal gradient in which the isotherms are spaced relatively far apart. Light that is strongly absorbed and strongly scattered (small α and large β) creates a steep thermal gradient and therefore does little damage to the adjacent tissue. However, if the pulses are long and the ablation velocity is low, thermal conduction of energy away from the ablation crater may damage tissues. In the case of laser/tissue combinations with low scatter and very high absorption (α

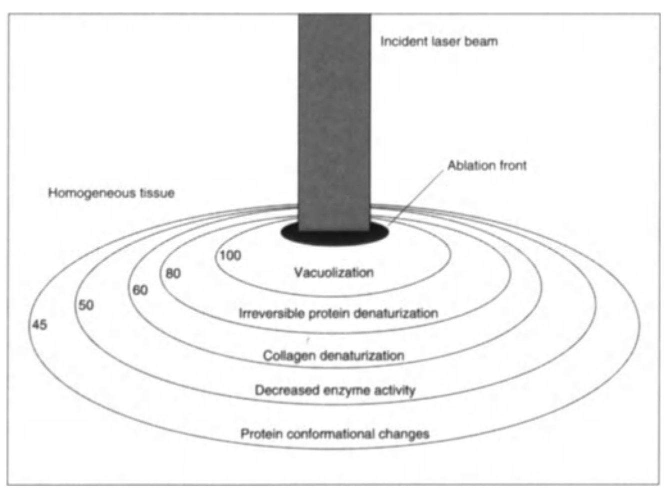

FIGURE 33.2.3. Ablation geometry. A laser beam incident on a homogeneous tissue mass produces a temperature gradient.

$\gg \beta$) the tissue isotherms are prolate spheroids (the shape of a rugby ball) with their axis of symmetry along the laser beam. In the case of tissue/laser combinations with high scatter and low absorption ($\beta \gg \alpha$) the tissue isotherms tend to be oblate spheroids (the shape of M&M candies) again with their axis of symmetry along the laser beam.

Surgical Laser Types and Applications

The lasers used in medicine today can be divided into three basic types: (1) visible-light lasers whose energy is strongly absorbed by pigments and transmitted by water (they have large α and β in water but small α in pigmented tissue); (2) midinfrared lasers that are strongly absorbed by water (they have small α); and (3) near-infrared lasers that are not well absorbed by either pigments or water (they have large α in water and pigmented tissue and large β in tissues that contain protein). The effects of different wavelengths depend not only on the wavelength but also on the properties of the target tissue, particularly the values of attenuation and scatter.

Visible-Light Lasers: Argon and KTP

The argon laser is an ion laser that has two principal emission wavelengths: 488 and 514.5 nm (in the blue and green portion of the visible spectrum). The KTP, or frequency-doubled Nd:YAG, laser is a hybrid multicrystal laser system. Light from an Nd:YAG laser is passed through a second crystal that is placed within the optical cavity, or resonator, of the laser. The second crystal has the effect of doubling the frequency of the beam from the Nd:YAG laser, producing a beam with a wavelength of 532 nm.

Visible light is transmitted through clear aqueous tissues, but the blue and green wavelengths are strongly absorbed by tissues that contain pigments such as hemoglobin, myoglobin, and melanin. Visible light can be guided by optical fibers; optical fibers as small as 50 μm can be used to direct energy from the argon laser to the area of application. The argon wavelengths penetrate pigmented tissue to a depth of between 0.1 to 0.5 mm. Light from the argon laser is scattered by tissue, however, resulting in a slight lateral spread of the laser energy.

The argon laser was the first visible-light laser to be used laparoscopically; a relatively low-power argon laser (6 W) was used to treat endometriosis.[25] The argon laser was chosen because its emission wavelengths are well absorbed by pigments and can be delivered by fiberoptics, and because the laser had adequate power for the procedure. A higher-power argon laser was later used for excision of endometriosis and adhesions as well as to vaporize or coagulate endometriotic lesions.[26] Additional applications of the visible-light laser in gynecology include treatment of distal tubal obstruction, polycystic ovarian disease, ectopic pregnancy, small subserosa uterine fibroids, and transection of the uterosacral ligaments for dysmenorrhea.

Visible-light lasers have also been demonstrated to be useful for other laparoscopic[27] and hysteroscopic[28] applications. The hysteroscopic applications include resection of uterine septa, vaporization of intrauterine adhesions, and vaporization of submucosal fibroids.

Collaboration between gynecologists and general surgeons led to the first laparoscopic application of the argon laser for cholecystectomy by McKernan and Saye.[29]

Infrared Lasers: CO_2 and Ho:YAG

The CO_2 laser has been used for laparoscopic gynecologic surgery since 1979. The CO_2 laser laparoscope was developed independently by Bruhat[30] in France, Tadir[31] in Israel, and Daniell[32] in the United States. The invisible infrared energy from this laser has a wavelength of 10,600 nm, a wavelength that is strongly absorbed by water, glass, and most plastics. A visible light laser must be superimposed on the CO_2 laser beam to allow the CO_2 beam to be aimed. Energy from the CO_2 laser cannot be transmitted by optical fibers. Electromagnetic radiation from the CO_2 laser is delivered to tissue by an articulated arm constructed by mounting mirrors in the ends of connecting tubes at 45° angles to the tubes. The mirrors are free to rotate about the long axis of the tubes. Because the tubes are long, these devices have a large bending moment that make it difficult to keep the mirrors in perfect alignment. The inertia associated with articulated arms also tend to make them difficult to use. Development of an optical fiber for the CO_2 laser is underway, but there are still technical obstacles that must be overcome before these devices can be used in medicine. Because of the long emission wavelength of the laser, these optical fibers have a large diameter and are therefore inflexible. CO_2 laser fibers are also water-soluble and toxic.

The holmium:YAG (Ho:YAG or THC:YAG) laser is another infrared laser that has properties that may make it attractive for future applications in medicine. This laser has a wavelength of 2.1 μm. The energy from this laser is also strongly absorbed by water, although not as strongly as that from the CO_2 laser. The energy from the Ho:YAG laser can be transmitted by optical fibers, thus avoiding the problems associated with articulated arms.

Near-Infrared Lasers: Nd:YAG

The Nd:YAG laser produces light at 1,064 nm, which is just beyond the visible portion of the spectrum. A visible-light laser must be superimposed on the Nd:YAG beam to allow aiming. Light in the near-infrared portion of the electromagnetic spectrum is not absorbed by water. While the pigments that absorb energy from the visible-light lasers also absorb energy from the Nd:YAG laser, they do not absorb it well. Energy from this laser passes through water and is scattered and absorbed by macromolecules within the target tissue.

The scattering converts the coherent column of photons into a diffuse oblate spheroid of radiation.[33,34] In the case of hollow viscera with a wall thickness of 2 to 3 mm, 30 to 40% of the applied power will be backscattered and 20 to 30% will be scattered forward through the wall.[33] This scattering results in the doubling of the effective beam diameter at the incident surface and a fourfold increase at the back of the wall. In other words, the area of irradiation is 4 times larger than the spot size on the incident surface and 16 times larger on the back of the wall.

The first medically significant application of the Nd:YAG laser was to control massive gastrointestinal bleeding.[35] The Nd:YAG laser was chosen because of the optical properties of fibers at this laser's wavelength and the interactions of this wavelength with tissue. Light in the near-infrared portion of the magnetic spectrum is not well absorbed by tissue and a significant portion is scattered. The long extinction length and significant scatter combine to make the Nd:YAG laser behave like a volume heater of tissue. For this reason, the laser is a good coagulator.

For the same reason, this laser does not cut well. It is possible, however, to force the light to be converted to heat in a much smaller volume, so that local temperatures can be achieved that allow this laser to cut. If a ceramic tip (a synthetic sapphire) is attached to the end of the optical fiber, the impedance mismatch at the tissue/ceramic interface causes rapid heating of the sapphire. When the hot sapphire tip is touched to tissue, thermal energy is transferred to the tissue by conduction. The tip shape can be manipulated to control the geometry of the thermal insult to the tissue.

Laser Safety: American National Standards Institute Guidelines

The American National Standard for the Safe Use of Lasers in Health Care Facilities (ANSI Z136.3–1988) and the American National Standard for the Safe Use of Lasers (ANSI Z136.1–1986) provide guidance for the safe use of lasers and laser systems. These standards deal with hazards to the eyes and skin and discuss protective eyewear, clothing barriers, and screens.

The ANSI standards introduced terms specific to the description of laser hazards.

Maximum Permissible Exposure (MPE). The highest level of laser radiation to which a person may be exposed without hazardous effect or adverse biological changes in the eye or skin. MPE is expressed in power per unit area, typically W/cm^2, and is often called the power density in the medical literature.

Nominal Ocular Hazard Distance (NOHD). The distance beyond which the exposure during normal operation is not expected to exceed the appropriate MPE.

Nominal Hazard Zone (NHZ). The neighborhood of the laser source within which exposure levels exceed the MPE. The outer limit of the NHZ is the NOHD.

Eye protection within the NHZ is mandatory. Optical viewing devices such as endoscopes, laparoscopes, or microscopes should be equipped with accessories that provide adequate protection for the operator. Persons viewing open procedures without the aid of viewing devices must wear protective eyewear of sufficient optical density to provide appropriate protection. Eyewear should be designed and labeled for use with specific laser wavelengths. Labeling on all eyewear should state the optical density of the filter material and the wavelength or range of wavelengths at which the eyewear will provide protection.

While eyewear is a convenient method of protecting the eyes, it is by no means the only method. For divergent beams, barriers or screens provide effective protection. The ether drape is a common way to protect anesthesiology personnel from the laser energy. Drapes have been shown to provide adequate protection as long as the viewer is behind them. Video systems also provide protection from laser radiation. It is not necessary to wear eye protection while watching procedures on a video monitor provided that there is an adequate physical barrier between the viewer and the laser beam. The video system, however, should be protected with appropriate filters. The abdominal wall provides adequate protection from radiation from the laser during endoscopic procedures.

The eye protection selected for patients depends on the type of anesthesia used. If a general anesthetic is used, taping of the eyes will provide sufficient protection during most procedures. Conscious patients should wear safety glasses, goggles, or be protected by a drape. Protective goggles, not glasses, should be worn by patients during surgery of the neck, face, or nose. When the surgeon is operating near the globe of the eye, protective metal eye caps may be used.

The development of the laser has added a versatile, powerful tool to the general surgeon's armamentarium. The laser is put to optimum use only if proper wavelength and treatment parameters are selected based on known laser and tissue characteristics. The laser can be a tremendously precise tool that can make a good surgeon better, but it does so only if the basic physics of laser/tissue interaction and thermodynamics are well understood. New and revolutionary applications of the laser based on this understanding are continually being developed.

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33.3 Ultrasonic Dissection

John H. Payne, Jr.

Introduction

Electrosurgical and laser dissection systems are widely available and generally useful, but the tissue effects of these instruments are relatively imprecise and not selective.[20] The conduction, reflection, or stray application of laser or electrical energy can injure tissue beyond the point of dissection.[21,37,41] For these reasons, alternative methods of tissue removal have been sought. The ideal laparoscopic dissector would be safe, selective, able to cut and coagulate, relatively easy to learn to use, and modestly priced. The ultrasonic dissector has most of these features.

History of the Instrument

In 1967 Kelman[24] began to use an ultrasonic phacoemulsifier for the removal of cataracts, and by 1973 he had treated over 500 cases. In 1978 Flamm and Ransohoff[9] reported the use of a more powerful version of the instrument for the removal of 38 meningiomas and acoustic neuromas. By 1981 Fasano and Zeme[6] had used the instrument for 52 cases of similar intracranial tumors. Loo and Applebaum[25] also found it useful for the dissection of five advanced pelvic and thoracic neuroblastomas.

Building on this early experience, Hodgson and his colleagues undertook laboratory and clinical investigations of an ultrasonic dissector in New York in 1979.[17,19] Fulguration of a rectal cancer, removal of a villous adenoma, and a commando procedure were among their first cases. The precision with which their procedures were accomplished and hemostasis was achieved impressed these investigators: "It is remarkable that these operative procedures were done with almost no blood loss, a feature that could have considerable economic impact." Biopsies of the liver, spleen, stomach, lung, kidney, and small bowel were quite suitable for histological assessment. In each instance, the selectivity of the device allowed precise removal of the specimen, sparing supportive structures, and clearing blood vessels for precise ligation.

Later that year Hodgson[17] used the ultrasonic dissector to transect the pancreas at the portal vein during a Whipple procedure. When tumor was found at the margins of the frozen section, a total pancreatectomy was performed using the device: "Total control was maintained at all times and very little bleeding occurred." In a report to the Royal College of the Surgeons of England in 1980,[16] Hodgson described 11 liver procedures, 12 extensive head and neck dissections, and five ultrasonic fulgurations of rectal cancers that had had similarly encouraging results. Putnam,[30] Ottow and Sugarbaker,[29] Fiddian-Green,[7] and others[4,10,12,23,26,34,37] have clearly shown the safety and utility of the instrument for hepatic surgery. Segmental resections that would not have been possible without the dissector's precision and selectivity have been described by these investigators. Matsumata and colleagues[27] raised the issue of transmission of hepatitis during ultrasonic dissection of the liver and advocated the use of eye shields. The use of eye shields is now mandated by OSHA for all procedures. Care should be taken when evacuating the plume created by the ultrasonic detector as well as by other energy sources; suction should be adjusted to promptly clear any smoke or vaporized material. The instrument must also be used cautiously when dissecting around nerves because prolonged direct contact can produce transient or permanent damage.[8,11]

Many other specialties have become aware of the value of the tissue selectivity that ultrasonic dissection can provide. In recent reports Heiman[14] and Helman[15] have described the use of the ultrasonic dissector in mucosal proctectomy. Addonizio[1] and Chopp[2] at the New York Medical College have used it to perform partial and complete nephrectomy with "increased visibility and reduced blood loss." In 1982 Derderian and his colleagues at Michigan State University confirmed the utility of the instrument for splenorrhaphy with "minimal blood loss" in the dog.[5] Verazin's group at Roswell Park has recently reported the value of ultrasonic dissection during 27 segmental or limited pulmonary resections.[40] Their success with ultrasonic dissection of the internal mammary artery (IMA) for coronary artery bypass grafting has led Suma and Fukumoto[35] to use it "routinely for IMA dissection" at the Osaka Medical College. Although cytoreduction for ovarian cancer remains a controversial and tedious procedure and resections of the liver, diaphragm, and bowel are often necessary to achieve maximum tumor clearance, Peter Rose of the University of Massachusetts has employed ultrasonic dissection with good results in patients with extensive ovarian disease.[32] After conventional cytoreduction procedures, 22 of 45 patients underwent further tumor removal with the instrument. Ten had stage IIIC disease, 9 had stage IV disease, and 3 had recurrent disease. Diaphragmatic, hepatic, splenic, and colonic implants were frequently encountered. Effective cytoreduction on the colon avoided the need for resection in 10 cases. Ultrasonic aspiration may also provide an alternative to topical agents and laser vaporization for vulvar lesions.[31]

The adaptation of ultrasonic dissection to laparoscopic procedures has occurred as part of the natural evolution of surgical technology.

Mechanism of Action[36,38]

During early tests of naval propellers in 1894, Thornycroft and Barnaby noted severe vibration, which increased as the speed of the spinning propellers increased. By 1917, Lord Rayleigh confirmed that the vibrations were due to the enormous turbulence, heat, and pressure of imploding cavities. This phenomenon became known as *cavitation* (Figure 33.3.1). It has provided chemists with an alternative energy source whose manner of interaction with matter differs from those of light and heat. Light provides very high energies on a short time scale, whereas heat supplies less energy on a longer time scale. Cavitation can fuel interactions on time scales and at energy levels distinct from those fueled by other energy sources.

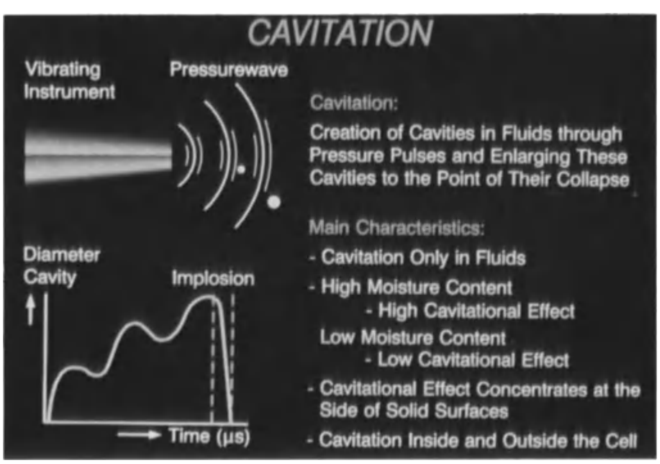


FIGURE 33.3.1. Turbulence produces *cavitation,* or the formation of cavities within a liquid.

The material effects of cavitation are consequences of the creation, expansion, and implosion of cavities in liquids. For cavitation to occur, there must be nuclei in the medium around which bubbles or cavities can form. These nuclei can be very small bubbles or even dust particles. The nuclei remain quiescent until they are acted upon by thermal, mechanical, or chemical forces that change their equilibrium. A local pressure drop, for example, will encourage the formation and growth of bubbles. When the bubbles collapse the gases inside them are compressed, creating intense heat. The high instantaneous pressures and resultant heat generated by the collapses cause the tissue destruction seen in ultrasonic tissue fragmentation. The region of destruction is quite small, and the heat quickly dissipates, protecting adjacent, less aqueous matter.

The mechanism of destruction of living tissue is actually more complex than this summary suggests. In tissues with a high water content, cavitation is the major factor in cell disruption. Bubbles form on both sides of the membranes of cells exposed to ultrasonic vibration (Figures 33.3.2 and 33.3.3). It is not the sound wave itself that causes the damage. The sound wave merely provides the energy that fuels the relatively slow formation of the bubbles. It is the rapid release of energy when the cavities collapse that is destructive (Figure 33.3.4). Very high temperatures (7200°C) and pressures (75,000 psi) can be generated in this way. A single implosion is relatively harmless, but millions of these cavities are formed during each second of exposure to ultrasonic vibration. Their cumulative implosion has significant effects on tissue.

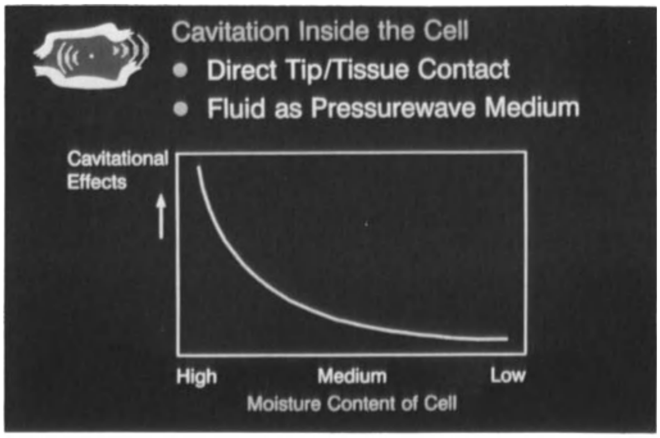
The energy released by cavitation also causes water to dissociate into free radicals:

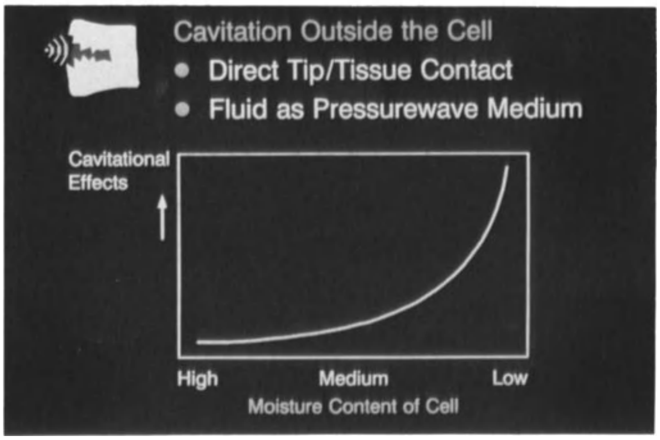
$$H_2O = H^+ + OH^-$$
$$OH^- + OH^- = H_2O_2 \quad H^+ + H^+ = H_2$$

Back reactions and oxidation and reduction reactions can then occur. These reactions may contribute to increased cell death.

Ultrasonic Dissector

The currently available instruments are manufactured by: Olympus, in Japan; the Surgical Technology Group (STG), in Britain; and Codman, Sharplan, Soring, and Valleylab, in the United States. The Olympus unit is available only in Japan. Only the CUSA Laparoscopic Accessory from Valleylab is currently equipped with electrosurgical capability.





FIGURES 33.3.2 and 33.3.3. Cavitation produces bubbles on both sides of cell membranes exposed to ultrasonic vibration.

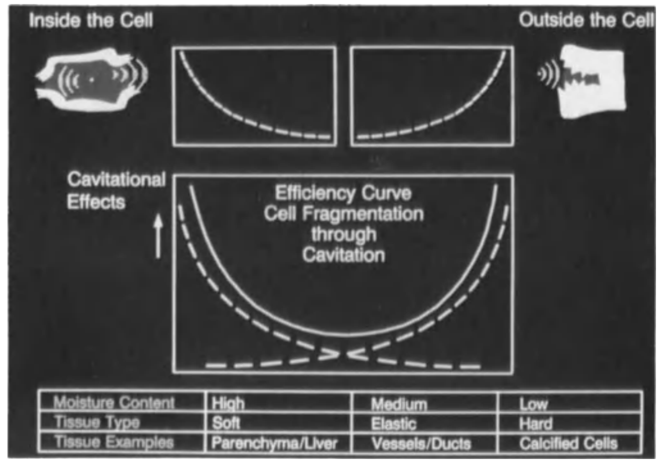


FIGURE 33.3.4. The rapid release of energy when the bubbles collapse causes tissue destruction.

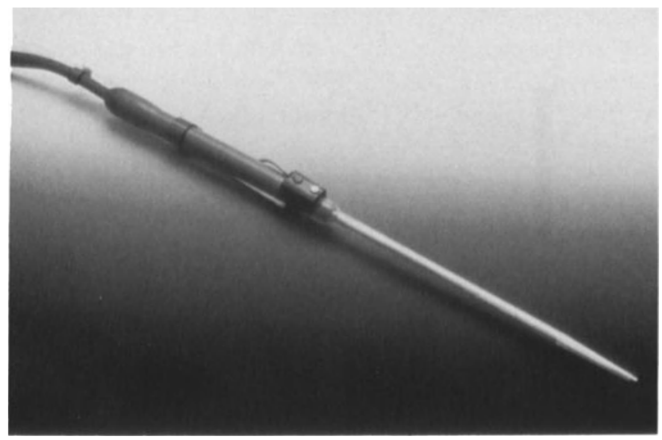


FIGURE 33.3.5. The Valleylab CUSA Laparoscopic Accessory with the CEM (CUSA Electrosurgery Model) provides ultrasonic dissection, electrosurgery, suction, and irrigation in one 10-mm laparoscopic unit.

Ultrasonic Generator

Devices that operate above 18,000 Hz, above the range of human hearing, are considered to be "ultrasonic." Most ultrasonic surgical dissectors operate at 23 or 24 kHz. This frequency was chosen because it is the lowest inaudible frequency with a practical amplitude.

Handpiece

Combining modes of operation in one instrument reduces the number of instrument changes required during a procedure and may reduce the need for other expensive pieces of equipment designed to perform the functions the integrated handpiece provide (Figure 33.3.5).

Ultrasonic Dissection

The handpiece is composed of an acoustic vibrator, a coupling section, and a replaceable aspirating tip (Figure 33.3.6). The acoustic vibrator is usually a magnetostrictive transducer that converts the electrical energy from the generator into mechanical motion. In the Sharplan

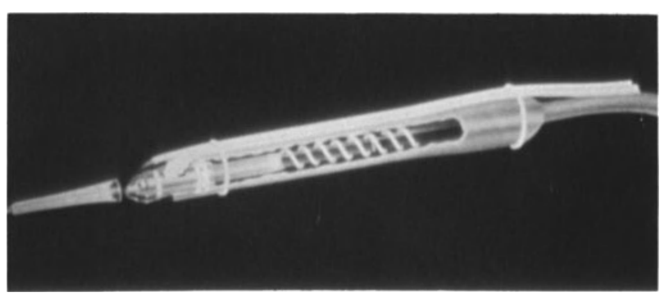


FIGURE 33.3.6. The ultrasonic handpiece contains the acoustic vibrator, a coupling section, and a replaceable aspirating tip. The variety of tips makes it suitable for open procedures in general surgery, neurosurgery, and urology, as well as for laparoscopic procedures.

dissector for open surgery and the STG laparoscopic unit, the transducer is a series of piezoelectric ceramic discs. The Valleylab transducer is composed of nickel-alloy laminations.

In all three cases when the transducers are placed in an alternating electromagnetic field, their length alternately increases and decreases. If the transducer is to function properly, its initial length must be an exact multiple of the wavelength of the excitation wave (Figure 33.3.7). At 23,000 Hz, 10.8 cm is one such multiple. The requirement that the operating frequency be inaudible also puts constraints on the size of the transducer and the amplitude of vibration. Operating at 40,000 Hz, ophthalmologic units can have smaller, lighter handpieces, but their amplitude is limited to 90 μm. This is sufficient for lens extraction, but an amplitude of between 200 and 350 μm is necessary for neurologic and general surgical applications. The total length of the transducer, coupling section, and operational tip also affects the operation of the unit.

The amplitude of vibration is also inversely proportional to the cross-sectional area of the tip. For this reason a tapered titanium tip permits more tissue destruction. At full power and an excitation frequency of 23,000 Hz, the amplitude of vibration of the standard handpiece is 350 μm. The length of the laparoscopic handpiece demands a decrease in amplitude and a gradual application of power. This became clear early in our experience with laparoscopic applications of the device. A Soft Start accelerator on the Valleylab CUSA 200 gradually increases the power as the handpiece approaches equilibrium in its operating range. The 200 μm displacement provided by this instrument is very effective for laparoscopic dissection.

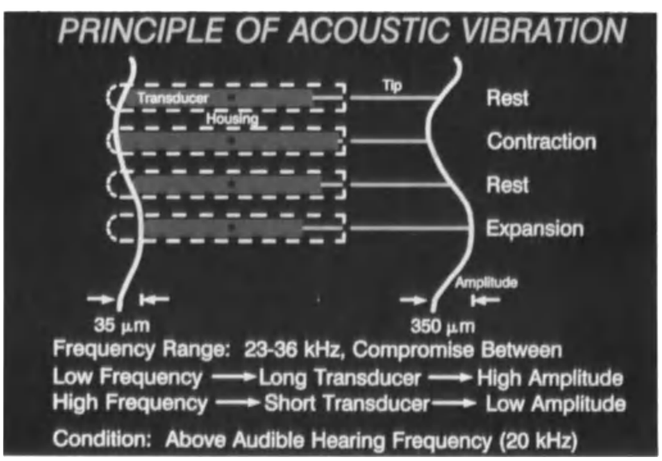


FIGURE 33.3.7. The length of transducer must be a multiple of the wavelength of the excitation wave. This places some constraints on the size of the handpiece and the amplitude of the vibrations produced.

Irrigation

Continuous irrigation cools the dissector tip and provides a medium for the emulsification of the disrupted tissue. Heparin may be added to prevent clogging and preserve the histologic suitability of the aspirated material. By adjusting the flow rate of the irrigant, the temperature of the ultrasonic tip may be regulated. STG believes its piezoelectric transducer produces less heat and may require lower irrigation rates to maintain tip cooling. Because of the reduced coolant flow the heat may be sufficient to coagulate small vessels during dissection. Bacteria and viral particles are subjected to the same destructive cavitational forces as the tissues being dissected. Indeed, cavitation is an effective method for cleaning and sterilizing instruments, a purpose for which it is frequently used in modern operating rooms. Whether the fine mist generated at the dissector tip poses a risk of infection to operating personnel is currently under study. The irrigant flow should be regulated to minimize this mist but still protect the tip from overheating. The laparoscope may be cleaned with a pulse of irrigant from the dissector, but care must be taken to prevent damage to the lens.

Suction

Emulsified debris is continuously removed through the suction channel. Any smoke that may be generated by instruments used to achieve hemostasis or blood and other fluids are rapidly cleared. A combination of suction and ultrasonic dissection can be used to fragment and remove small, spilled gallstones or blood clots. This ensures a clear field of view that makes laparoscopic dissection safer.[21,28,33] During laparoscopic procedures, the level of suction must be reduced to avoid evacuation of the pneumoperitoneum.

Hemostasis

The basic ultrasonic dissector relies on the heat generated by the operating tip of the ultrasonic dissector that controls small vessels. Larger vessels are skeletonized and ligated with clips or sutures. Although instrument exchanges during laparoscopy are reduced by the integration of suction, irrigation, and ultrasonic dissection in a single instrument, the need to control smaller vessels or lymphatics will arise at some point in nearly every laparoscopic procedure. Cuschieri employs a two-handed technique, operating the ultrasonic dissector with one hand and a diathermy unit with the other.[3] Currently, only the CUSA Laparoscopic Accessory (Valleylab) integrates electrosurgery with the other features of the ultrasonic dissector. This makes the instrument more flexible and further reduces the number of instrument changes.

Clinical Experience

We had been using the ultrasonic dissector for open hepatic resections for some time when laparoscopic cholecystectomy was developed. The dissector's ability to reduce blood loss and increase precision during these major resections has been shown by many studies. The idea of adapting ultrasonic dissection to laparoscopy occurred to several investigators independently.[3,13,42] This explains the simultaneous development of units in the United Kingdom, Japan, and the United States, and it may also be an indication of the synergism of laparoscopy and ultrasonic dissection.

Laparoscopic Cholecystectomy

Once it was clear that the ultrasonic instrument could be used to precisely dissect portal structures and separate gallbladders from livers during open surgery, animal studies verified the feasibility of the laparoscopic adaptation of these procedures and a randomized, prospective trial was undertaken with a dissector that did not include electrosurgery capability.[42] The goal of this study was to verify the safety and efficacy of ultrasonic dissection during laparoscopy (Tables 33.3.1 and 33.3.2). Comparing ultrasonic to laser and electrosurgical instruments was a secondary goal. While the study did not prove the superiority of ultrasonic dissection, the instrument was clearly shown to be safe and effective.

Technique

Important tips for the use of the ultrasonic dissector in laparoscopic cholecystectomy are summarized in Table 33.3.3.

Results

The lack of a built-in means to control small vessels was a definite drawback of the initial unit, but a later version added electrosurgery to the three basic functions. We have now used the Valleylab CUSA Laparoscopic Accessory for more than 50 laparoscopic cholecystectomies. Our growing experience (Table 33.3.4) with this multifunction handpiece has confirmed our initial impression that the ultrasonic dissector can be a very valuable tool for laparoscopic cholecystectomy, an impression shared by those members of the Valleylab pre-release panel[39] who used it for this procedure. The instrument is especially useful if there is acute inflammation or excessive

TABLE 33.3.1. Distribution of patients and results of preoperative investigations in control and study patients.

Variable	Electrosurgery (n = 21)	Laser (n = 15)	CUSA (n = 37)
Mean age (yr)	49.9	44.4	48.8
M:F ratio	6:15	4:11	7:30
WBC count	11	7.9	7.6
Hematocrit	40.7%	44.9%	40.6%

TABLE 33.3.2. Operative results and technical difficulties.

Variable	Electrosurgery (n = 21)	Laser (n = 15)	CUSA (n = 37)
Operative time (min)	97	56	90
Blood loss > 10 cc no. (%) of patients	1 (4.8)	0	4 (10.8)
Operative complications	0	0	0
Technical complications no. (%) of patients	1 (4.8)*	2 (13.3)**	8 (21.6)***
Deaths	0	0	0
Mean hospital stay (days)	1.1	1.0	1.4
Mean time off work (days)	7.9	11.6	8.0

Technical complications:
*Broken electrosurgical hook.
**Broken laser fibers.
***Vibration of the prototype handpiece. This was corrected when the power was applied gradually. Gradual acceleration is now accomplished by SoftStart in the CUSA 200 System.

TABLE 33.3.3. Tips for use of the ultrasonic dissector in laparoscopic cholecystectomy.

1. The suction must be adjusted to the lowest level possible so that it does not compromise the pneumoperitoneum. The insufflator must be able to deliver a high flow of gas throughout the dissection.
2. The subxyphoid trocar should be 10- or 11-mm and have a flap rather than a trumpet valve. Trumpet valves tend to bind the instrument, alter the relation between the flue and the tip. Local heating may occur where the flue is compressed against the shaft of the instrument. This trocar should also be so located that it provides the optimum angle of access to the porta and the gallbladder. This may mean it should be placed lower than normal.
3. The operating table may need to be lowered to provide free motion of the handpiece without contamination from the surgeon's gown or mask.
4. The addition of heparin to the irrigant will facilitate clearance of clots and other debris.
5. The tip of the instrument should be swept in gentle strokes parallel to the structures to be preserved.

TABLE 33.3.4. Dissection times (min) for patients with acute cholecystitis.

n = 14	Hilum	Gallbladder	Total
CUSA with CEM*	21	12	34

*CEM = CUSA Electrosurgical Module.

fat in the porta hepatis or gallbladder fossa. The instrument's value was considerably enhanced by the addition of electrosurgery. This reduced the number of instrument exchanges during procedures and facilitated the control of bleeding in the gallbladder bed. Any smoke produced was quickly cleared by the suction.

Other Applications

Mesenteric Dissection and Colectomy

The next area of application studied was dissection of the mesentery during laparoscopic bowel resection. The feasibility of this dissection was confirmed during open colectomy and in animal trials. The spatial precision and tissue selectivity of ultrasonic dissection, even during the dissection of thick or inflamed mesenteries, was impressive. In a recent paper, Cuschieri reported his early experience, which included two right hemicolectomies for cancer, three abdominal rectopexies for total prolapse, and four anterior resections for cancer.[3] He believes the dissection of the major vascular pedicles of the colon is the most important application of the technology, in part because it shortens the procedure considerably.

While ultrasonic dissection is unnecessary during laparoscopic appendectomy, this application can demonstrate its utility and provide the new user with an opportunity to practice prior to using the instrument during a colon resection.

Nissen Fundoplication

Cuschieri has the greatest experience using the ultrasonic dissector for this application.[3] His results and those of Cuesta[39] in Amsterdam are encouraging. The ability to selectively dissect the esophagus, vagus nerves, and short gastric vessels has been particularly helpful during fundoplication.

Splenectomy

In a letter to the *New England Journal of Medicine* published in 1992,[13] Hashizumi from Japan reported two laparoscopic splenectomies performed with the Olympus ultrasonic dissector. The patients had idiopathic thrombocytopenic purpura. While he felt "this technique should be useful for patients requiring splenectomy for benign disease," the six to eight hours the procedure required suggests further improvements in technique are needed.

Pelvic Lymphadenectomy

The author has used the CUSA for pelvic lymphadenectomy to stage three patients with prostatic malignancy. It was particularly useful for controlling small vessels and lymphatics as the node packet was removed from beneath the iliac vessels. Kavoussi[39] at the Brigham and Women's Hospital in Boston has also found it quite useful for this procedure.

Thoracic Applications

Cuschieri has described the utility of the instrument in 10 patients undergoing right thoracoscopic esophagectomy.[3] He believes the selectivity of the instrument and the dry field it provides have decreased his operating times more than increased experience alone. Whether Verazin's experience[40] with ultrasonic dissection for open lung resection can be achieved during thoracoscopy should be studied.

Nephrectomy and Adrenalectomy

Kavoussi[39] has also used the CUSA for two laparoscopic nephrectomies. Fletcher and Jones[39] at the Austin Hospital in Melbourne, Australia, found the ultrasonic dissector the "method of choice" for their laparoscopic right adrenalectomy for pheochromocytoma.

The Learning Curve

Prior to the release of the CUSA in 1992, presentations and hands-on labs were organized in conjunction with the Third World Congress on Endoscopic Surgery in Bordeaux, France, and the First International Symposium on Minimally Invasive Surgery in Saskatoon, Canada. A group of 25 experienced laparoscopic surgeons were first exposed to the instrument during these sessions. The majority found it easy to use. All were able to separate the cystic duct from the artery in the 50-lb pigs without injury to either structure. These surgeons, who comprised the pre-release panel, then performed a wide variety of procedures with the dissector in their own hospitals around the world (Table 33.3.5). Most of these surgeons cited the precision and tissue selectivity of the dissector, and the multifunctional handpiece as significant advantages. It seems unlikely that most experienced laparoscopists will require extensive formal training to learn to use the instrument safely. This is in marked contrast to the situation with lasers and perhaps even with electrosurgery.

Conclusion

Ultrasonic dissection and tissue removal has been utilized by a growing number of specialties for several years. Many procedures, including neurosurgical and hepatic resections would be much more difficult, if not impossible,

TABLE 33.3.5. CUSA laparoscopic accessory pre-release panel: surgeons and procedures.

Surgeons:

Maurice Arregui Indianapolis, IN	Stephen Blamey Heidelberg, Victoria, Australia	P. Testas Paris, France
Denis Collet Bordeaux, France	M.A. Cuesta Valentin Amsterdam, The Netherlands	Kenneth Ciardiello New Haven, CT
W. Peter Geis Park Ridge, IL	Peter Go Maastricht, The Netherlands	John Donohue Rochester, MN
John Hunter Atlanta, GA	Bob Jones Melbourne, Australia	Sherif Hanna Toronto, Canada
Douglas Olsen Nashville, TN	David Ota Houston, TX	Louis Kavousi Boston, MA
Jacques Perissat Bordeaux, France		John Payne Honolulu, HI
Tim Wilson Dee Why, NSW, Australia		Lawrence Way San Francisco, CA

Laparoscopic procedures:

Cholecystectomy	83
Coloectomy	5
Nissen fundoplication	3
Nephrectomy	2
Appendectomy	2
Inguinal hernia	2
Adrenalectomy	1
Ripstein	1
Excision of a hepatic cyst	1
Total	100

without the unique tissue selectivity of the instrument. The adaptation of the technology to laparoscopic surgery grew out of the search for alternative, possibly safer, methods of dissection. The current units combine the functions of three or four separate instruments, reducing the need for instrument exchanges during a procedure. This flexibility, combined with the ability to provide a clean, smoke-free field, improves safety while shortening operating times.

Endoscopic ultrasonic dissection has been successfully adapted to several procedures by many investigators. Their results warrant further study as we seek to clarify the ultimate role of this promising technology in minimal-access surgery.

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34
Physics of Stone Fragmentation

34.1
The Principles of Electrohydraulic Lithotripsy

Desmond H. Birkett

Introduction

In a particular case, minimal-access management of bile duct stones depends on the available access routes to the biliary system, the anatomy of the biliary system, and the size and number of the stones. The most common method of stone removal is endoscopic retrograde cholangiopancreatography (ERCP) with papillotomy and balloon or basket extraction of the stone. Extraction can also be achieved via a T-tube tract, if present, or by transhepatic percutaneous access to the biliary tree, when the other two routes are not available. Transhepatic biliary access is achieved by percutaneous puncture under local anesthesia and pursued under radiological guidance. Those stones that are too large to be extracted whole are fragmented.

Stone fragmentation, which is one of the oldest operations performed by surgeons, was first performed in the urinary bladder. Over the years the technology has improved, and the early large and cumbersome instruments were replaced by more sophisticated methods. With the advent of minimal-access procedures, stones in the ureter, renal pelvis, and biliary tree have been treated, as well as those in the urinary bladder. Stone fragmentation is now performed in the extra- or intrahepatic ducts of the biliary tree and in the gallbladder.

A variety of methods are currently used for intracorporeal fragmentation of biliary stones. The baskets used for mechanical lithotripsy are large and can be advanced only via the sphincter of Oddi and through a large-channel duodenoscope. Ultrasonic lithotripsy requires a large rigid endoscope such as a nephroscope. The only two techniques that make use of small flexible endoscopes are laser lithotripsy and electrohydraulic lithotripsy. The latter is a cheaper and significantly easier method of stone fragmentation.

History

The principle of electrical impulse fragmentation was discovered by Yutkin at the Institute of Technology in Kiev,[1] and developed in the former Soviet Union as a commercial method of breaking rock.[2] In 1959 Rese, an engineer from Riga, conceived of using electrohydraulic impulses to break up ureteral stones after he underwent an operation to remove ureteral stones. Goligowky developed the technology for clinical use. The product of this effort was the first clinical unit, the Urat-1.[1] Subsequently electrohydraulic lithotripters were developed in the United States by Northgate. Later ACMI produced a model.

The first report of the use of the Urat-1 in the United States was by Reuter, who documented its use in 50 patients with ureteric stones. Other groups reported excellent results with this lithotripter.[3–5]

Burhenne was the first to use electrohydraulic lithotripsy in the biliary tree through a T-tube tract.[6] Koch reported the use of electrohydraulic lithotripsy to fragment a common duct stone through a duodenoscope. Lear and colleagues, reported its use transhepatically to fragment common duct stones.[7] Josephs and Birkett reported the use of the ACMI lithotripter to fragment retained common duct stones under direct vision; the electrode was passed through a choledochoscope introduced into the biliary tree via a T-tube tract in 12 patients.[8] In all patients the biliary tree was cleared of stones without complication.

Mechanism of Action

In electrohydraulic lithotripsy the discharge of high-voltage sparks in a liquid medium results in a train of high-amplitude hydraulic shock waves. In the clinical situation the most satisfactory medium is saline because it is electrically conductive and serves the additional purpose of irrigating the operative area. The spark vaporizes the saline, producing a shock wave. The shock waves fracture and fragment a nearby stone. The discharges are developed by capacitors in a generator that converts 60 Hz current into 50 to 100 dc discharges of 4 to 6 kV per second. The lithotripter itself is a flexible 10F probe on the end of which are two coaxial electrodes. The size of the probes has gradually been reduced; probes as small as 3F and 1.9F, with the same coaxial electrodes, are now available. The smaller probes have significantly shorter lifetimes than the larger probes and, if there is a large stone burden, more than one probe may have to be used.

Tissue Effect

The usefulness of any instrument depends on its side effects and complications as well as on its intended effects. The electrohydraulic lithotripter was designed to fragment hard urinary stones, and the same unit easily fragments the softer biliary stones, propelling them deeper into the biliary system. Every effort must be made to confine the energy discharge to the surface of the stones, because the energy absorption is not selective and surrounding tissue may be damaged. No system can be considered effective if it is unsafe and, therefore, the effect on surrounding tissue is of paramount importance. Harrison and coworkers showed that discharge of the electrohydraulic lithotripter can result in the perforation of the bile duct.[2] They demonstrated no effect if the probe was held 1 mm or more from the surface of the tissue. We reported similar results, finding that only a few discharges were needed to produce a substantial hole in the bile duct wall of the pig when the probe was held at right angles to and in contact with the surface of the bile duct.[9] Injury is probably less likely if the probe is held at an acute angle to the tissue. However, Tanaka and coworkers found the common duct was perforated even when the probe was held at an acute angle to it and also reported perforations when the probe was discharged within 2 mm of the bile duct wall.[11] The injury is a thermal injury; the spark across the two electrodes burns the tissue of the duct wall.

Despite these experimental reports the incidence of bile duct injuries resulting from clinical use of lithotripters is extremely low. Typically the injury manifests as a self-limiting hemorrhage. Transfusion may be required; one of our patients required 4 units of blood. Bonnell and colleagues reported bleeding from the bile duct that required transfusion and bile duct perforation.[12] However, these complications were related to rapid dilation of the percutaneous transhepatic tract rather than to electrohydraulic lithotripsy. Several other groups have reported bleeding, usually minor in nature, as a complication.[13–15] It was felt that the bleeding was caused by the stone fragments damaging the side of the duct rather than by the electrical discharge from the probe.

Electrohydraulic lithotripsy is a relatively safe technique, provided it is performed under direct vision so that the position of the probe can be monitored at all times and the electrical discharge is stopped if the probe gets near the wall of the bile duct. It is certainly very effective; the fragmentation of stones as big as 55 × 33 mm has been reported.[13]

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34.2 The Physics of Laser Stone Fragmentation

Graham Watson

As laparoscopy becomes more sophisticated, it becomes increasingly important to be able to fragment calculi with an instrument that is extremely flexible and of narrow caliber. Lasers are expensive, but there is no other modality that can match them for fiber size and for flexibility and safety. The lithoclast (an air gun that fires a pin against a retaining device) is very safe, is certainly cheaper, and is just as effective, but to date lithoclasts are rigid devices. Ultrasonic probes are also rigid. Electrohydraulic probes are flexible and narrow, but not as flexible or narrow as lasers; they cause far more trauma to tissue than pulsed dye lasers.

The physics of laser stone fragmentation may be as exciting as reading Virgil in the original Latin. However, one cannot use lasers safely without some understanding of the how they work. The surgeon contemplating using lasers should have a working knowledge of their properties and their interactions with tissue and stones.

What Is a Laser?

Laser is an acronym for light amplification by stimulated emission of radiation. Stimulated emission occurs when an electron occupying a high energy state is stimulated to fall to a low energy state and gives off a photon in the process. If photon emission is stimulated by another photon, the two photons travel in phase and in the same direction. If a mirror is placed at either end of a rod of lasing medium, and one mirror is partially transparent, the photons will travel repeatedly between the mirrors, increasing in number with every pass. The beam of photons that emerges from the partially transparent mirror is a laser beam. It is intense, has excellent beam quality (is collimated), and is entirely in phase (coherent). Because of its beam quality, the laser can be focused and transmitted via fine quartz fibers. The properties of collimation and coherence are lost during transmission, but the beam of light remains intense and can be directed into any part of the body.

Laser Interactions with Stones

The majority of the laser/material interactions exploited in medicine are thermal. In the case of laser interactions with stones, however, thermal effect is inappropriate. Stones can be classified as inorganic and organic. Inorganic stones constitute the majority of urinary calculi; they tend to be calcium-containing and to have boiling points of several thousand °C. Organic calculi, which include gallstones and are therefore the most important type in laparoscopy, tend to have boiling points of 200 to 300 °C. Many stones have some calcification, usually peripheral, that results in patches of very high boiling points. If a laser with a continuous-wave output is focused on a stone, even if it is used only briefly, then very high temperatures may be produced. The irrigant, of course, will tend to protect the surrounding tissue, but if one is to have any effect on the stone, there is a distinct risk of damaging surrounding tissue. Stones may occasionally be fractured by thermal stresses, but because of the safety concerns, *continuous-wave lasers should never be used on calculi.* Pulsed lasers with sufficiently short pulses are more effective at fragmenting stones and have minimal or no thermal effects.

History of Stone Fragmentation

The first attempt to fragment a calculus using a laser was in 1968 when Mulvaney[1] from Cincinnati used an early laser on stones and penile cancer. Very high pulse energies were used, delivered from a ruby laser via solid quartz rods. Later continuous-wave CO_2 (Tanahashi et al.)[2] and Nd:YAG lasers (Pensel et al.)[3] were assessed *in vitro*. These were inappropriate for clinical use because of their thermal effects. Pensel then went on to show that *in vitro* one could use a Q-switched Nd:YAG laser to fragment stones. He used pulse energies as high as 5 J and pulse durations of 10 ns (0.00000001 second) to fragment stones in air. Very short pulses cannot be delivered at such high energies via quartz fibers, but this experiment did show that one can use a pulsed laser to fragment stones without any obvious thermal effect, an important contribution. Fair showed that one could convert laser pulses into shock waves using an "optomechanical coupler," a thin layer of aluminium sputtered onto a layer of glass that was interposed between the laser and the stone.[4] The research, however, did not lead to a clinical device. Watson showed that trains of lower-energy Q-switched pulses had a more consistent effect on stones than single giant pulses.[5] These pulses were still too short to be easily transmitted through fibers. A 100 μs (0.0001 second) pulsed Nd:YAG laser was tested, but it proved to have a combined thermal and mechanical effect on stones, and so could not be used *in vivo* without risking tissue damage. Moreover, it was totally ineffective or at best less efficient on pale calculi than on dark calculi.

The problem, then, was to find a laser whose energy could be delivered via fibers but which had pulses short enough that the thermal effect was limited. The laser also had to be one pale calculi absorbed efficiently enough that they would fragment. More needed to be known about the absorption spectrum of calculi and pulsed laser transmission through fibers.

The Absorption Spectrum of Calculi

A Beckman spectrophotometer was used to study the absorption spectrum of calculi between 250 and 2,500 nm, that is from the ultraviolet to the midinfrared. This range includes all laser wavelengths that might be used to fragment stones. Lasers have an effect only if they are absorbed, and a wavelength that penetrates deeply will affect a greater volume of stone than one that is absorbed at the surface.

All calculi had a common absorption pattern. Absorption was extremely strong in the ultraviolet and decreased with increasing wavelength through the blue to the red wavelengths, reaching a minimum at 1 μm (the near infrared). The absorption then became more variable, but with peaks at water's absorption wavelengths (1,400, 1,900, and 2,500 nm). In addition, gallstones had an absorption peak in the range from 450 to 550 nm. Black stones had a stronger absorption across a range of wavelengths, whereas pale calculi had more variable absorption. Thus the difference between the effects of the long-pulse Nd:YAG laser on pale and dark calculi is explained by absorption alone.

The Pulsed Dye Laser

Once the absorption pattern of calculi was identified, the next challenge was to investigate transmission of pulsed lasers in fibers. Pulsed dye lasers with outputs varying from 1 to 300 μs were coupled into fibers.[6] It proved possible to couple even 1 μs laser pulses into fibers as small as 200 μm in diameter with standard fiber holders provided that the fiber's cut face was reasonably smooth. The pulsed dye lasers were far more effective at stone fragmentation than the long-pulse Nd:YAG laser. A parametric study looking at the influence of wavelength, pulse duration, and fiber size on stone fragmentation was performed. The threshold for fragmentation of a stone was found to be least when the fiber size was smallest, when the pulse duration was shortest, and when the wavelength was best-absorbed by the stone. The lowest threshold was achieved with a 200-μm fiber, the shortest possible wavelength, and a 1-μs pulse. Green light (504 nm) was selected rather than shorter wavelength because pulsed dye lasers operate efficiently at this wavelength and because it lies in the region of maximal differential absorption between stones and surrounding tissue. Tissue proved to have a far steeper decrease in absorption in the green than either urinary or biliary calculi. This maximal differential absorption meant that the pulsed dye laser had a built-in safety margin.

The Mechanism of Action of the Pulsed Dye Lasers

Subsequent to the research described above the pulsed dye laser has been marketed by the Candela Laser Corporation, Wayland, MA and by the Technomed Company, Lyon, France. The laser can deliver very high energies but these are limited for safety reasons to a maximum energy for each fiber size. Different fiber sizes are supplied because it has been found that using larger fibers with higher pulse energies results in more rapid fragmentation of hard stones. The stone is immersed in water or saline and the fiber is held as close as possible to or lightly touching the stone. The laser is used at a repetition rate of 5 to 10 Hz, and the fiber is repositioned after fracture until the stone is completely fragmented. There is a threshold below which there is no effect on the stone whatsoever. As the energy is increased, a noise is produced at the stone surface. When the pulse energy is raised still higher, tiny fragments start to be released from the stone surface. At still higher energies larger fragments are released. As the energy increases, the recoil of the stone also increases. The optimum energy is an energy at which fragmentation definitely occurs with each burst of pulses but not so high that the stone is propelled away from the operator.

Following up on my research Teng and colleagues performed some elegant studies on the mechanism of action of pulsed dye lasers.[7] They found that a plasma is produced when the stone fragments. Plasmas are ionized gases that manifest as flashes of light and noise emanating from near the stone's surface. One can demonstrate calcium emission lines on spectroscopy of the plasma light. For fragmentation to occur the expanding plasma bubble must be confined by fluid. High-speed photography has shown that the plasma bubble expands and then, a few microseconds later, suddenly collapses with an inrush of water jets onto the stone surface. It is this collapse that fragments the stone.[8]

If one were using a 200-μm fiber, the smallest fiber available, a typical pulse energy would be 50 mJ. But 50 mJ is only 0.01 calories; it is sufficient if converted to heat to raise the temperature of 1 cc of water 0.01 °C. So how does it produce an ionized-plasma bubble and fragment the stone? The first consideration is that the pulse lasts only 1 μs. Thus the power during the delivery of the 50 mJ is 50,000 W. The next factor is that the pulse is delivered via a 200-μm fiber. Thus the 50,000 W is compacted into an area of 0.000314 cm^2. The power density is therefore 160 million W/cm^2. Absorption of this laser energy at the stone's surface results in such a strong force field that electrons and calcium ions are liberated, causing cascading ionization. The plasma itself then further absorbs laser light.

If the laser fiber is a 320 μm, then the area absorbing the laser pulse is more than doubled. Thus one needs to deliver a higher energy pulse to achieve the same effect. The increase in laser energy does not need to be proportional to the rise in surface area, however. A rise of 50% in pulse energy gives a comparable result. Increasing the pulse energy further results in improved fragmentation. A larger-diameter fiber is also easier to see emerging from the endoscope. It is considerably less flexible.

Laser Safety

The pulsed dye laser is intense light energy. As such it is a potential hazard, particularly to eyes, which focus the light directly onto the susceptible tissue of the retina. Basic safety rules are as follows:

1. The procedure should be performed in a laser-safe operating room with appropriate safety features, including warning signs, interlocked doors, and laser-opaque windows.
2. Personnel should be trained in laser safety.
3. One member of the team should be assigned the duty of switching the laser on and off during the procedure.
4. The laser should be enabled only when the fiber is inside the endoscope.
5. The staff and the patient should wear protective eyewear of appropriate optical density for the wavelength being used. Since we currently tend to work exclusively from a television monitor, we could work without goggles. However, if a fiber broke, light might spill from the broken end, and this might happen outside the body. One compromise is to use spectacle-type protective eyewear of the appropriate optical density; the spectacles tend not to mist up so much as goggles.

Performing the Laser Procedure

As a urologist, most of the laser procedures I have performed have been for ureteric calculi (2,500 cases) rather than gallstones (15 cases). Since gallstones are treated laparoscopically, however, I will discuss them here.

Access to the common bile duct is described in more detail elsewhere. Once an incision is made in the proximal cystic duct a special-purpose sheath can be inserted into the common bile duct over a guidewire via a 5-mm port via the right hypochondrium. A 6F choledochoscope (only 2 mm diameter) (Candela Corporation) can be introduced through the sheath. If it is impossible to introduce the sheath into the common bile duct, then a guidewire can be inserted down the duct; it may prove possible to pass the choledochoscope over the guidewire into the duct. The guidewire is removed and and irrigation introduced through to the endoscope. Under direct vision the common bile duct can then be inspected down to the ampulla. Small stones tend to be flushed downwards and to swirl in the irrigant, and larger stones impacted in the common bile duct are more readily apparent. Once the stone is seen, the next step is to introduce the laser fiber. I favor the 200-μm fiber introduced through a flexible endoscope. With the irrigant on a side port a bung such as a Tuohy-Borst adapter is used for the laser port. The fiber is introduced carefully to avoid scratching the delicate channel. The endoscope is held as straight as possible to facilitate passage of the fiber. Once inserted into the endoscope the aiming beam of the laser is switched on so the fiber can be seen as soon as it emerges from the endoscope. If the fiber will not pass through a bent section of the endoscope, the endoscope can be withdrawn until the fiber can pass. With the fiber barely protruding, the endoscope is advanced to the stone. It is then possible to actively deflect the endoscope. The endoscope should be 5 mm from the stone and the fiber should just touch the stone when fragmentation commences. Fifty millijoules should be selected as a starting energy and a burst of two seconds or so of pulses at 10 Hz delivered. If the stone is small, irrigant should be turned down and an attempt made to secure the stone with the fiber against the sidewall but with the aiming beam pointing at the stone. Each burst of pulses should be accompanied by a cloud of debris and some impact should be felt via the fiber. The operator should have a clear view before delivering the next burst of pulses, and the fiber should be kept on the stone surface. A crater should soon develop, and this can be further developed until the stone breaks. Then the daughter fragments can be further broken down. If the fiber sinks into the stone, fragmentation can be continued within the stone until the impulse is no longer felt over the fiber. Then the fiber should be pulled out of the stone and work begun again at the stone's surface. If the pulse energy is high, more care must be taken not to injure the common bile duct wall. Perforation can occur at higher pulse energies, although the safety margin is far greater with a pulsed dye laser than with an electrohydraulic probe.

If fragmentation at the time of cholecystectomy fails, the laser can also be introduced via endoscopic retrograde cholangiopancreatography or via a percutaneous transhepatic route. The laser can be used via a mother-daughter scope; the daughter scope is introduced directly into the common bile duct, and the laser fiber is then directed onto the stone. Again saline irrigation is used. The daughter scope does not have active deflection, but by maneuvering the mother scope it is usually possible to place the fiber on the stone surface. If the stone burden is great and the ducts are dilated, one can employ an antegrade approach. The tract can be created acutely or be preformed and allowed to mature. The advantage of both the antegrade and the laparoscopic approaches is that fragments clear into the duodenum and so the operation is over when all pieces of stone have been cleared from the duct.

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34.3
The Physics of Extracorporeal Shock Wave Lithotripsy in Stone Fragmentation

Steven E. Raper and Frederic E. Eckhauser

History

Courvoisier was the first to remove a common bile duct stone in 1890. For the next 90 years operative choledochotomy remained the gold standard for clearing calculi from the biliary tree.[1] Retained stones represent a persistent and significant source of morbidity, affecting several thousand patients per year. In an effort to reduce the potential morbidity and mortality associated with treating biliary calculi, especially in elderly or frail patients, a number of alternative technologies have been developed including extracorporeal shock wave lithotripsy (ESWL).

ESWL was developed in the former Soviet Union some 30 years ago as an industrial technique for the fragmentation of rock.[2] This technology was first used clinically for the removal of urinary calculi in 1980, and proved to be successful in 90% of patients, thus sparing many individuals an operation.[3] In 1986 Sauerbruch and colleagues reported the successful application of ESWL to biliary stones in both the gallbladder and common bile duct.[4] Since then, many clinical trials have confirmed the safety and efficacy of ESWL in the management of biliary lithiasis.

Physics of ESWL

ESWL is an engineering triumph; the selective, precise application of brute force. The important components of a functional ESWL device include a shock wave generator, an ellipsoidal reflector, a localizing device to identify and target the stone, and a liquid or gel medium to minimize acoustic impedance so that the maximum shock wave energy is delivered to the target.

Several different methods of shock wave generation have been developed. The two most popular are spark-gap and piezoelectric generators. Spark-gap electrodes develop shock waves by discharging electrical energy stored in a capacitor from one electrode to another. The electrical discharge vaporizes fluid between the electrode tips resulting in a spherically symmetric shock front. The velocity of the front is greater than the speed of sound, and thus a spherically expanding shock wave results in which the compressed gas is at higher pressure and greater density. The shock wave manifests as a steep rise followed by an exponential decrease in the pressure of the gas.

Piezoelectric devices are mosaics of thousands of small ceramic elements arranged in a bowl-shaped configuration. When a voltage is applied across these elements, they flex suddenly, producing an acoustic wave much as does the diaphragm of a loudspeaker. Other devices have been tried with less success, including electromagnetic, microexplosive, and laser technologies.[5–7]

To focus a spherical shock wave to a point, fluid-filled semiellipsoidal reflectors are used. To be useful for lithotripsy, shock waves must be in the range of 600 to 1,200 bar. Spark-gap generators produce the highest pressures and the most reproducible waves. If the media through which the shock wave is propagated are acoustically matched, pressures high enough to fragment common bile duct stones are generated. Water, fat, muscle, kidney, liver, and gallstones all have similar acoustic velocities and acoustic impedances.[8] In contrast, air has a much lower acoustic velocity and impedance; hence, air pockets in the shock wave path, such as the bowel lumen, should be minimized.

When a shock wave strikes a dissimilar material, part of the wave is transmitted and part is reflected. This phenomenon can be represented mathematically by the following set of equations:

$$P_t = \left(\frac{2Z_2}{Z_2 + Z_1}\right)P_i$$

$$P_r = \left(\frac{Z_2 - Z_1}{Z_2 + Z_1}\right)P_i$$

$$Z = pc$$

where P_t = transmitted pressure, Z = acoustic impedance, P_i = incident pressure, P_r = reflected pressure, Z_1 and Z_2 are dissimilar materials through which the pressure wave passes, c = velocity of sound in the material, and p = the material's density.

When a high-pressure shock wave collides with a common duct stone, the transmitted pressure far exceeds the reflected pressure. Further, since the compressive strength of stones is greater than their tensile strength, tensile pressure waves reflecting off the back wall of the stone help to fracture the stone, a mechanism known as spalling. Cavitation may also occur as tensile wave reflection reduces the local pressure in the stone below the vapor pressure of trapped fluid, leading to expansion or collapse of the elements internal to the stone rapid enough to exceed fracture strength. Since stones have complex surfaces, shock waves have off-axis reflections, which develop into shear waves, that further enhance the fragmentation process. The low acoustic impedance of air results in large negative pressures when the air/tissue interface is hit by a shock wave. Severe damage to lung or intestinal tissue may result; tissue/gas interfaces should be avoided whenever possible.

One technical problem is coupling the generated shock wave to the patient. Initially, patients were set in large tubs of water, but this made it difficult to provide anesthetic management, monitoring, and ventilation. In addition, small air bubbles were difficult to eliminate, and they decreased the effectiveness of generated shock waves. Later-generation machines were equipped with water-filled flexible bags placed between the patient's skin and the shock-wave-generator porthole. Currently, a layer of mineral oil or other conducting gel is applied to the patient's skin, and the generator is directly applied. This simplifies the logistics of lithotripsy.

Other considerations in the design of an effective lithotripter are the need for materials able to withstand the repeated application of thousands of generated shock waves, control of conductivity, the ability to degas the propagation media, and the ability to remove gaseous byproducts.

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35
Visualization

35.1
The Hopkins Rod-Lens System

Sarah Cheslyn-Curtis and Harold H. Hopkins

Introduction

The word *endoscope* denotes "an instrument so arranged as to give a view of some internal part of the body through a natural canal." The earliest endoscope using lenses was the crystoscope of Nitze (1879), which was passed through the urethra to examine the interior of the urinary bladder. About the same time, a gastroscope was developed and passed through the mouth for the partial examination of the esophagus and stomach. Until the development of modern endoscopes, the instrument consisted of a rigid metal tube containing lenses. Illumination was provided by a small electric bulb at the distal end. The level of illumination, image sharpness, color rendering, and image contrast were all very poor in this traditional form of endoscope. Photography of the endoscopic view was almost impossible and the endoscopic performance of therapeutic procedures without the need for open surgery was very limited.

A general advancement in science and technology, led to two inventions that brought about a dramatic change in the quality and application of medical endoscopy. The invention of fiberoptics made it possible to provide better illumination and image-transmission through flexible glass fibers.[1,2] Construction of flexible endoscopes for the examination of the esophagus, stomach, and duodenum (gastroscope); the entire colon (colonoscope); the bladder and urethra (cystoscope); the bile and pancreatic ducts (side viewing duodenoscope); the bronchial tree (bronchoscope); the ureter; and small bowel became possible. Following the work on fiberoptics, attention was turned to the optical design of endoscopes using lens systems, and the rod-lens system was invented.[3]

Optical Systems for Rigid Endoscopes

The Traditional Endoscope

The traditional endoscope employed a group of lenses constituting the objective followed by a succession of relay systems (Figure 35.1.1). A suitable reflecting prism system was incorporated in the objective assembly, if an angled direction of view was required. The objective formed a reduced image of the object 0 at I_1 inside the endoscope tube. The reduced image at I_1 was relayed to I_2 and then passed through succeeding relay systems until it reached the proximal end of the endoscope where it was magnified by the eyepiece before reaching the eye of the observer. In practice, the lenses were 2 to 3 mm in diameter and there were five or more relay stages. Field lenses placed at each intermediate image ensured that all rays leaving the preceding relay objective were refracted to pass through the following relay system.

The Rod-Lens System

In the rod-lens system, the image is relayed by a succession of rod lenses (Figure 35.1.1). The traditional system consisted of a tube of air with thin lenses of glass, whereas the rod-lens system may be regarded as a tube of glass with thin lenses of air. The light transmission is many times greater than the traditional system and the image quality is superior to that obtainable with even the best fiber-optic endoscope. The advantage of the fiberoptic endoscope is its flexibility, but wherever a rigid endoscope can be used the rod-lens system is preferred. The roles of the objective and eyepiece in the rod-lens system

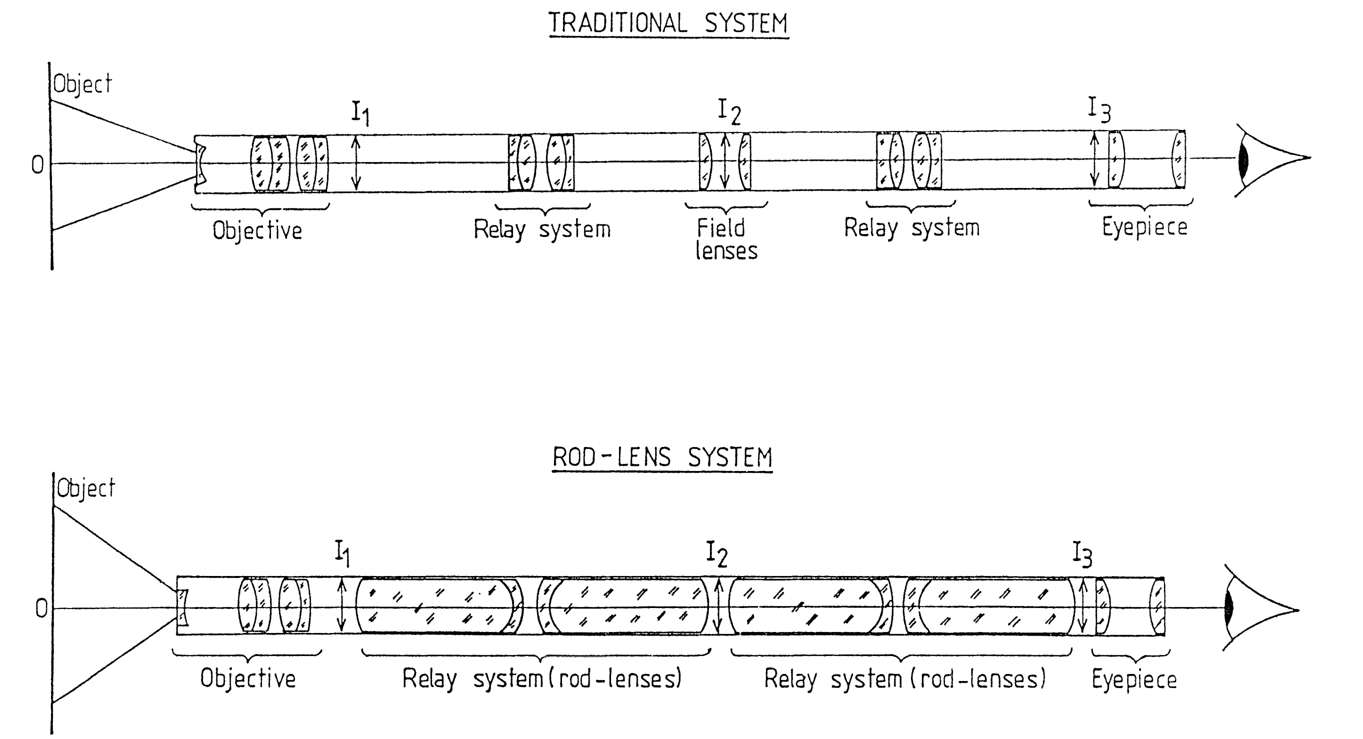

FIGURE 35.1.1. Diagram of the optics of a traditional endoscope and of a rod-lens system. (By permission of H.H. Hopkins, Optical principles of the endoscope. In: G. Berci [ed], *Endoscopy,* Appleton & Lange, Norwalk, CT, 1976, p 16.)

are essentially the same as in the traditional system. The new invention concerns the relay systems employed. The effect of using glass spaces and air lenses in place of air spaces and glass lenses is twofold.

Optically, the total amount of light (F) that can be transmitted through the optics of an endoscope is:

$$F = K\left[\frac{n^2\rho^4}{D^2}\right]$$

where K is a constant dependent on the intensity of illumination and the reflectance of the object and $2D$ is the distance between successive images (I_1 to I_2, I_2 to I_3).

F is proportional to n^2 where n is the refractive index of the space. For the glass used in rod lenses, the value of n^2 varies between $(1.5)^2 = 2.25$ and $(1.65)^2 = 2.72$, whereas for air in the traditional endoscope $n^2 = 1$. Therefore, there is an increase in the light transmitted by a factor of 2.25 to 2.72. Secondly, the total light transmitted is proportional to ρ^4, where ρ is the clear aperture available to the optical system. In the traditional endoscope it was extremely difficult to mount lenses of 3 mm diameter in a 300-mm tube. Usually the lenses and spacers were assembled first in a very thin-walled, slightly flexible tube that was then fed into a thicker rigid outer tube (Figure 35.1.2A). As a result, the clear aperture available for the light was appreciably smaller than the outer diameter of the tube. Rod lenses, typically 20 mm in length, may be precision ground to an accurate cylin-

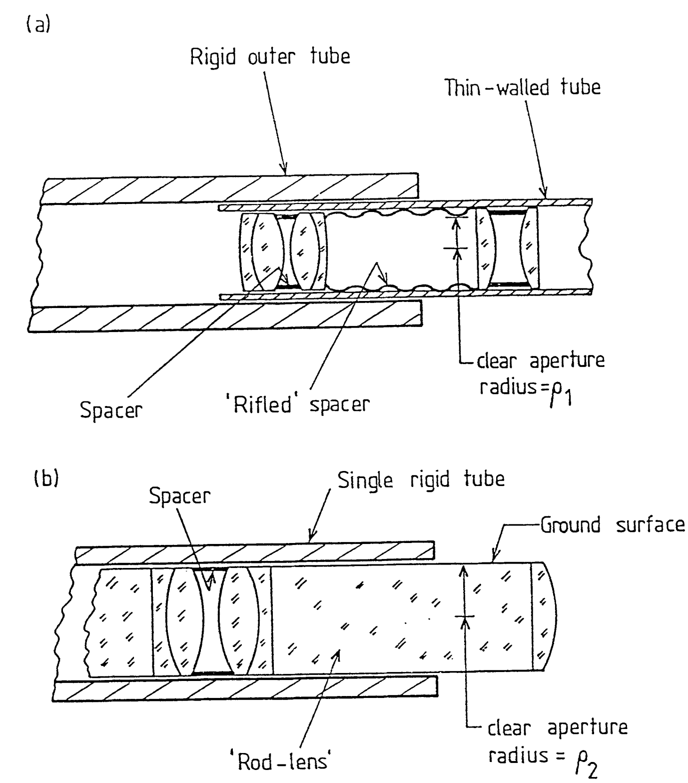

FIGURE 35.1.2. The construction of (A) the traditional endoscope and (B) the rod-lens system. (By permission of H.H. Hopkins, Optical principles of the endoscope. In: G. Berci [ed], *Endoscopy,* Appleton & Lange, Norwalk, CT, 1976, p 16.)

drical shape and merely inserted into a relatively thin-walled metal tube (Figure 35.1.2B). Mechanically, the ease and precision of mounting the rod lenses permits a greater diameter lens to be used for a given outer diameter of the endoscope. In prototypes, these two factors gave an increased light transmission of about nine times. Subsequent commercially produced endoscopes employed these advantages to produce endoscopes with smaller outside diameters and wider fields of view.

Another factor that contributes to the brightness and contrast of the image is the use of efficient multilayer antireflection coatings on the surface of the lenses. When light enters or leaves a lens with untreated surfaces, 4 to 6% of the light is reflected backwards. With more than 40 air/glass surfaces in an endoscope, this results in a serious loss of light. Some is then reflected forward, again giving a general haze or glare over the image. This reduces contrast and ghost images may form. Simple blooming of the type commonly used for ordinary camera lenses reduces this effect and multilayer coatings give a further improvement. With the transmission advantages of the rod-lens systems, the modern endoscope will have a total light transmission of some 80 times greater than the traditional system of the same external diameter.

Image quality is also dependent on the aberrations of the optical system. The application of the methods of linear systems theory and Fourier transform techniques made it possible to relate the aberrations of an optical system directly to their influence on the quality of the image. Despite the small aperture size, telescopes need to have correction of aberrations and a production precision comparable to those of a good quality microscope objective. The production precision is greatly facilitated, particularly in assembly, by the use of precision-ground rod lenses. Considerable advances in optical design have been made by using computers for the intricate computations involved. It is now possible to design and produce very high precision optics for modern endoscopes.

Light Delivery for Rigid Endoscopes

The Light Source

In the traditional endoscope, illumination relied on a small tungsten filament lamp carried at the distal end of the endoscope. The level of illumination and color temperature were low, giving a yellowish light and poor color rendering. In the modern rigid endoscope, fiberoptics has replaced the former distal lamp and has made possible the use of external light sources of high intensity and color temperature. Illumination, using a high-power xenon arc light source, can be intense enough and sufficiently white for both still and cine photography, and the attachment of a TV camera for display on a remote monitor. The high power is needed because of light loss in different parts of the illuminating system and the small diameter of the endoscope fiber bundle. A high color temperature ensures that the light is not deficient in blue, as there is greater absorption of blue light by glass in the light guides than red or green parts of the spectrum. Good color rendering is needed in the images of objects in which detail consists of small differences in color rather than brightness.

The Flexible Light Cable

The fiberoptic light cable plugs into the endoscope and is connected to a light source remote from the operating table. It is very flexible and consists of a large number of glass fibers. Each fiber in the bundle consists of a core of glass of high refractive index, with a thin cladding of glass of lower refractive index. Light falling on the core of any fiber undergoes repeated reflections at the fiber wall (about 10,000 for 1 m of light cable), so that the entering light is trapped and transmitted to the distal end of the fiber (Figure 35.1.3 inset). Light falling on the claddings or on the interstices between the fibers is not trapped and is lost by absorption at the sheath surrounding the bundle. Light is also lost at the entry-face and again at the distal exit-face of the fiber bundle. A good quality bundle will give an overall transmittance for white light of about 50% for a light cable of 1 m in length. Longer light cables result in an increased loss of light but only due to absorption in the greater length of glass. Since the object of the light cable is to convey light from the proximal to the distal end, there is no need for the fibers in the bundle to be in corresponding order at the two ends of the bundle (incoherent bundle). In a flexible fiberoptic endoscope,

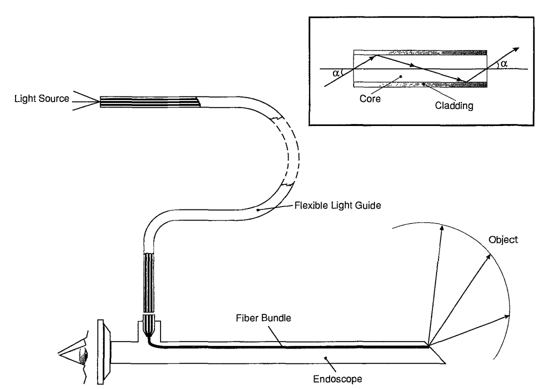

FIGURE 35.1.3. Light delivery for the rigid endoscope. Inset: Light is transmitted through the fiber core by repeated reflections at its wall.

the bundle of fibers is ordered so that the position of each fiber at the distal end corresponds with its position at the proximal end (coherent bundle). The need for exact ordering is why an image bundle is much more expensive than the incoherent bundles used as light cables. The life of a coherent bundle is much less than that of an incoherent bundle because broken fibers in a coherent bundle produce black dots that seriously impair the image, whereas broken fibers in the incoherent bundle of a light cable merely reduce the light transmission.

The ability to have high levels of illumination with high color temperature and with no danger to the patient from heat has depended on two further independent advances in technology: the development of high-intensity white light sources such as the quartz-halogen filament lamp and the xenon arc; and the development of cold mirrors with reflecting surfaces consisting of multilayer thin films. The reflectance can be reduced to $< 20\%$ for infrared radiation but maintained as high as 95% for the visible part of the spectrum. The use of a cold mirror with absorption in the light cable removes most of the radiant heat from the illumination that eventually falls on the object.

The Endoscope Fiber Bundle

The light cable is made to abut on a fiber bundle incorporated in the endoscope itself (Figure 35.1.3). There are light losses at the coupling that arise from three separate causes—separation effect, reflection, and mismatch. There is a finite separation between the abutting ends of the two bundles, which results in some of the light emerging from the fibers in the light cable bundle and falling outside the entry face of the endoscope bundle. The second cause of light loss is a 6% reflection of light at each of the two abutting air/glass interfaces. Finally, there is mismatch between the individual fibers of the two bundles with an overall degree of overlap of about 80% for randomly arranged fibers. The overall transmittance of a coupling between the light cable and endoscope fiber bundle is about 70%.

Discussion

The smaller diameters of rigid endoscopes using the rod-lens principle and the flexibility of fiberoptic endoscopes not only enabled the visualization of many parts of the body that were inaccessible to the endoscopist before their invention, but also gave rise to the new discipline of minimally invasive diagnosis and therapy using endoscopic, laparoscopic, and thoracoscopic routes. The rod-lens system has provided much greater light transmission, coupled with improved color rendering, an increase in the field of view, and great improvements in both contrast and detail rendition in the image. These improvements have been possible while using a smaller diameter endoscope.

References

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2. van Heel ACS. A new method of transporting optical images without aberration. *Nature* 1954; 173:39.
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35.2 Fiberoptic Endoscopy

Joseph R. Williams

Fiberoptics has played a major role in both diagnostic and therapeutic medicine for the past quarter century. With the advent of newer technologies enhancing the capabilities of the fiberoptic endoscope, more sophisticated procedures can be performed less invasively and more effectively—advantages for the patient and ultimately, the healthcare system. The following discussion of fiberoptics, its history and fundamental technologies, will examine the current status of this expanding technology. It should also serve as a basis for creativity and diversity in the proliferation of new patient therapies.

History

Optical principles relevant to modern fiberoptics are relatively fundamental, and can be traced to ancient civilizations. The Sumerians of ancient Mesapotomia were the first to develop a cuneiform script writing system as early as 4000 B.C. They used sharp bones or reeds for writing instruments and etched their characters into soft stone. The characters were distinct and decipherable. This alone is quite an accomplishment. What is even more astonishing is the fact that many of these inscriptions were minute, and could not be read unless they were magnified. The Sumerians used rock crystals as magnifying lenses. Magnification, certainly, is a key aspect of modern optical principles. They have also been credited with two other significant developments. Colorful paintings have been found on cave walls, indicating the use of some type of illumination system. Evidence of the use of mirrors has also been found.

The ancient Greeks were the first to explore the principles of optics and vision. Although the theories of Democrities, Plato, and Euclid were incorrect, their identification and interpretation of the fundamental laws of geometry are still relevant to optical principles. In his *Republic* (350 B.C.), Plato refers to the apparent bending of objects when placed in water, demonstrating refraction. Refraction was studied later by Cleomedes (50 A.D.) and Ptolemy (170 A.D.), who determined precise measurements of the angles of incidence and refraction for several media. But perhaps the greatest developments in refraction were those by Snell and Descartes during the Middle Ages. Willebrord Snell (1591–1626) was a professor at Luplin who, in 1621, discovered the law of refraction. Renes Descartes published Snell's law of refraction in terms of sines in 1637. As we will explore later, Snell's law plays a key role in the development of modern optical technology.

Both Galileo's and Newton's interest in the theories of reflection and magnification led to their development of telescopes. Galileo had a comprehensive understanding of the laws of optics, but Newton established the chromatic theory, that white light is composed of a range of independent colors. Christian Huygens, a Dutch mathematician and peer of Newton, established the wave form theory of light, which directly explains the principles of refraction and reflection, and specifically, total internal reflection, which serves as a basis for the phenomenon of light transmission through glass fibers.

The investigators of the nineteenth century verified these principles of optics and light wave theories. In 1845, Michael Faraday discovered a relationship between electromagnetism and light when he demonstrated that polarization could be altered by applying a strong magnetic field. James Clerk Maxwell developed a single set of mathematical equations and ultimately determined the speed of light. It was also during this time that the first primitive endoscope was utilized. In 1806, Phillip Bozzini was able to examine the urinary tract and rectum using a thin, tubular type of periscope and candle light. This was the simple yet profound beginning of endoscopy.

Concentrating on these basic optical principles and Bozzini's simple endoscope, additional endoscopes evolved. In the 1860s, a German physician, Adolf Kussmaul, designed an instrument for examining the stomach. This gastroscope was like Bozzini's, composed of a straight, rigid tube. Not surprisingly, patients found this instrument objectionable. Like Bozzini's instrument, its use of a flame as a light source made it even more dangerous.

Nitze's cystoscope (1879) was somewhat more sophisticated than the preceding instruments, and like endoscopes of today, contained a channel for irrigation, an instrument channel, and an image relay system. This relay system or telescope was composed of a series of lenses including a distal objective and proximal eyepiece. Illumination was accomplished by a small electric lamp at the tip of the instrument. Although the dangers of an open flame were eliminated, patients were exposed to the heat and potential harm of the distal electric light bulb.

In 1928, transmission of light through flexible quartz or glass fibers was described and patented by Logic Baird in England (Patent No. 285, 738). He demonstrated the transmission of images through fiber bundles and projected them onto a screen. His applications were based directly on the discoveries of Christian Huygens 250 years earlier. Others would refine these applications, including both Hansell in the United States and Lamm in Germany, in 1930. They both independently improved transmission rates by reducing surface contaminants of the optical fibers. Although these were dramatic improvements, it would take another 25 years before fiber technology could be used for practical endoscopic applications.

While rigid endoscopic systems continued to become more sophisticated, it became obvious that a flexible endoscope would be required for examination of much of the anatomy. Curved anatomical passages could not tolerate a straight, rigid endoscope. In 1932, German physician Rudolf Schindler codeveloped with instrument maker Georg Wolf, the Wolf-Schindler semiflexible gastroscope. Image transfer was accomplished by a series of articulating prisms, which for the first time, allowed the distal flexible portion of the instrument to comfortably negotiate the esophagus.

In the early 1950s, active development of fiberoptic technology was undertaken. Hopkins and Kapany in England and Ven Teel in Holland began improving glass bundles for the purpose of light transmission. As a result of these investigations, a team of investigators at the University of Michigan at Ann Arbor designed and used the first fiberoptic endoscope in 1957. Physicians Basil Herschowitz and H.M. Pollard collaborated with physics professor C. Wilbur Peters and student Lawrence E. Curtiss to design a technologically advanced gastrofiberscope that would be clinically acceptable. Although their fiber bundle design was of critical importance, the optics were still relatively crude and the instrument still considered a novelty. In 1961, the broad clinical experience of Dr. Herschowitz was published, which definitively documented the significance of flexible fiberoptic gastroscopy.

During the 1960s, advances in fiberoptic technology included the development of sigmoidoscopes and colonoscopes. N.S. Kapany, formerly associated with Johns Hopkins, and Dr. B.F. Overholt, an intern at the University of Michigan, crossed paths several times while developing a flexible sigmoidoscope. Eventually, the Illinois Institute of Technology, Research Institute, and Eder Instrument Company developed the first successful prototype sigmoidoscope. Dr. Overholt provided the clinical data substantiating its benefit to the patient.

Fiberoptic endoscope technologies have continually progressed since these initial product introductions. As clinical acceptance grew, so did the dedication to technological advances, which in turn, led to greater clinical acceptance. Optical advances have included more efficient fiberoptic images and light transmission systems. Endoscopes would gain multidirectional deflection, distinct irrigation and instrumentation channels, and a wide variety of support accessories. Within the past 20 years, the applications of fiberoptic endoscopy has grown from novelty status to an essential diagnostic and therapeutic modality.

Principles of Optics

Reflection and refraction are fundamental principles in the discussion of optics and play a key role in the transmission of images through flexible glass fibers. Figure 35.2.1 illustrates the change in direction of a ray of light as it travels from air to glass.

Figure 35.2.1A shows that a ray of light traveling from air to glass at an incident angle α will be both refracted and reflected. Most of the ray passes into the glass at angle α' and appears to bend. A small portion is reflected at an angle equal to the incident angle α. As the angle of incidence (α) is increased, the angle of refraction (α') is also increased (Figures 35.2.1B and 35.2.1C). The relationship between the angle of incidence and angle of refraction can be stated as follows:

$$\frac{\sin \alpha}{\sin \alpha'} = \frac{n'}{n} \quad \text{Snell's Law}$$

The refractive indices for air and glass are n and n', re-

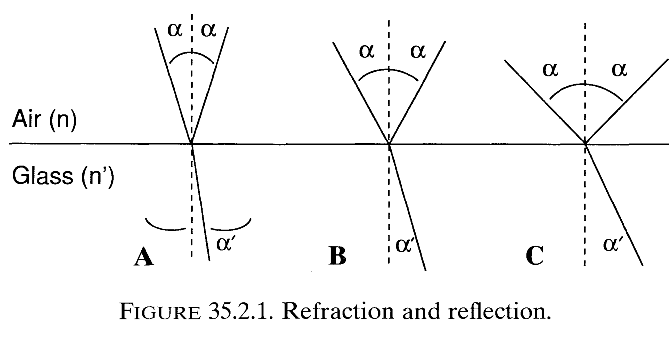

FIGURE 35.2.1. Refraction and reflection.

spectively. The refractive index refers to the manner in which light is refracted through a certain medium. It is related to the velocity of light through the medium.

Light rays are also governed by the principle of reversibility, which states that if a reflected or refracted beam is reversed in direction, it will retrace its original path. When light travels from a medium of a greater refractive index to one of lower refractive index, that is, from glass to air, an interesting phenomenon occurs. As the angle of incidence is increased, the angle of the refracted ray increases until it eventually travels along the boundary surface. This incident angle is considered the *critical angle* and is shown in Figure 35.2.2.

Here, the angle of refraction α' is 90°. The critical angle can be calculated by substituting (sin 90° = 1) into the equation as follows:

$$\frac{\sin \alpha}{\sin \alpha'} = \frac{n'}{n} \qquad \frac{\sin \alpha \text{ critical}}{\sin 90^\circ} = \frac{n'}{n} \qquad \sin \alpha \text{ critical} = \frac{n'}{n}$$

This equation indicates that the critical angle is directly related to the indices of refraction of both media at the interface. If the angle of incidence is further increased beyond the critical angle, the ray is totally reflected. The angle of reflection always equals the angle of incidence. This condition is known as *total internal reflection* and is the basis for light transmission through glass fibers.

Total internal reflection can be maintained through the glass fiber as long as the angle of incidence exceeds the critical angle and there are no surface defects along the boundary surface. Any debris or breaks can cause leakage and reduce the efficiency of the transmission system. To compensate, the fiber can be coated with a different type of glass having a lower index of refraction, which maintains total reflection.

It is important to note that the angle at which the light ray encounters the fiber surface is critical for transmission. As Figure 35.2.3 illustrates, a ray incident at angle α on the end of the fiber is refracted at the fiber face and enters the fiber at angle α'. It then undergoes internal reflection through the length of the fiber. The relationship between α and α' is determined by substituting the refractive indexes of air (n) and glass (n') into the equation. However, as the angle of incidence of α is increased at the fiber surface, the angle of internal reflection decreases until the critical angle is reached and the ray is no longer reflected. The maximum incidence angle at which total internal reflection can be achieved is referred to as the *maximum acceptance angle,* αc. This acceptance angle αc can be calculated by the following equation:

$$n \sin \alpha_c = \sqrt{(n')^2 - (n'')^2} = \text{N.A.}$$

N.A. refers to the numerical aperture of the fiber. n is the index of refraction at the fiber interface. n' and n'' are the indices of refraction for the fiber and cladding, respectively. Therefore, the greater the differences between n' and n," the greater the numerical aperture and the larger the cone of light the fiber will accept and transmit. Light entering at angles greater than the numerical aperture will not undergo total internal reflection and will be lost.

Not all light entering the face at incident angles less than the maximum acceptance angle will be transmitted. Other factors that will affect transmission are:

1. Absorption by the core glass. The glass itself absorbs a small amount of light. This loss is proportional to the length of the fiber and the total number of internal reflections. A long, thin fiber, with many internal reflections, would contain the greatest loss.
2. Light scatter at the cladding interface. A minute amount of light is refracted at the fiber/cladding interface with a fractional light loss. However, after multiple internal reflections through a long, thin fiber, the loss could become substantial.
3. Surface reflections. A small degree of reflection naturally occurs at the glass surface. With respect to a fiberoptic endoscope, these reflections would occur on the surfaces of all lenses within the system, including ocular and objective lenses as well as the surface of the fiberoptic bundles. Surface coatings, such as magnesium fluoride, are applied to substantially reduce reflection.
4. Packing fraction loss. Packing fraction is related to the cross-sectional surface area of the core glass fiber to

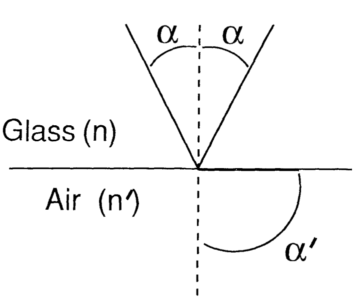

FIGURE 35.2.2. Refraction and reflection at the critical angle.

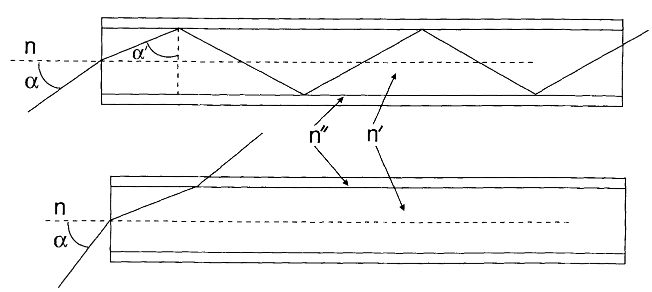

FIGURE 35.2.3. Light pathways through fibers.

the cross-sectional area of the entire fiber bundle. It is therefore important to tightly pack bundles to reduce interstitial spaces and also to have a high core glass to cladding ratio, for greatest bundle efficiency.

Fiberoptic Bundles

A fiberoptic bundle is constructed to transmit an entire image, with each individual fiber responsible for a small fraction of the transfer. The fibers must be properly aligned so that the incident image pattern is properly maintained throughout the length of the bundle, with an identical exit pattern. This relative positioning of fibers is referred to as the *coherence.* Coherent bundles may also be referred to as image guide bundles. Typically, coherent bundles are fused at both ends and loosely packed within an outer sheath for the remainder of their length. This allows maximum flexibility, an important attribute in the overall construction of flexible endoscopes.

The degree of image detail a bundle can convey is referred to as *resolution.* Resolution is dependent upon the diameter of the fiber core, the cladding thickness, and the degree of coherence of the fiberoptic bundles. Therefore, the smaller the fiber diameter, the thinner the cladding, and the greater number of fibers within the bundle, the better the resolution.

Generally, modern fiberoptic fibers are approximately 6 μm in diameter, with a cladding diameter of 1.5 μm. While it may be technically possible to reduce the core diameter, cladding thickness is difficult to reduce. To maintain an efficient packing fraction—the high ratio of core to cladding—the core diameter cannot be further reduced. Otherwise, the percentage of cladding within fiberoptic bundle would increase, and reduce the brightness and quality of the image. Typical packing fraction is approximately 60%.

Image guides vary in diameter ranging from 0.4 to 3.0 mm. The smaller bundles may contain 3,000 fibers, while the larger ones as many as 40,000. Image guides are selected with respect to the available size for a particular application. Colonoscopes and gastroscopes utilize large bundles, while angioscopes and ureteroscopes, restricted by size, contain small bundles. Fiber sizes also vary, but are typically 8 μm to 12 μm in diameter.

Incoherent fiber bundles are those where the individual fibers are randomly aligned. Therefore, they cannot be utilized for image transfer. However, they can be used in endoscopes as illumination or light guide bundles. They are less expensive to produce since alignment does not need to be maintained. To optimize their light carrying efficiency, they are thicker than image guide fibers. Typical diameter is 30 μm.

Fiberscope Optical System

The optical system of a fiberscope contains not only the fiberoptic bundle, but also the objective and ocular lenses. Figure 35.2.4 illustrates a typical optical system. The objective lens focuses the image onto the distal end of the fiberoptic bundle. The bundle transmits the image to the proximal end. Since the objective lens inverts the image, the bundle must be twisted 180° for proper image orientation. Since the image is too small to be viewed, the ocular lens (eyepiece) magnifies the image, presenting an enlarged, virtual image. An adjustment at the endoscope eyepiece allows focusing of the image with respect to the viewer's corrective focal diopter requirements. Magnification of the objective lens is variable and is determined by the distance of the lens from the object.

$$\text{Magnification of the objective lens} = M_o = \frac{X'_o}{X_o}$$

X′ is the height of the produced image. X is the actual size of the image. In most cases, $M_o < 1$. With the objective lens at a fixed distance from the fiber bundles, there is a limited range in which the image will remain in focus. This distance is usually 3 to 100 mm from the tip of the objective, and is referred to as the depth of field.

Ocular lens magnification is determined by the focal length of the ocular lens:

$$\text{Magnification of the ocular lens} = M_1 = \frac{X'_1}{X_1}$$

Similar to the previous equation, X'_1, and X_1, represent the apparent image and actual image sizes, respectively. M_1 typically is 15 to 30×. Ocular magnification is limited by the individual image fibers. As the image becomes more magnified, so do the proximal ends of the fibers, making a "grid" pattern more apparent and deteriorating the image quality. Image brightness also is reduced by magnification. Magnification of the entire optical system is as follows:

$$\text{Total magnification} = M = M_o \times M_1$$

Field of view is determined by the objective lens. A modern endoscope has a field of view of approximately 100 to 120°. A wide field of view presents greater peripheral

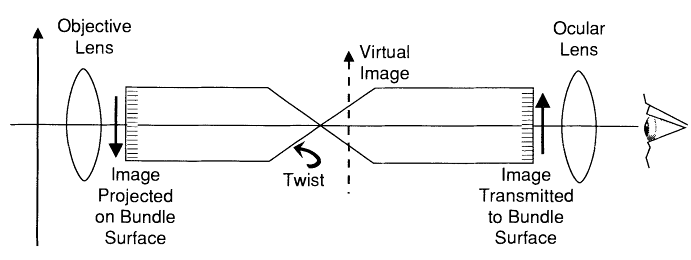

FIGURE 35.2.4. Fiberscope imaging system.

imaging which improves orientation and depth perception. However, too wide a view field reduces image size and limits image detail.

Beyond these fundamental optical technologies, sophisticated improvements have vastly improved optical efficiency, brightness, and resolution. Compound lens systems, advanced surface coatings, and optical prisms have to be utilized and continue to enhance imaging ability.

Fiberscope Construction

A simple fiberscope contains an imaging system and an illumination system. Additional capabilities are added based upon functional requirements.

Illumination

An incoherent fiber bundle is utilized for illumination, and is referred to as the light guide. As previously indicated, fibers may be as wide as 30 μm, which have a high numerical aperture and transmission ratio. Lens systems on both ends of the light guide are designed to effectively capture light from the source and illuminate the view field. Illumination of the field must be wide enough to match the field of view, and should be evenly distributed so there are no "hot spots." Special dichroic coatings and filters have been designed to dissipate the heat generated by modern, high intensity light sources.

Insertion Tube

Endoscope components are contained in the insertion tube. The tube is actually quite sophisticated in design, construction, and materials. Advanced polymers are used to provide flexibility, strength, and "glide." Stainless steel bands and mesh may also be added for reinforcement. Functionally, its flexibility should match its application. Being too stiff or too flexible could severely limit its ability to be properly inserted and directed.

A number of other systems may be passed through the insertion tube. These include air and fluid channels, and angulation and elevating wires. Specific flexibility must be designed with all these components taken into consideration. The flexibility of some insertion tubes may differ by design from one section of the tube to the next. A ureterorenofiberscope, for example, contains a "secondary" bending section, where a portion of the distal tip is flexible with respect to the surrounding sections. This allows for finer control and direction within the renal cortex. Clinical interaction is critical for effective design.

Angulation

The insertion tube is a sophisticated balance of materials providing strength and flexibility. Most fiberoptic endoscopes also offer *angulation,* the ability to actively direct the distal tip of the insertion tube. A scope may deflect in either one, two, or four directions. Tip deflection is accomplished by rotating the control knob, which in turn pulls on wires that run the length of the insertion tube and are anchored at the distal tip. As the wire is pulled, it deflects the tip in the direction of the wire under tension. With four-way deflection, which incorporates up/down and left/right angulation, when tension is applied to two wires, the tip can be deflected towards an intermediate position. Thus, deflection in any direction can be achieved. The mechanisms of deflection systems have become highly sophisticated. A chain and sprocket system has replaced the simple drum design at the control levers. Wires are designed to be strong but also thin, so the outer diameter of an endoscope is not unnecessarily enlarged. This is especially important for small diameter endoscopes, such as ureterorenoscopes and angioscopes, where all steps are undertaken to reduce diameters to match anatomical limitations.

The distal, deflectable end is composed of metal joints that, when connected in series, form a multidirectional hinge. These components must be able to withstand the force applied by the deflection wire, provide strength to the distal tip, and at the same time be small and lightweight. Clinical application is a critical concern in designing an angulation system. Tip diameter is an obvious concern and limitation. Bending radius, however, is a more challenging design parameter and in many applications is of primary importance. The degree of deflection has also improved as angulation systems have become more technologically advanced. Some tips can be deflected 230° in one direction. Locking mechanisms have been incorporated to maintain the desired deflection even if the operator lets go of the control knob.

Some endoscopes also contain a passive bending section in conjunction with the angulation system. When an endoscope encounters a surface, the scope deflects at a strategic location along the distal insertion tube. This section is composed of material of a softer durometer (degree of stiffness). This feature is incorporated into flexible ureterorenoscopes, to enhance the approach to calyces in the renal pelvis.

Instrument Channels

Instrument channels are essential for therapy. Generally, plastic tubes are used. They are anchored into the control section, packed into the insertion tube, and are fixed at the distal tip of the endoscope. Channel diameter is directly related to the outer diameter of the endoscope and instrumentation requirements for a particular application. Tubes must be strong to prevent instrument extravasation, but also flexible so as not to impede overall insertion tube flexibility. A variety of mechanical, electrical, and laser instrumentation is used for scores of endoscopic therapeutic applications.

Endoscopes may also contain secondary irrigation/aspiration channels. These may be independent from the instrument channel or may be an extension of the primary channel. Valves for control of irrigation/aspiration may or may not be utilized. Valves may be reusable or single-use disposables. The secondary channel may also be used for an air/water channel, which can provide a directed burst of water and air to the distal objective lens to maintain cleanliness and ensure proper visualization throughout a clinical procedure.

Other Features

In addition to the features already discussed, there are numerous features that are not immediately obvious to the user. Electrical safety must be designed into the endoscope to provide proper protection for the assortment of electrosurgical accessories used through or near the instrument. Sophisticated elevators may be built into the distal tip of the scope to enhance the positioning of accessories. Side-viewing endoscopes utilize optical prisms.

In general, all flexible fiberscopes for medical use are soakable in disinfectant and are also ethylene oxide sterilizable. Therefore, all components and construction must be able to withstand the rigors of these processes. Most flexible endoscopes contain a valve that vents the interior of the insertion tube during the vacuum and pressure phases of the Eto sterilization cycle. Without it, the instrument could be severely damaged during each cycle.

The Future

The role of the endoscope in patient therapy continues to evolve with the proliferation of less invasive procedures. The recent clinical demand for video-based endoscopic products has not reduced the need for improvements in fiberoptic systems. Enhancements include greater efficiency in packing fractions for better fiberoptic resolution and illumination. These relate directly to better observation and diagnosis.

The application of advanced materials for components such as insertion tube, deflecting cables, and epoxies facilitates handling and enhances the approach to obscure anatomical locations. Durability and biocompatibility are likewise improved. Ultimately, as fiberoptic endoscope systems evolve, outer diameters and instrument channel diameters can be optimized for a particular therapeutic application, enhancing product efficacy. Angioscopes with outer diameters as small as 500 μm are currently commercially available.

The refinement of therapeutic accessories continues to be of critical importance. The miniaturization of mechanical components allows the development of instruments that are smaller and just as effective as their predecessors. Instrument channel diameters can likewise be reduced to either allow reduction in the outer diameter of the fiberscope or the addition of components (i.e. larger optical system) while maintaining the same outer diameter.

Electronic and electromechanical product enhancements also continue. High-resolution video cameras are routinely coupled to fiberscopes. Some systems, such as angioscopes, contain no conventional eyepiece and attach directly to a sophisticated, high-resolution charge coupled device (CCD) video system. Specialized couplers have been developed to reduce the effect of interference pattern (moire) between the CCD pixel and the optical fiber. Integrating advanced ultrasound systems allows a detailed examination beyond mucosal walls, dramatically expanding the diagnostic capabilities of fiberoptic-based endoscopes.

Certainly, with the current trend in healthcare towards minimally invasive procedures, fiberoptic endoscope technology will continue to become more sophisticated and diverse, maintaining a vital role in diagnostic and therapeutic procedures for years to come.

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35.3
How the Medical Video Camera Became the Surgeon's Tool

William Chang

Video cameras entered the operating room via commercial broadcasting. In a remarkably short time, innovative medical device companies such as Stryker Endoscopy studied the equipment and techniques originally developed for broadcasting and used these tools to adapt, simplify, miniaturize, and enclose standard broadcast cameras for use in the surgical environment. In less than 20 years, the technology has produced high-quality, true-color, safe and reliable medical video cameras that are easy to operate and fit comfortably into the palm of a surgeons's hand.

This chapter provides the surgeon and layman with background and an overview of the development of medical video cameras; a discussion of major video camera technologies, with points for comparison; guidelines for selecting the type of video equipment that best meets specific needs; a look toward future developments in medical video technology; and an understanding of key video terms.

Remarks about Laparoscopic Surgery

As early as 1901, both Georg Kelling and D.O. Ott used cystoscopes to look inside the recesses of the body.* Since then, different surgical specialties have adopted the use of both flexible and rigid optics and light sources to examine and treat human pathology in a minimally invasive manner. Despite the advantages of minimal invasiveness, surgeons found that directly viewing the patient's anatomy through a scope for hours at a time posed several difficulties:

Fatigue, discomfort: Maintaining eye-to-scope-eyepiece operating positions for extended time periods was tiring and uncomfortable.

Coordination problems: Since one of the surgeon's hands was needed to hold the scope, only one hand was available to operate. Having a surgical assistant hold the scope proved difficult to coordinate.

Image restrictions: Although the scope provided the surgeon with an excellent view of the image, sharing that image with residents, other surgeons, and operating room staff was difficult. Thus, traditional opportunities to teach and consult were limited.

Eye strain: Long procedures using the scope often gave surgeons eye strain.

Medical video cameras provided solutions to these problems because they eliminated the need for the surgeon to spend long hours in cramped positions, bent over a scope; freed both the surgeon's hands to operate; permitted everyone in the operating room to share the image of the operating field; and eliminated postsurgical eye strain.

Evolution of Medical Video Cameras

Since the introduction of medical video cameras, the technology and equipment have evolved along three separate paths: (1) ease of use has increased as size was decreased; (2) new video signal formats have improved resolution, color reproduction, and image brightness; and (3) photosensitive chips have further improved the quality of video images.

Ease of Use

The first medical video cameras were not the small, sleek models of today. Weighing about 6 oz, these units were heavy, cumbersome, fragile, and nonsterilizable. Draping was required. The earliest video cameras employed glass tubes, measuring 1 in. in diameter and about 6 in. long, as devices to pick up images (Table 35.3.1). These "Vid-

*US Surgical Corporation. Endoscopic Surgery: surgical training materials. September 6, 1989.

TABLE 35.3.1. Summary of medical video camera development.

Year	Type of pick-up device	Highlights/features/comments	Resolution[1]	Sensitivity to light[2]	Signal to noise ratio (S/N)[3]
To 1981	Glass vacuum tubes, 1-in. and ⅔-in. diameter	First cameras were nonsoakable[4] and used 1,500 V.	250 lines	30 lux	35 dB
1982	⅔-in. diameter metal oxide silicon (MOS) chip	First solid state, soakable 1-Chip camera; used only 12 V; much smaller.	260 lines	100 lux	35 dB
1985	⅔-in. charged coupled device (CCD)	First camera to use CCD; smaller.	350 lines	30 lux	42 dB
1989	3½-in. CCDs	Three separate chips provide more lifelike colors and improve resolution.	700 lines	10 lux	46 dB
1992	½-in. CCD	Super-VHS (S-VHS) technology improves brightness in 1-Chip unit.	470 lines	10 lux	46 dB
1992	½-in. CCD	Digital processing improves color and resolution in 1-Chip unit.	500–600 lines	3 lux	47 dB
1992	3-Chip[5] microchip camera with Hyper[6] CCD	3-Chip CCD has three prism block filters that gather and use all available light. This enables camera to actually see in the dark.	850 lines	1.5 lux	60 dB
To come	HDTV broadcast camera	High definition TV technology will bring better resolution to medical videos.	1200+ lines	0.1 lux	70 dB

[1]Cameras separate an image into its components (i.e., horizontal and vertical lines). Resolution is measured by the number of horizontal lines per video frame; the higher the number, the greater the detail, and the sharper the image. The average TV set is capable of 250 to 400 lines of resolution (see Glossary).
[2]Light sensitivity is measured in lux; the lower the number, the better the camera (see Glossary).
[3]Interference (i.e., static, unwanted signals) that distorts the video image and prevents good reception. Measured in decibels (dB) (also see "Noise" in Glossary).
[4]"Soakable" units can be immersed in disinfectants such as glutaraldehydes; nonsoakable units cannot.
[5]3-Chip is a trademark of Stryker Corporation.
[6]Hyper CCD is a trademark of Sony Corporation.

icon" [vid(eo) + icon (scope)], and later "Saticon" tubes focus the image on a transparent, thin metal film covered with photosensitive material that is scanned by an electronic beam. Not only was the early video camera bulky and fragile, but it was also risky, requiring 1,500 V of electricity and prone to reflecting interference from stray magnetic fields. Further, the surgeon's view was impeded by the sterile plastic drape covering the scope and eyepiece.

In early 1982, the first solid-state, soakable medical video camera was introduced. "Soakable" cameras can be immersed in disinfectants such as glutaraldehydes. Instead of employing a bulky, high-voltage, breakable glass vacuum tube as a pick-up device, this camera used a single 12-V metal oxide silicon (MOS) element to transmit an image. An MOS is really a semiconductor—a chip—that has a photosensitive side.

Compared to the glass vacuum tube unit, this new solid-state chip was much smaller and more durable; the camera unit could even be dropped without breaking. In addition, since this camera was soakable, the need for a sterile drape was eliminated. Further, because of its reduced size, the "1-Chip" camera was much easier to hold and maneuver. Thus the surgeon was able to relax, forget about manipulating cumbersome equipment, and freed to concentrate on the patient and the procedure at hand.

Signals, Signal Formats, and Their Effect on Images

A picture is composed of two elements: light information and color information. In the process of reproducing an image, the camera employs a video signal format to pick up and transmit this picture information. Several different formats with different features are available to manufacturers at this time (Figure 35.3.1). The choice of signal format a video camera system employs determines in large part the quality of the image that system can reproduce. For example, resolution and color accuracy are often related directly to the format the manufacturer has chosen.

Composite video signals combine light and color information onto one signal. Hence, this signal format can be carried by one-pin, coaxial BNC type cables. Also referred to as "NTSC" (after the National Television Standards Committee, which pioneered it during the 1940s),

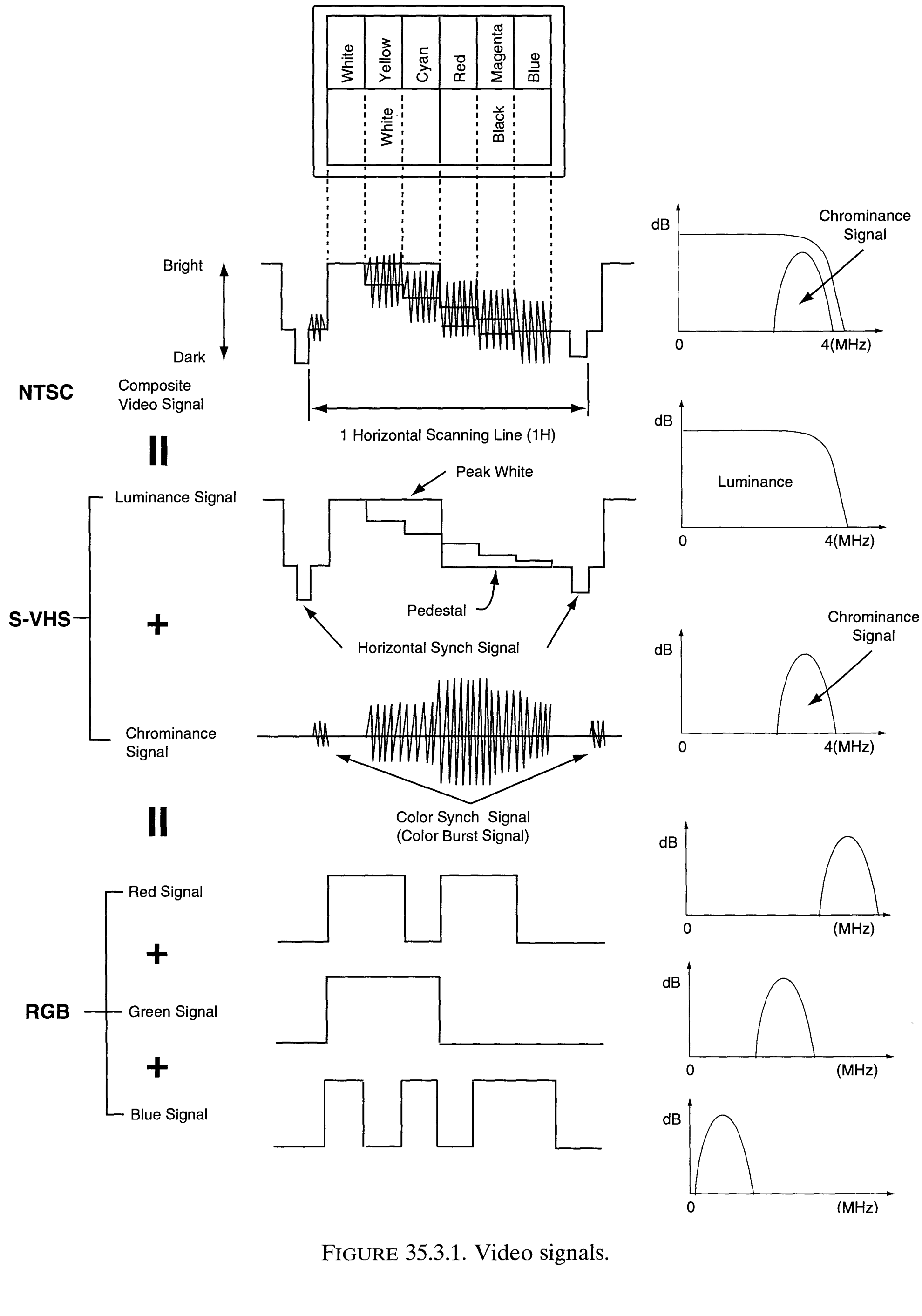


FIGURE 35.3.1. Video signals.

composite or NTSC remains a versatile, recordable signal widely used today. However, manufacturers have departed from NTSC and begun to employ component signals in high-end equipment.

Component signals convey video information as separate signals. *S-VHS* or "Y/C" conveys light information (Y) and chrominance or color information (C) as separate signals from camera to monitor or documentation device. *RGB* format, on the other hand, transmits picture information as red, green, and blue components. The green component carries the bulk of the light information, and all three share the color information.

There are no specific guidelines to assist prospective buyers in choosing the right video system, with the type of signal format, that will best meet their specific needs. However, note that Y/C and RGB, when used in three-chip cameras, can deliver higher horizontal resolution than NTSC, because the latter format is limited to 525 lines of resolution. On the other hand, also note that RGB cannot be recorded on videotape without special coding/decoding equipment. In addition, RGB rules out the viewer's ability to adjust picture quality on the monitor.

The prospective buyer should test different types of equipment under different conditions and watch for the choices the manufacturer has made. Both RGB and Y/C can reproduce color very effectively. However, because of the bandwidth configurations chosen by the manufacturer, Y/C equipment may have the edge in picture brightness, resolution, or accurate reproduction of the color red. In turn, RGB can sometimes produce very high signal-to-noise quality images when used with three-chip cameras. It is important to test different systems over a variety of conditions, and choose the system with the picture quality and versatility you prefer.

As video technology progresses and the speed of computer processors increases, more medical video systems will use *digital signal processing* (DSP). The DSP format simply converts analog picture information into 1's and 0's (or "bits and bytes," in computerese) for color processing. This digital information is then converted back to analog for beaming onto the monitor screen. In addition to allowing images to be processed with minimal loss of information, DSP facilitates the sharing of data with computers.

HDTV: Signal Format for the Future

High definition television (HDTV) is generally considered tomorrow's universal format because of the benefits it offers to surgeons, especially better picture quality. For example, HDTV incorporates a much higher number of scanning lines per television screen than other current video signals (1,125 lines versus 525 lines). This higher number of scanning lines greatly increases the amount of picture information that appears on the TV monitor. HDTV also has a much higher *aspect ratio* than a conventional television screen (9:16 versus 3:4). Aspect ratio is an engineering measurement that reflects both the amount of information that can be packed into the screen space and the extent of the picture viewed horizontally. Taken together, these two measurements illustrate that HDTV can produce images with more detail and higher quality than other video formats.

Endoscopic surgeons will find HDTV beneficial in many ways, especially because it offers a much broader view of the surgical site and more true-to-life images than possible with other current video signal formats. In fact, surgeons will find HDTV colors so rich and vibrant, with such great color gradation and high resolution, that the image on the monitor will mimic the three-dimensional view of the surgical site. With the quality of the image so improved, surgeons will be able to locate and identify pathology much faster, and feel more confident in diagnosis. HDTV will also enable endoscopic surgeons to practice "telemedicine." Because it can transmit and receive picture information from distant sites without degrading the image, HDTV allows for surgeons at locations far apart—even in different countries—to assist one another easily, in real time.

There are, however, some obstacles to overcome before HDTV can be implemented widely in medicine. First among these is cost. At present, few medical institutions can afford HDTV, but as the volume of users increases, the cost of HDTV units will fall. Another obstacle is the size of the equipment: the weight of today's HDTV cameras (6 Kg or more) makes them difficult to use during lengthy surgical procedures. However, redesign of these bulky camera heads is already in progress, and smaller, more practical equipment will be available in the near future. The exciting possibilities posed by HDTV will spur this development.

Photosensitive Chips Revolutionize Medical Video Systems

A chip is a solid-state unit that is covered with tiny light-sensitive squares, or picture elements ("pixels"). As Figure 35.3.2 illustrates, each pixel sees (that is, picks up) its own small component of the total picture. (Also see Table 35.3.2 and Figure 35.3.3.)

1-Chip CCD

In a 1-Chip CCD, each pixel is dyed a certain color and sees only objects of its own color. The camera integrates this information and reproduces an image. However, since the pixels can see only one color, some portions of the object that fall between the pixels are missed. To compensate and reproduce a complete image, the camera electronically "infers" the missing colors or reverts to default colors. This process often causes the image to appear cartoon-like.

3-Chip CCD

In 1990, the first 3-Chip medical video camera was introduced. This technology revolutionized medical video systems by bringing the highest quality broadcast color reproduction capability into the operating room. Unlike the 1-Chip, the 3-Chip CCD does not have to electronically infer anything, or revert to artificial default colors. The result is true life-like color reproduction. This can be of great importance to the general surgeon operating in a color-rich environment. Finally, 3-Chip CCDs provide three times the pixels as a 1-Chip CCD, thus significantly improving the crispness and sharpness of the image, as measured in horizontal lines of resolution. With current

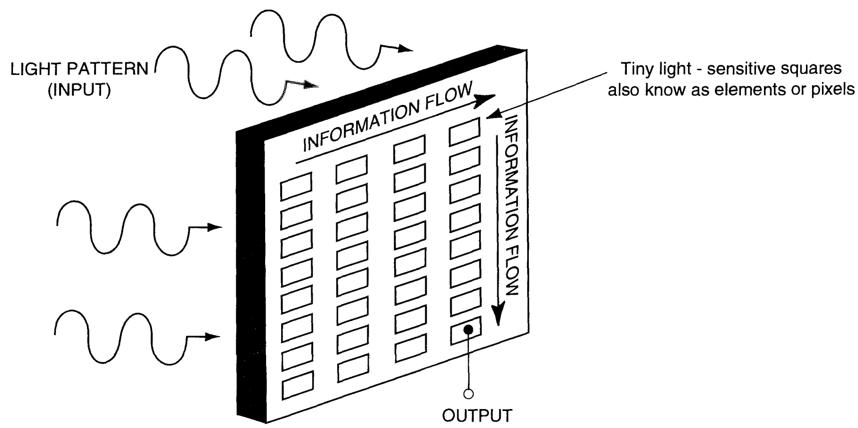


FIGURE 35.3.2. Solid-state image pick-up device. When light hits the sensors, they convert the light into energy, which is processed to the video processor circuit.

technology, the best 1-Chip cameras are capable of reproducing images with nearly 600 lines of resolution, while the best 3-Chip video units are capable of over 800 lines of resolution. The highest resolution possible is of critical importance to a surgeon looking for minute pathologies as small as a few millimeters across. For a side-by-side comparison of 1-Chip and 3-Chip medical video systems and additional information on CCDs, please see Table 35.3.2, and Figures 35.3.3–35.3.6.

Hyper CCD

Hyper CCD technology is a major advance in video camera systems. This technology makes outstanding visualization possible in extremely low-light areas. In fact, with Hyper CCD, the surgeon can actually see at 1- to 2-lux levels; this achievement approaches the capability of the naked eye to recognize light (see Figure 35.3.6). Since poor illumination is one of the chief challenges posed by laparoscopic surgery, surgeons should demand Hyper CCD technology in a medical camera because it makes the camera more sensitive to light.

Considerations when Choosing Components

Medical video systems are expensive. To ensure that the time, money, and effort put into building a system are not compromised, individual components and accessories must be of uniformly high quality (Table 35.3.3).

Looking Toward the Future

Although medical video camera technology has come a long way in a short time, there is still far to go. Among the advances and an idea about when to expect them are:

Digital processing on 3-Chip cameras—one year
3-D Virtual Reality—one to two years
HDTV—two to five years.

With technology improving so rapidly, projections more specific than these are only educated guesses. It seems abundantly clear, however, that the future will bring many more advances and exciting surprises. Medical video camera technology is still in its infancy.

Glossary of Key Video Terms

Surgeons and hospital personnel who work with medical video systems should understand these common key video terms.

Autoexposure
: Feature on some video cameras that automatically adjusts the shutter speed to accommodate changing light conditions.

Auto-Iris
: Feature of some video cameras that automatically adjusts light source to changing conditions.

Balance: Color
: A necessary adjustment of the video monitor to ensure that its color test pattern matches the printed color bar guide supplied with the monitor.

Balance: White
: An adjustment of the camera to ensure that individual color signals (red, green, blue) mix correctly to create pure white. This must be done before recording a procedure. To ensure uniform accurate picture quality, the camera must be white-balanced every time the light source is changed.

Camera, 1-Chip
: Video camera with one photosensitive chip (CCD). Each of the pixels on this chip will pick up only one color—red, green, blue, or yellow, and mix them back

TABLE 35.3.2. 1-Chip versus 3-Chip technologies.

A careful look at the features can be helpful when choosing a medical video system.

1-Chip features	3-Chip features
Each pixel is dyed either a primary color (red, green, blue), or a secondary color (cyan, magenta, red). Instead of seeing the whole image, each pixel sees only the elements in its own color.	Color is more accurate and more detail is possible because photography color filters are used instead of dyeing the pixels. This feature permits each pixel to see the entire image.
Red-dyed pixels only detect reds, greens detect green, etc. To compensate for the colors missed, the camera generates the missing colors electronically. This can cause color distortion (i.e., cartoon-like appearance).	Each of the three chips is dedicated to a separate color, and misses nothing. Since all colors are picked up, the camera does not have to electronically generate or infer anything to complete the image. Thus, colors appear more true-to-life.
Gaps between pixels cause the chip to miss parts of objects (i.e., horizontal and vertical lines) that fall between the pixels.	Chips are offset so pixels will capture all parts of an image. The green chip picks up details missed by the red and blue chips, etc., so nothing is missed.
Fewer total pixels mean fewer effective pixels and lower resolution than a 3-Chip CCD. To find the number of effective pixels on a 1-Chip CCD, divide the total pixels (335,554) by the number of pixels needed to produce a color image (3): 335,554/3 = 111,848 effective pixels.	The 3-Chip camera has three times as many total effective pixels as the 1-Chip, and they are placed closer together, so the 3-Chip's image has higher resolution and sharper detail: (768 horizontal pixels × 494 vertical) × 3 = 1.14 million. 1.14 million/3 = 380,000 effective pixels.
Maximum resolution with current 1-Chip cameras is approximately 500 horizontal lines.	Maximum resolution with current 3-Chip CCDs is 800+ horizontal lines of resolution.
Signal-to-noise ratio: 46 dB	Signal-to-noise ratio: 60 dB

Remarks on choosing components for a medical system appear in Table 35.3.3.

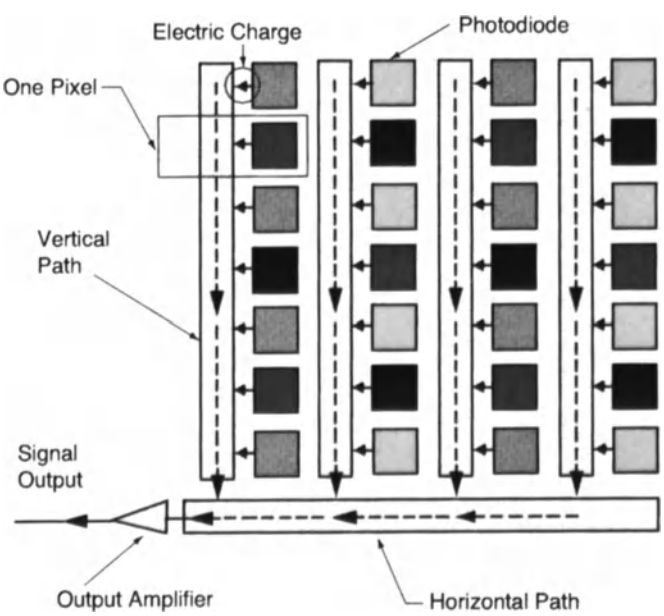


FIGURE 35.3.3. Pixels and other basic elements on a typical 1-Chip CCD.

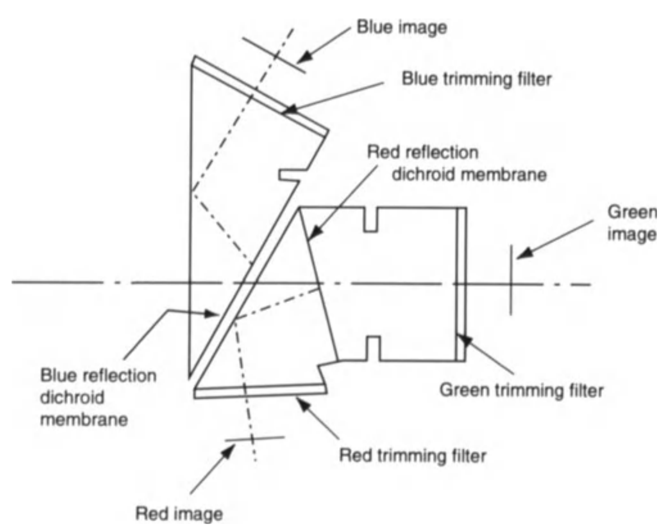


FIGURE 35.3.4. Arrangement of primary color photography filters on a 3-Chip CCD. Three CCDs mean that one filter is dedicated to each of the primary colors: red, green, and blue. Thus, with three times the pixels, three CCDs mean higher resolution and far purer, more accurate rendition of color.

together to produce a full-color picture. The accuracy of the picture depends on how well the chip performs. The mixing can produce cartoon-like, unnaturally colored images.

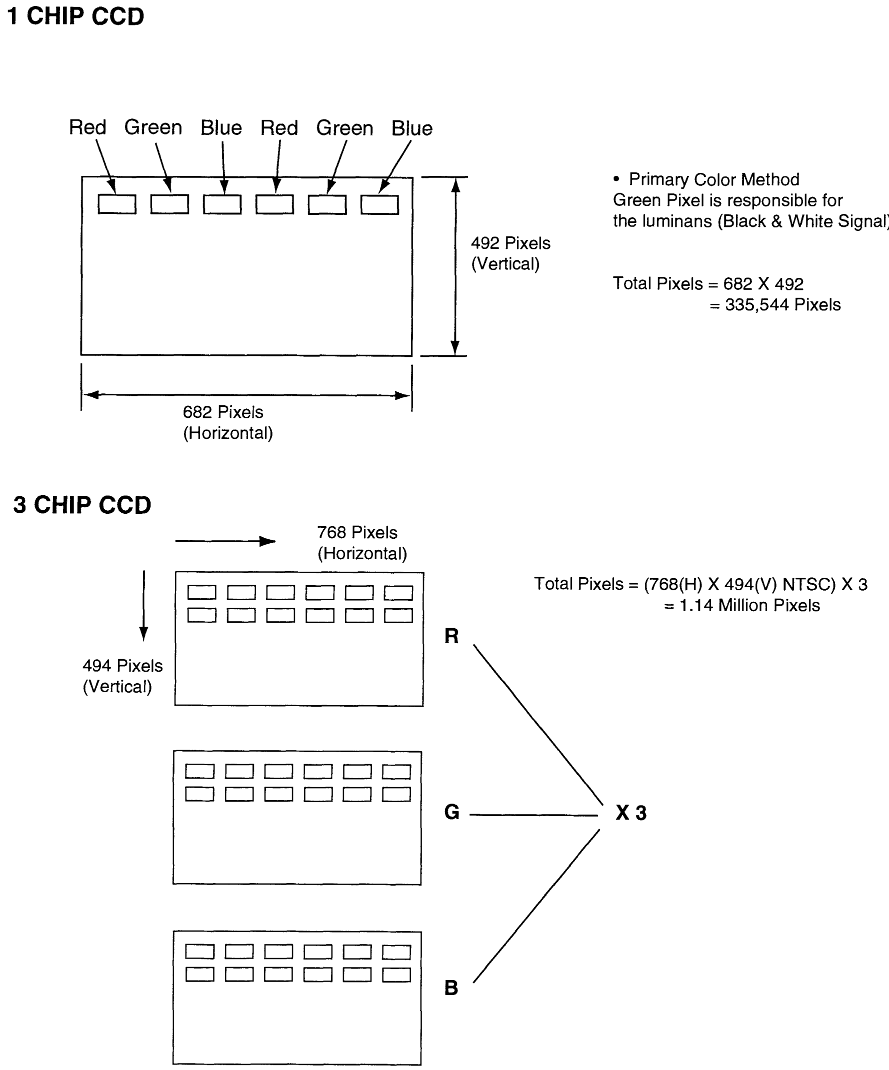
Camera, 3-Chip

Video camera with three photosensitive chips, each dedicated to a specific primary color (red, green, blue). Since the total pixels is three times greater than a 1-Chip camera, the 3-Chip camera can deliver an image of much higher resolution.

CCD

Charged coupled device. One of the tiny silicon microchips that determines a video camera's resolution and sensitivity. Each CCD contains rows and columns of

FIGURE 35.3.5. CCD comparison: pixels on 1-Chip and 3-Chip sensors.



light-sensitive silicon cells (pixels) that emit an electronic signal when light falls on them.

CCU
: Camera control unit (also known as camera processing unit [CPU]). The equipment that provides the camera's power supply. It converts the electronic input from the camera's microchips into a video signal, translates the signals into images that can be visualized on a monitor or a documentation system.

Lux
: A measure of illumination (brightness) expressed in footcandles (FTC); 1 FTC describes what a "standard candle" can illuminate a scene at a distance of 1 ft. Generally, the lower the lux at which a camera can operate, the better the camera. Today's best 1-Chip cameras transmit at 3 lux; the best 3-Chip, 1.5 lux. This extremely low lux level approaches the capability of the human eye at the same lux level.

Noise; S/N
: Interference, expressed as a ratio of signal to noise (S/N), and expressed in decibels (dB). Signal-to-noise ratios follow a logarithmic scale, usually ranging from 30 to 60 dB. The higher the number of decibels, the higher the clarity and the more still and coherent the video image.

Pixel
: The individual picture elements or light-sensitive sensors on a solid-state video chip. When light falls on an individual pixel, it emits an electronic signal and sends it to the CPU, so it can be translated into an image.

Resolution
: A measure of video image quality, expressed by a number typically ranging from 200 to 1,200. The number refers to the total of horizontal lines per screen height that comprise the image. The higher the number, the

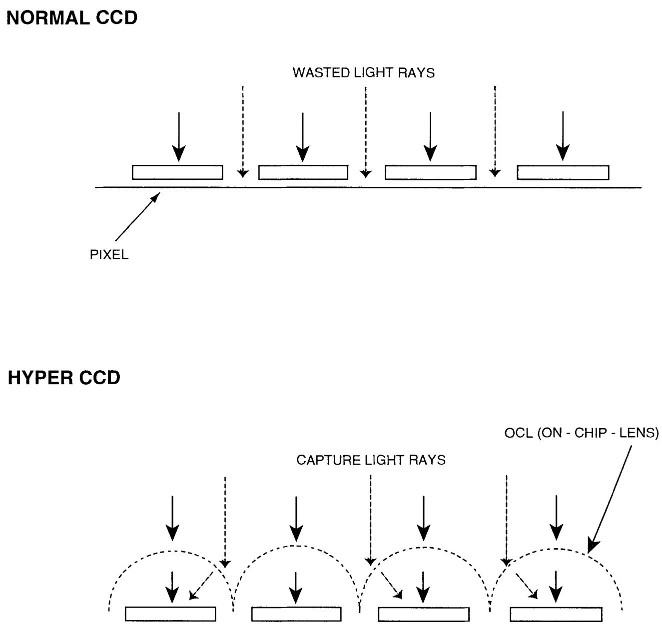


FIGURE 35.3.6. CCD technology: normal versus Hyper CCD. Hyper CCD has individual microlenses etched on top of each pixel, which captures light rays that fall between pixels. Therefore, lower light sensitivity. Great pictures at low light levels!

TABLE 35.3.3. Elements of a complete medical video system.

Component	Requirements and comments
Laparoscope	A quality scope with good optics will pass on the highest quality image.
Camera	A camera with high resolution, true color, and maximum possible depth of field, that operates at lowest light levels will capture the image accurately and augment the procedure by acting as the surgeon's eyes.
Light source and cables	The light source should provide adequate, true light, so the camera can pick up real color. Metal halide emits continuous bright white light; xenon emits pulsating light that can appear bluish. The thicker the cable, the more light it can convey. Be sure to use cable with a diameter of 5+ mm for procedures that require a lot of light (e.g., pelviscopy or hernia repair).
Monitor	A high-resolution monitor is necessary to capture the signal and reproduce it without interference, noise, or loss, so the image is not impaired or degraded.
Accessories	Optional equipment like a VCR, video printer, digital photography unit, and floppy disk memory system can be used to document surgical procedures. Because adding accessories will compromise the signal, always wire the camera on its own line, accessories on a secondary line.

more detail the image provides, and thus the better the picture (also see Table 35.3.2).

Video System

A series of components that work together to perceive, transmit, reproduce, and document (optional feature) images. The components needed for medical video procedures, including scope, camera and CCU, light source, light cable, monitor, and accessories such as a VCR, video printer, digital photography unit, laser disks, and floppy disk memory system (also see Table 35.3.3).

35.4 Light Sources for Endoscopic Procedures

William Chang

The development of light sources for endoscopic procedures has paralleled that of medical video cameras, which are discussed in the preceding chapter (35.3). This chapter will explain the basics of endoscopic light source technology, provide an overview of light source development, discuss light source equipment and important safety factors, and analyze features and benefits of selected equipment.

Endoscopic Light Sources and How They Work

A light source is an electronic unit that supplies light to endoscopes. The light permits the surgeon to view body cavities and perform diagnostic or surgical procedures, with minimal heating of tissue. The components in a typical light source system include a projector, a lamp, fiberoptic cables, and connectors/adaptors to link the light source to the other components of the medical video system (Figure 35.4.1).

FIGURE 35.4.1. Stryker Quantum 4000 in operation. The clear casing of the Stryker cable attached to the front of the unit reveals that the power is on.

The light source transmits a focused beam of intense light through a fiberoptic cable that is connected to the scope, which then illuminates the surgical field. The light source makes adjustments in the amount of light transmitted to the site, based upon the video information it receives from the medical video camera. If the camera determines that there is too much or too little light for optimal viewing, the camera signals the light source, which instantly adjusts the amount of illumination provided. The light continues to be adjusted automatically, based on the changing information received from the surgical site.

With sufficient illumination, the surgeon has several options for endoscopic viewing. These typically include: direct examination of the field through the scope eyepiece for diagnostic procedures; projection of an image of the surgical field onto a monitor, which makes the image visible to everyone in the operating room; and documentation of a surgical or diagnostic procedure via videotapes, slides, or still photography. Although a light source is common to all of these viewing options, each one requires different peripheral equipment.

Overview of Light Source Development

Clear and accurate visual information is critical in either diagnosis or surgery. Therefore, the ability to control the brightness and intensity of the beam has been an important factor in light source development. The earliest light sources used in endoscopic surgery were low-powered (12 V) units with incandescent tungsten bulbs at the tip of the scope and rheostats to regulate light intensity. These early units were bulky and awkward to use, and they were unable to provide sufficient quantity or quality of light for many endoscopic procedures. In addition, the temperature and consistency of illumination could vary when voltage was regulated. Early light sources were also vulnerable to unexpected power surges.

To decrease loss of light intensity and provide the surgeon with better, safer control of illumination, manufacturers turned to fiberoptics. This technology enabled manufacturers to separate the light source system into components. The redesign made the equipment lighter and simpler to control; also, individual components were easier and more economical to replace. Besides adding convenience, fiberoptics improved the quality of illumination delivered to the surgical site. A steady beam of powerful light was transmitted via filaments in a cable to the scope, with little loss of intensity.

Lamps, Cables, and Purchasing Considerations

To produce illumination, light source manufacturers use various types of lamps, each with different types of components, wattage, color, brightness, intensity, and length of bulb life. Each of these elements affects the type and quality of illumination a lamp can produce (Figures 35.4.2, 35.4.3, and Table 35.4.1).

Because of the number of variables, the surgeon may wish to consider the primary purpose for which a light source will be used, before purchasing new equipment. If the equipment will be used primarily for endoscopic surgery, high-intensity lamps that produce very bright light, such as xenon and metal halide, would be optimal. If the equipment will be dedicated primarily to diagnostic procedures, lamps of lower intensity, such as quartz halogen or tungsten, may be equally effective and more economical. For greatest flexibility, several multipurpose lamps are available. They provide excellent illumination in both surgery and diagnostics. Another consideration before purchase is the compatibility of new and existing video equipment. How will a new light source work with the other components in your medical video system? A final important factor to consider is safety.

Safety Factors

When light sources produce illumination, they also produce heat. Accidents in the operating room, such as fires, burns, and optical damage, have been reported. Many of these accidents can be prevented, if equipment is selected with safety in mind and operating procedures are followed meticulously. Among these procedures are:

Lamp Procedures

Any time a lamp reflector is touched, even slightly, it must be cleaned with a cotton swab and alcohol. Fingerprints leave dark spots on the bulb's surface and compromise the lamp's performance.

When replacing a lamp, first turn off the unit and unplug the power source. Wait at least five minutes for the reflector and the housing to cool before proceeding.

After replacing a lamp, the usage display should be reset if necessary.

Cable Procedures

Before beginning a surgical or diagnostic procedure, check the ends of the fiberoptic cable for evidence of damaged filaments, which will look darker than the others. If more than 20% of the cables appear damaged, use another cable. Clean off the tip of the cable with alcohol before proceeding.

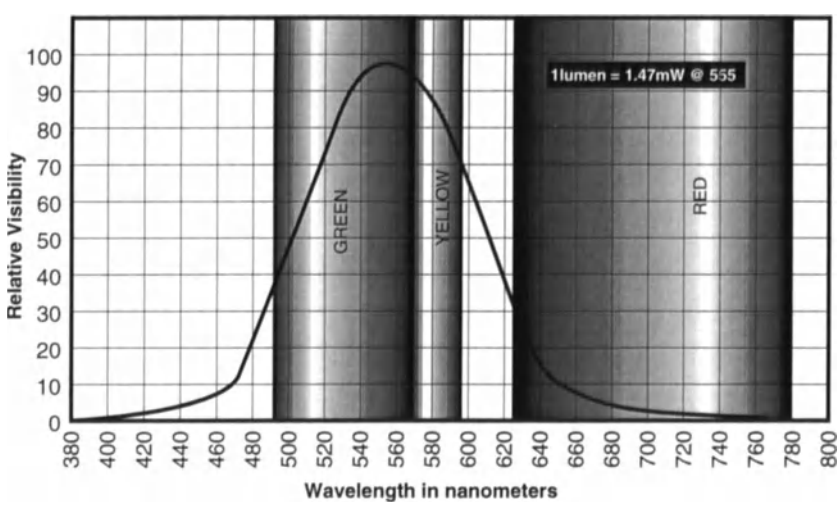


FIGURE 35.4.2. The graph measures how the human eye responds to the electromagnetic spectrum. The vertical axis represents the relative visibility of color; the horizontal axis measures color visibility in nanometers between 400 and 700 nm. Components at either end of the spectrum are invisible (infrared is over 70 nm; ultraviolet is below 300 nm). For reference, note that peak visibility during daylight is about 555 nm; sunlight is rated approximately 580 nm. (See also Figure 35.4.3 and Table 35.4.1.)

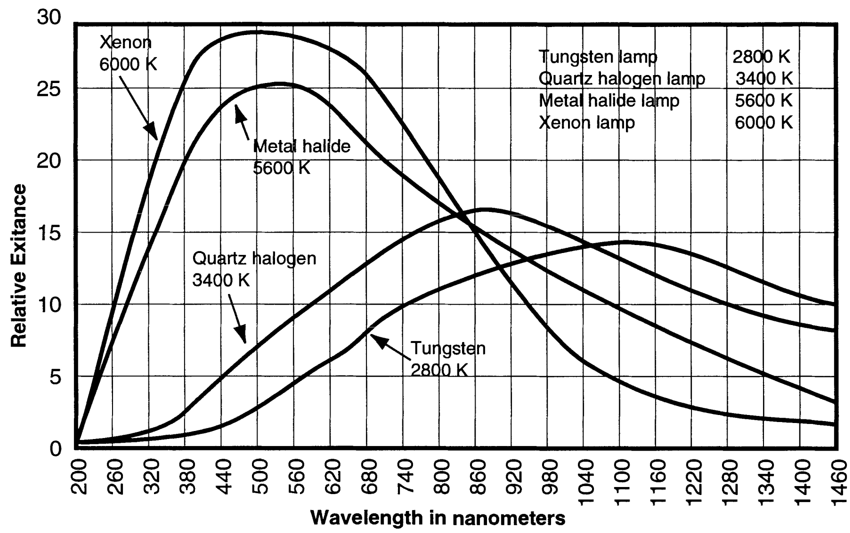


FIGURE 35.4.3. This graph shows the effect of color temperature (i.e., degrees Kelvin [K—see Table 35.4.1, note 4)]) on the visible output of various lamps. Relative exitence measures how much power different light sources give out. Note that xenon lamps peak at 500 nm and metal halide, between 500 and 560 nm; both are well within the visible spectrum (300 to 800 nm). Tungsten lamps, in contrast, peak at 800 nm, or outside the visibility range of the human eye. (See also Figure 35.4.2 and Table 35.4.1.)

TABLE 35.4.1. Some important features of commonly used lamps. (See also Figures 35.4.2 and 35.4.3.)

Type of lamp	Wattage[1]	Color[2]	Average lamp hours[3]	Degrees Kelvin (K)[4]
Tungsten	25–150	Brown-yellow	75	2,800
Quartz halogen	50–300	Yellow	50	3,400
Metal halide	250–300	White	250	5,600
Xenon	175–300	Bluish white	500	6,000

Data from Product Comparison System: Light Sources, Fiberoptic, Flexible Endoscopic; Rigid Endoscopic/Multipurpose. Product Codes: 12–343, 16–831. ECRI, November 1992.

[1]The higher the wattage, the more light a lamp can produce.

[2]Since color accuracy is critical in laparoscopy, a lamp that approaches "white" sunlight, which contains all colors of the visible spectrum, is preferable.

[3]Average lamp hours indicates the bulb life. To ensure maximum light output, bulbs should be changed either at the end of their indicated life or when a lamp no longer illuminates the surgical site sufficiently. (Light sources keep track of a lamp's hours of use in different ways. The Stryker's Quantum 4000, for example, has a digital HOURS display, which should be reset whenever the lamp is changed.)

[4]Degrees Kelvin (K) is a rating that indicates the color of the light emitted from the bulb, compared to an artificial indicator. The higher the number, the greater the intensity.

Some manufacturers, such as Stryker Endoscopy, house their cables in clear casings. With a clear casing, the entire cable is illuminated when the light source is in operation; this instantly alerts the staff to proceed with caution. Also, since the clear casing makes broken filaments easy to spot, the operator can tell if a cable is compromised and replace it before surgery.

During a procedure, monitor the cable at all times. A hot cable can singe sterile drapes, cause fire, or burn body tissues. Also, a misdirected light beam can be an optical hazard. To ensure maximum illumination, be sure to clean off the tip of the cable as blood and other material accumulate during a procedure.

After a procedure, never set the cable down next to flammable materials of any kind.

Cold Light

Cold light is a term sometimes used to describe the production of consistent, high-intensity light, with minimum transfer of heat to the tip of the endoscope. This common term, however, is misleading. Rather than cold, *cooler* would be more accurate. By means of special filters, light sources absorb or divert infrared rays before they enter the cable. These filters permit cooler, *white* light (that is, light in the visible spectrum) to pass through (Figures 35.4.2 and 35.4.3). White light, while cooler than infrared, is actually hot enough to be dangerous. Therefore, caution is mandatory any time light source equipment is in use.

Training

For maximum safety, operating room teams must be properly trained before they operate or maintain light source equipment. Hospitals should take advantage of the free expert training opportunities manufacturers provide.

Testing

Light sources, like other types of medical equipment, are expensive and prospective purchases should be evaluated carefully. Before selecting a new light source, surgeons should test several models on the market (Table 35.4.1). The tests should be designed to compare how similar units from various manufacturers perform during different surgical procedures.

Quantum 4000

The Stryker Endoscopy Quantum 4000 is a multipurpose unit that produces excellent illumination in all types of endoscopic procedures (Figure 35.4.1). The Quantum 4000 is designed specifically to address safety concerns. Several features make the Quantum 4000 noteworthy.

Brightness control. The best light sources provide reliable, convenient ways to control brightness, without annoying flickering, delay, or excessive glare. The Quantum 4000 lets the surgeon choose between automatic and manual brightness control; the selection can be changed easily. When *automatic brightness control* is chosen, the Quantum 4000 provides a steady supply of optimal illumination at the surgical site. This is achieved by electronically pairing the Quantum 4000 light source with the video camera. This creates a continuous electronic feedback loop between the video camera and the light source. This continuous feedback loop permits the paired components to monitor the light requirements continually and adjust the supply of light as needed. Adjustments are made rapidly, without notice or intrusion.

Manual brightness control, on the other hand, provides steady, unchanging brightness. Manual brightness may be appropriate when the video camera's electronic shutter is enabled, or when the surgeon wants to view the site directly through the scope eyepiece. To change from automatic to manual, the surgeon simply moves the slide switch.

Ease of maintenance. Light sources should be user friendly. Control units should be easy to operate and keep clean, and lamps should be designed for quick and simple replacement by regular operating room staff. The Quantum 4000 design is clean and simple, and the lamp, convenient to replace. In five minutes, the unit is cool enough so the reflector can be changed by a member of the operating room team. Other light sources may require skilled technicians for routine maintenance, or special equipment, just to replace a lamp.

Safe to operate. The light source should be safe to operate and maintain. The Quantum 4000's "Standby" operating mode makes this unit exceptionally safe to use. On Standby, the Quantum 4000 emits the lowest level of light intensity. As the default mode, Standby is engaged whenever the Quantum 4000 is turned on; the unit stays on Standby until another mode is selected. In the operating room, the Standby mode combines safety and convenience. While the operating room staff is preparing for surgery, the light source can be turned on to warm up. The light remains at the lowest level, and there is no chance that the cable will develop excess heat, or that stray beams can create hazards. When it is time to begin, the surgeon turns off the Standby switch and turns on either automatic or manual brightness control. The Quantum 4000 reaches full power only when this switch is turned.

Color and intensity. Different light sources produce beams that vary in color quality and brightness intensity. The color of the light from some lamps is more lifelike than that of others. Also, since surgery and diagnostic procedures require different levels of light, it may be wise to consider how the equipment will be used, and under what conditions. Quantum 4000 is a proven multipurpose unit that emits very bright white light. The choice of automatic or manual brightness control makes this unit appropriate for all types of endoscopic surgical and diagnostic procedures.

Adjusts to different cables. Fiberoptic cables range in diameter from 1 to 7 mm. Quantum 4000's unique "universal jaws" readily accommodates cables of any size. As an added safety control, the operator must open the special In/Out clamp for the port to admit the cable. Once the universal jaws are open, the lamp ignites. The power is turned off automatically when no cable is present.

Compatibility. Not every light is compatible with every video camera. Equipment from different manufacturers cannot always be successfully mixed and matched. Quantum 4000 is the natural complement to other Stryker medical video components. Features such as its universal jaws allow this light source to be integrated easily into systems from other manufacturers.

Lamp life. Most lamps have a life expectancy of between 0 and 500 hours. The Quantum 4000 lamp has a life expectancy of 250 hours. With the Quantum 4000, lamp replacement is simple and convenient for the operating room staff. Changing the bulb and resetting the HOURS indicator require no special tools or training. The cost, frequency, and ease of lamp replacement should be balanced against the overall quality of equipment and safety factors.

Looking to the Future

Safety and convenience will continue to be primary goals in light source research, with cost remaining a significant factor. Light source manufacturers will continue to refine existing equipment and improve technology. One way to achieve these goals cost-efficiently is to tap into research for stage lighting. In the future, the medical community can look for lamps and cables to be designed with the same diameter. This highly desirable feature will eliminate the need for a reflector and will minimize energy loss. Improvements of this magnitude will keep light source manufacturers and researchers busy for a long time to come. The results should be worth waiting and working for.

35.5
Photodocumentation: Video-Based Digital Photographs and Video Imaging During the Laparoscopic Procedure

S. Jan Morgan

Photographic documentation of endoscopic surgery has always been problematic. Equipment choice, camera operation, and film selection appear to be insurmountable obstacles to obtaining reliable photographic results. The proliferation of video devices for primary viewing and documentation has caused a gap in the publication of quality photos and slides. Part of this problem involves the interruption of a video procedure to remove the video camera and attach a bulky 35-mm camera. This is an awkward, if not impossible, task.

The difficulties in editing many hours of videotape into useful teaching and publication material is impractical for most physicians. Even the sophisticated video printers are inadequate. Their results feature low resolution, flat limited color, and poor archival quality. In spite of all the available new technology, nothing has replaced the simple high-resolution film-based color slide.

The 35-mm Camera

Currently, there are two types of photo documentation. The first type is the 35-mm camera. The second type is video photography that uses the endoscopic video camera to produce still photo images. The demands of modern laparoscopic surgery have made the use of 35-mm film cameras for documentation of endoscopic findings impractical. The procedure must be halted and the video camera removed to install the 35-mm camera. The surgical team is then blind, making detailed photos of surgical technique impossible. In addition, some endoscopic instrument suites have eliminated the scope eyepiece, making 35-mm camera adaptation difficult. Recently, new products have been introduced to take photos during the endoscopic procedure. These include: instant photo printers; film recorders; image management computer programs; disk recorders; computer image/report recorders; and the Digital Camera Unit (aka Digital Photographer).

Video Cameras

The endoscopic video camera has become the most important and misunderstood element in modern laparoscopic surgery. Each manufacturer makes claims and counterclaims pertaining to a video camera's performance. Camera specifications are confusing to interpret and are not standardized between manufacturers. Each camera maker measures specifications differently. In reality, endoscopic camera specifications cannot be compared on paper. Testing in an actual surgical environment is the only way to determine which camera is best. A video camera's performance, therefore, is best described in terms that can be seen on the video screen.

Resolution is expressed as lines. All video pictures are made up of horizontal and vertical "scan" or "TV" lines. The higher the number of lines, the more resolution or detail in the picture. *Dynamic range* is the term used to describe a video camera's ability to assimilate light; that is, its ability to distinguish from the brightly lit foreground to the dark background. Most video cameras have very poor dynamic range. When the foreground is brightly illuminated, the background is lost. *Gain* is the video camera's ability to increase sensitivity. Almost all medical video cameras have an "automatic gain" to maintain a properly illuminated picture on the monitor.

As light decreases, the camera gain circuit automatically brightens the picture. As the gain circuit brightens the picture, noise becomes apparent. *Noise* (aka graininess or snow) is amplified as the camera's sensitivity increases to compensate for the lack of light. Noise is most apparent when the viewing field is primarily red.

A video camera's dynamic range and auto gain are important factors to consider when video photography systems are used. The video or digital photo system grabs a single frame of the video and renders all of the details including noise, brightness, raster lines, and focus.

There are two types of modern endoscopic cameras:

the single chip and the three chip. Single-chip cameras have been the primary endoscopic camera design for the last 10 years. They have only one imaging device to produce the color picture. Resolution, color saturation, and dynamic range are limited by the single-chip design. Although these cameras are quite suitable for laparoscopic surgery, they are not suitable for the high resolution, still video photography necessary for publication. Photos taken with single-chip cameras have prominent TV lines, noise, and unwanted color (usually green). These problems are not generally visible when using the camera in surgery. They appear when a single frame of video is captured and imaged. In broadcast video, where maximum resolution, true color rendition, and minimal noise are essential, single-chip cameras are not used. Three-chip cameras are the industry standard.

All single-chip cameras must have a *color stripe filter* in order for the single chip to pick up the red, green, and blue colors necessary to produce color video. This filter reduces the light to the camera and restricts the resolution. Thus, the single-chip camera is noisier, has less sensitivity, and more visible TV lines when used in photography.

The three-chip camera uses three imaging devices. Each one is specifically tuned for a red, green, or blue primary color. The lack of a stripe filter improves resolution by as much as 100%; noise is reduced by 60%; and the camera is more sensitive with much greater dynamic range. Digital photos taken with a three-chip camera and properly processed have a filmlike quality equal to the best 35-mm images taken with a film camera. The video picture, print photo, or slide can be no better than its weakest component. When attempting to produce publication-quality prints or slides, a three-chip camera must be used. It is important to test each manufacturer's three-chip camera to determine which manufacturer's camera will produce the best results.

Instant Printer

The instant printer is the most common still photo device used in endoscopic video. These devices produce a photo-like rendition of the video image. The printers can produce photos in many sizes, including multi-image formats, on a single sheet of printer material. Up to six photos may be taken in rapid succession with the best printers. These images are held in memory until a print command is given. During the two-minute printing process, additional photos cannot be taken. The memory must be cleared before photography can continue.

Photo color rendition is controlled manually. The optimum color result is achieved by trial and error. The printer will retain the desired color settings once they are determined. The color, photo size, and multi-image format memory functions of the printer demand familiarity with complex-multiple function single button controls, convoluted instruction manuals, and constant on-screen displays. The printing media must be replaced when it is used up. These printed photos are not of publication quality. Similar to a Polaroid snapshot, the images have limited resolution (300 to 500 TV lines); and flat color rendition (only about 200 colors). As of this time, no printer can produce a publication slide. It is possible to photograph a video print as a slide; but the copy slide is expensive and the result poor.

The best photographic results can be obtained when the printer is connected directly to the camera control unit through the S-VHS or RGB (separate red, green, and blue video signal available from some video cameras) output. Connecting any other document device (such as a VCR) to the printer output produces a signal of very low quality. If the printer is connected to its own monitor, there will be no on-screen displays or frozen printer images to block the primary viewing screen.

Video Film Recorders ("Medical Grade Film Recorder")

A video film recorder is a video device with a 35-mm camera body attached. The video data are recorded on 35-mm film, and developed as conventional slides or as print negatives. Originally designed as a computer peripheral, the film recorder is used to photograph computer-generated video images. These images are static and are stored in the computer for future reference. The photographs may be inspected for color, the recorder settings changed, and the photographic information altered until a satisfactory image is obtained. The photo or slide quality of a film recorder is generally better than that of a printer. This is the result of using film as a medium. The resolution of the typical video film recorder is 300 to 525 lines (horizontal). Consequently, video raster lines are still evident.

Film recorders are slow, taking 25 seconds (or longer) to take a photo. Most of the video film recorders have an internal memory (image buffer) that allows for two to four photos to be taken in quick succession. The photos must then be exposed to film before more photos can be taken. Color correction must be made manually by trial and error. After the photos are taken, processed, and examined, adjustments are made to the recorder and more film taken. This trial and error method may be costly and time-consuming; and may be impossible if there is no device to store the electronic images to be photographed. In use, film recorders are much like 35-mm cameras, as there is no way to know the results until the film is developed. Incorrect colors and fuzziness due to motion and focus are among the typical problems. The video film recorder should be connected directly to the camera control unit via the S-VHS or RGB input/output.

Digital Film Recorders

Digital film recorders are the only devices capable of making publication quality slides or negatives. Although they offer more than 10 times the resolution of video film recorders, they are expensive. They demand a separate, dedicated computer system with a trained, experienced operator. Digital film recorders are not suitable for use in the operating room environment.

Digital Image Recorder ("DAT" Image Recorder)

These devices instantly record images on DAT (Digital Audio Tape). The quality is equal to S-VHS tape (300 lines). The DAT recorder does not make print or slide images. The DAT recorder must be attached to a film recorder. The picture must then be chosen from the DAT tape, and photographed individually by the film recorder. This is time-consuming.

Floppy Disk Systems (SONY Mavica)

These disk recorders simply use a micro-floppy disk to replace videotape. Their resolution and color rendition are equivalent to S-VHS videotape. These devices must be connected to a film recorder or printer. The results have characteristic video raster lines and noise. Image recorders work best if connected to the S-VHS or RGB outputs of the camera control unit.

Computer-Based Digital Image Capture Systems

Over the past five years, computer-based *frame grabbers* or *image managers* have been introduced into the surgical environment. These systems use a computer and a frame grabber or digitizer board to capture a still image from a video source. By means of special software, the video image is captured and stored in the computer as a digital image. Additional software files the photos within the computer for future reference.

Images captured in computers are digitized as 8-, 16-, or 24-bit image files. This number of bits is described as the amount of digital information that forms each photo. Eight-bit color will give a photo rendition of 200 colors. Twenty-four bit will give a photo rendition of 16.8 million color variations. There is a corresponding increase in resolution and detail with the larger 24-bit images. Twenty-four-bit image files are necessary for publication-quality photo documentation.

Computer systems operating with 8- or 16-bit image capture cannot reproduce the limited resolution and narrow color range of single-chip cameras and therefore, cannot reproduce the quality of a three-chip camera. Thus, 8- and 16-bit image capture systems are impractical for publication-quality photo documentation.

Most computer-based imaging systems are unable to "grab" and file the information as 24-bit images. Special hardware and software considerations are necessary for 24-bit image capture in surgery. Taking and storing pictures rapidly is very difficult because of the time required to move images inside the computer. All computer image management systems require knowledge of computer protocol and keyboard commands to capture, view, and edit images before moving them into storage within the computer or to removable tape or disk.

Since computer systems cannot create images themselves, the digital information must be fed to a film recorder capable of handling digital images. *Image managers* utilize 16-bit color and include video film recorders. Image managers allow annotation of slides or prints as well as formatting many images on one print or slide. This type of system produces image quality limited to the TV type resolution of the recorder and 16-bit color. Photos or slides produced with standard medical printers or video film recorders are subject to limitations discussed earlier and do not achieve publication quality.

Image management/capture programs demand multiple functions. Patient data must be manually entered via the keyboard before the photo session begins. Images are captured, then reviewed. If information is to be added to the photo, still more review of the image and typing is necessary before the image may be committed to film. The fastest film recorder takes 25 seconds per image, and is impractical for use in the high-pressure and time-limited environment of surgery. In order to allow space for the annotation, the image management program must reduce the size of the photo image, reducing the resolution.

Continuous review, addition, storage, annotation, and erasure of images from the computer memory may cause problems in the system's reliability. Time-consuming steps must be taken to maintain a contiguous computer memory. A thorough knowledge of computer protocol and maintenance is necessary to eliminate computer crashes and the resulting down time.

Many hospitals have computer specialists who may try to create an image capture system for use in surgery. These systems record the images digitally on disk, then process the photos in the hospital media department on the existing film recorder and image manipulation software. Although this sounds like a good idea, there are pitfalls. Computer image capture programs demand many keyboard commands. New proprietary software would have to be written that would allow fast photography without the confusing keyboard, especially for the 24-bit image scheme. The computer itself would need modifications to meet biomedical engineering requirements and FDA guidelines for equipment used in surgery. Editing and photographing the digital images as slides will demand still more special software, and much time and manpower to handle the necessary 24-bit format.

Digital Photographer

The Digital Photographer, or Digital Camera Unit or On-Call Photographer, is a computer-based photographic system utilizing 24-bit digital imaging. Its software and hardware combination allows a digital image to be taken every five seconds, automatically storing it on a removable disk. The disk's capacity is more than 178 images and is reusable. Images may be reviewed and edited at full screen magnification upon completion of the photo session. Images are taken using a hand or foot switch. The captured image is displayed on the computer monitor for five seconds, and is automatically stored on the removable disk. The five-second delay allows the image to be checked for motion and focus. If the image on the monitor is not of good quality, it may be retaken. Since there is no keyboard, control of the system is by track ball or mouse. The control commands for the unit consist of TAKE PICTURES, VIEW PICTURES, and SHUTDOWN (off). As with other computer-based systems, the Digital Photographer cannot make slides itself. The digital information must be processed in a separate computer using specific software and coupled to a high-resolution digital film recorder. This service is provided by the unit's manufacturer.

With the use of a high-quality, three-chip endoscopic video camera, photographic quality from the Digital Photographer is comparable to the best 35-mm film photos. Low-quality cameras (for example, single chip) will show lines, noise, color artifact, and low resolution in the finished slide. A fine three-chip camera will produce a slide that is indistinguishable from a 35-mm film slide.

Digital image capture offers many more options than the traditional 35-mm film slide. Prints from negatives may be produced. Photos in digital form may be stored for future reference on disks. Color images may be transmitted over phone lines. Digital photos can be used for CD-ROM publication without the process of scanning hard copy prints. As digital information does not fade over time, photos stored digitally will always be suitable for printing. Text and graphics may be added.

Computer-based systems using 24-bit color generally have a resolution comparable to about 1,100 lines (about three times sharper than conventional video images). The best three-chip endo-video camera produces about 800 TV lines (considered a very high-quality TV signal). The final slide result, when produced using a high-quality digital film recorder, is 4,000 TV lines—horizontal and vertical. This is an extremely sharp image.

When using the digital photo system with 24-bit image capture, it is now possible to take publication-quality photos and slides during the endoscopic procedure. The Digital Photographer offers the best photographic result with its 24-bit imaging scheme, and is the easiest to use. The manufacturer offers publication-quality prints and slides, with the addition of text and graphics, if requested. Computer photo archive systems are also available.

On-Site Processing

Digital Photographer image data may be processed on site. The manufacturer offers various viewing, editing, archiving, and annotating software and hardware systems. New software offerings include high-speed phone transmission and image viewing and archiving in both MAC or PC environments. Independent software companies offer image display and manipulation software. Although these programs are powerful digital imaging tools, they are difficult to master, slow in operation, and demand powerful computer systems.

The reality is that on-site image processing is expensive and time consuming. On-site digital image processing demands a separate computer system, an expensive, difficult-to-use film recording system, cumbersome software schemes, and a photographic processing lab. A specially trained technician will be needed to manage these systems. Photographic slides demand special handling not necessary to the production of standard lecture text slides.

The cost of the hardware and software, personnel, and time must be weighed against the cost of processing the images through an outside contractor. In most cases, the computer suite necessary to produce publication-quality images will far exceed the cost of thousands of publication-quality slides produced by a competent digital imaging center.

Digital imaging may be far less expensive than conventional film, as the charges are per image rather than per roll (if most photos on the "roll" are discarded) and digital images may be selected before they are committed to film. Digital imaging labs can easily produce single images without the charge for an entire roll of film.

TABLE 35.5.1. Photo quality versus ease of operation.

Product	Color rendition	Resolution (digital rendition)	User friendly	Labor intensive	Publishable quality
35-mm camera	Inconsistent	Inconsistent	No	Yes	Inconsistent
35-mm video film recorder Medigraphics/Surgislide/Polaroid	Poor	Poor	No	Yes	No
Video printer Sony/Toshiba	Poor	Poor	No	No	No
Video image recorder Sony—Mavica/Panasonic OMDR	Fair	Fair	No	Yes	No
Computer-based image manager Dyonics—Dyna Vision/Olympus	Fair	Fair	No	Yes	No
Computer-based image capture Stryker Digital Photographer/PPL Digital Camera Unit, On-Call Photographer	Excellent	Excellent	Yes	No	Yes

Above chart is predicated upon the use of a Hi-Resolution 3-Chip Video Endoscopy Camera.
Single-chip cameras are not recommended for video photography.

Photos from Tape

Although all of the video photo devices can be connected to a VCR, the photos will not be of publication quality. None of the available videotape formats (VHS or S-VHS) have sufficient imaging quality to produce a publishable photographic result.

Good Photos and Good Video

It is generally thought that if it can be seen in the scope or on the monitor, it can be photographed. As many physicians and bioscientific photographers have discovered, this is not always the case. The most important part of the video documentation is the camera. Today, the best camera is the 782 Stryker Three Chip Endoscopic Video Camera. It has, *visibly,* the best color rendition, sharpest image, least noise, and best dynamic range. Slides taken using this camera, with 24-bit digital image capture and a digital film recorder are as good or better than 35-mm film camera endoscopic photos.

Since sending a video signal from device to device weakens the signal and degrades the photos or tapes, it may be necessary to install a professional-quality distribution amplifier. A distribution amplifier will boost a single video input signal, provide four to six output lines, and ensure a good, clean signal to each device. Video wiring is simplified (Table 35.5.1).

Photographic Technique

Regardless of the technology involved, good photographic technique is necessary to obtain good photographic documentation. All video or digital photo systems are limited by the video camera scan rate. The video camera grabs a frame of image in 1/30th of a second. Thus, it is very important to hold still when taking photos. Most endoscopic conventional 35-mm photos are taken at about 1/30th of a second. Some computer-based image capture systems feature 1/60th of a second exposure time. Be aware that images taken at this speed will have half the detail and resolution of a 1/30th of a second exposure.

Since all endoscopes have a narrow range of focus (depth of field), check the focus before taking the photo. Center the subject to be photographed. Hold still and focus. Don't forget to take the picture. With good equipment, taking publication-quality video photos and slides is simple. Processing the images and identifying the slides is still the difficult task it has always been. The production of finished or instant video slides in the operating room is not practical or even possible in the foreseeable future. As always, good photos and slides come from good digital information handled by a lab experienced in medical imaging and digital photo processing.

Summary

Documentation quality depends on four elements.

First: The camera must deliver a high-resolution, low-noise, evenly illuminated picture and it must demonstrate good dynamic range. Three-chip cameras are best suited to provide these factors. Single-chip cameras are to be avoided if documentation quality is a vital part of the procedure.

Second: The photographic documentation device providing the slides or prints must be able to record high-resolution images of publication quality. Only the Digital Photographer and Digital Camera Unit have the necessary 24-bit imaging system to provide endoscopic slides and prints of publication quality. Twenty-four-bit imaging is absolutely necessary. Video printers and video film recorders are to be avoided if documentation quality is a vital part of this procedure.

Third: The photographer (physician) is an important element. Images must be centered, focus must be checked, and motion must be controlled. After exposure, check the digital camera monitor image and reshoot, if necessary. If the photographer is to manage image production, avoid using a video film recorder or video printer.

Fourth: The disk processing laboratory must provide knowledgeable disk to slide or print conversion. The lab must be able to provide necessary annotation services and archiving at a reasonable price on a per-image basis. Familiarity with the physician and the surgery procedures is tantamount to good image production.

36
Roentgenologic Imaging of the Biliary System During Laparoscopic Cholecystectomy

John G. Hunter

Introduction

It took many years after its description in 1931 for surgeons to appreciate the value of operative cholangiography. A number of papers dating from the late 1950s to the early 1980s showed a dramatic decrease in unnecessary bile duct exploration when operative cholangiography was employed.[1–3] While not denying the importance of operative cholangiography, the majority of research supported selective cholangiography when laparoscopic cholecystectomy became available in 1988. The argument as to whether cholangiography should be performed routinely or selectively during open cholecystectomy was never settled, and likewise the argument has not been settled for laparoscopic cholecystectomy.

The arguments for selective cholangiography are that noninvasive tests (ultrasound, liver chemistries) and clinical observations can predict cholangiographic findings most of the time.[4–6] Not only are normal cholangiograms expensive, they are associated with a small, but definable, morbidity and a 20% false-positive rate, resulting in many unnecessary bile duct explorations. Arguments for routine cholangiography include detection of unsuspected bile duct stones (5%), avoidance and detection of biliary injury, training of residents, and maintaining surgical proficiency.

The arguments for laparoscopic cholecystectomy are similar. Data supporting the selective use of operative cholangiography were advanced at the Southern Surgical Society meeting in 1991.[7] An excellent argument for routine operative cholangiography was made at the NIH Consensus Conference on cholelithiasis in 1992.[8] No aspect of laparoscopic cholecystectomy has raised a more vigorous debate. Unfortunately, in most forums the debate has suffered from a confusion on the ground rules. Most surgeons advocating selective cholangiography discuss the shortcomings of *static* cholangiography. Advocates of routine cholangiography uniformly argue for *fluoroscopic* cholangiography. A number of proponents of selective cholangiography joined the routine cholangiography camp when fluoroscopic equipment was made available to them. Even the strongest advocates of selective cholangiography agree that surgeons performing laparoscopic cholecystectomy should be able to perform cholangiography. The arguments for both approaches will be presented later in this chapter.

Techniques of Laparoscopic Cholangiography

Cholecystocholangiography

During the early development of laser laparoscopic cholecystectomy, some surgeons advocated cholecystocholangiography to delineate biliary anatomy.[12] This technique was utilized because it was easier than cystic duct cholangiography. The shortcomings of cholecystocholangiography are several. In 15 to 20% of cases, the cystic duct or gallbladder infundibulum will be occluded with a stone or edema, making cholecystocholangiography impossible. It is difficult to judge the amount of contrast needed in order to adequately, but not excessively, opacify the common bile duct. Similarly, contrast in the gallbladder may obscure visualization of the common bile duct. Lastly, if cholecystocholangiography is performed *before* dissection of the cystic duct, there remains a risk of confusing cystic and common ducts during subsequent dissection.

One circumstance in which cholecystocholangiography may be helpful is when preliminary dissection of Calot's triangle reveals a duct that, in the surgeon's mind, could be either cystic or common bile duct. If the surgeon places a clip next to the dissected duct and performs a cholecystocholangiogram through the infundibulum of the gallbladder, the true nature of the duct may be revealed and a common bile duct injury is avoided.

Access to the Cystic Duct

The techniques of cystic duct cholangiography have been well described for laparoscopic cholecystectomy.[9] Initially, access to the cystic duct was obtained through the lateral most trocar, after removal of the grasper securing the fundus of the gallbladder. Soon surgeons realized that maintaining cephalic retraction on the fundus of the gallbladder would aid in performing cholangiography; thus, the trocar in the midclavicular line was utilized to introduce the cholangiocatheter. The initial placement of this trocar was generally too low and medial, resulting in many valiant but abortive attempts to insert the catheter into the cystic duct from a perpendicular approach.

With time, it became apparent that the ideal trocar position for performance of cholangiography was immediately beneath the right costal margin at the anterior axillary line[10] (Figure 36.1). This results in alignment of the cystic duct, with the trocar shaft allowing easier cannulation of the cystic duct.

After dissection of the gallbladder neck, a clip is placed across the gallbladder infundibulum. The cystic duct is then incised with a pair of microscissors introduced from the subcostal port. The surgeon on the patient's left (primary surgeon) holds tension on the gallbladder neck and, observing the video monitor, aligns the cystic duct parallel to the microscissors. It is usually necessary to push the cystic duct back slightly toward the liver to produce an angle between the cystic duct and scissors of approximately 30° in the coronal plane. A nick just large enough to allow insertion of a 5F catheter is made on the side of the cystic duct facing the laparoscope. The catheter (which will be described in the next section) is passed through a 5-mm metal guide, introduced through the subcostal trocar, and held in place with a laparoscopic clip. Alternatively, the catheter may be loaded into a specialized cholangiographic clamp (Figure 36.2). This clamp has a central channel for passage of the catheter and two wings that clamp down on the cystic duct. The saline-flushed cholangiographic catheter is brought into the abdomen with 1 cm of the catheter exposed beyond the tip of the clamp. With the cystic duct held in the same orientation as for creation of the ductotomy, the surgeon should be able to advance the catheter into the cystic duct unless it is occluded with stones or valves of Heister. After the catheter has been advanced 1 to 2 cm, the catheter is secured in position.

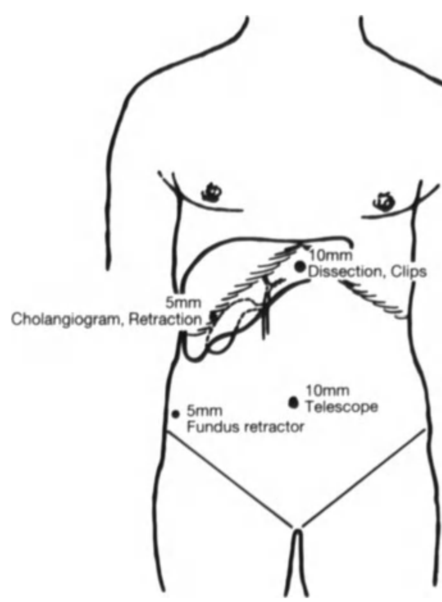


FIGURE 36.1. Trocar positions for laparoscopic cholecystectomy. Note the high, lateral position of the subcostal port.

Percutaneous Cholangiography

A method of percutaneous cholangiography was developed for situations when a two-winged cholangiographic clamp was unavailable.[11] The advantages of this system are three. First, the use of a light, flexible plastic introduction system reduces the torque on the catheter introduced by the weight of the trocar and metal guide. Second, the percutaneous access site can be chosen after the cystic duct anatomy has been defined, ensuring optimal placement for coaxial alignment of the catheter and cystic duct. Third, it is possible for the primary surgeon, from the left side of the table to place the catheter, decreasing the need for a skilled assistant. The disadvantages of percutaneous cholangiography are that another hole must be made in the abdominal wall and that two-handed coordination is frequently necessary to guide the catheter into the cystic duct.

With percutaneous access, a long, thin-walled plastic intravenous catheter, generally 14-gauge, is inserted directly through the abdominal wall, close to the subcostal port. The intravenous catheter is brought close to the cys-

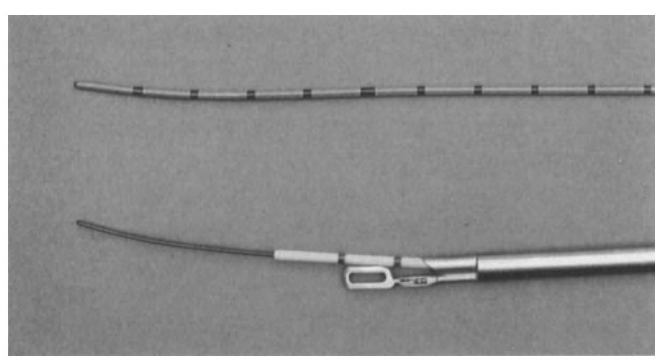


FIGURE 36.2. Inexpensive access to the cystic duct may be gained with ureteral catheters and a specialized clamp. Hydrophilic guidewires slip through the tight spinal valves and are extremely useful in difficult cannulations.

tic ductotomy, the needle removed, and a second 4- or 5F cholangiocatheter is passed through the guide into the cystic duct. The left hand guides the catheter through the skin and the right hand, using a grasper passed through the epigastric trocar, advances the catheter into the cystic duct. The grasper is then exchanged for a clipper, and saline is injected as the clip is squeezed together.

In order to ensure adequate but not excessive clip pressure, the surgeon should inject saline through the catheter with the left hand while tightening down the clip with his right hand. As soon as the flow in the catheter stops, releasing pressure with the right hand will usually allow sufficient clip relaxation for the flow in the system to resume, yet the catheter will not become easily dislodged.

Catheters for Laparoscopic Cholangiography

The most commonly used cholangiographic catheter is a ureteral catheter. The most popular ureteral catheter is whistle-tipped. This catheter offers a tapered tip and 1-cm markings, allowing the surgeon to measure how far into the duct the catheter is inserted. The disadvantage of the whistle-tipped catheter is that most of these catheters have many side holes, requiring that the catheter be advanced at least 3 cm into the cystic duct to ensure that all of the side holes are inserted. This may be difficult if the valves of Heister are intact. Additionally, 0.035-in. guidewires will not fit through a 5F whistle-tipped catheter. A major disadvantage of ureteral catheters is that they tend to be somewhat thick-walled. The 5F ureteral catheter, which allows the passage of a 0.035-in. guidewire, does not have a tapered tip and may be hard to introduce into the cystic duct. Thinner-walled catheters with rigidity sufficient for laparoscopy have been manufactured for angiographic and endoscopic retrograde cholangiopancreatographic (ERCP) use. The 5F catheter of this type is tapered, yet will accommodate a 0.035-in. guidewire. This is the ideal cholangiographic catheter.

One of the original catheters used, a Taut catheter (Taut, Inc.), is still used by some surgeons because it has a fine-pointed conical tip, allowing easy cannulation. The disadvantage of this catheter is that the cone-shaped tip is effectively a barb that creates difficulty in catheter extraction. Newer Taut catheters have eliminated this "barb" configuration.

Yet another type of cholangiocatheter has been designed that requires neither a specialized clamp nor a clip to hold it in place. These are balloon catheters, in which a balloon is inflated to secure the cholangiocatheter after it is placed in the cystic duct. While these catheters may be easy to insert, they lack versatility. For example, they cannot be used in a short cystic duct as the balloon will slip into the common bile duct, obstructing the flow of contrast into the proximal biliary system. In addition, the balloon may be mistaken for a stone. Another disadvantage of this system is its expense; it costs about five times more than a ureteral catheter.

Occasionally, it will be impossible to thread any catheter into the common bile duct. This is usually a result of poor cannulation angle but may reflect spiral valves in the cystic duct, cystic duct obliteration, or a cystic duct stone. In response to this latter problem, the surgeon should first "milk back" the cystic duct from the common duct junction to the cystic ductotomy, to ensure that there are no cystic duct stones. Then, if there is a long cystic duct, a ductotomy may be made closer to the common bile duct. Alternatively, a hydrophilic guidewire, 0.035 in. in diameter ("slime" wire) may be passed through the catheter into the common bile duct and the cholangiocatheter then passed over the guidewire. The hydrophilic, polyethylene oxide coating causes this guidewire to become "slippery when wet" and allows a more successful passage through the narrow, tortuous cystic duct. Once the guidewire has been removed, the catheter will be full of air. An attempt may be made to aspirate the air out of the catheter, but it is usually necessary to place the patient in a steep Trendelenburg position and irrigate the common bile duct with 50 mL of normal saline, thereby flushing all air out of the biliary system into the duodenum. The patient is then returned to the supine position for performance of the cholangiogram.

The X-ray Image

Static Cholangiography

Prior to the development of laparoscopic cholecystectomy, most surgeons relied on static images of the bile duct, obtained with an overhead portable machine, to survey for common bile duct stones. The shortcomings of static cholangiography are many, including the time required to get a film positioned, exposed, and developed; the frequent inadequacy of images; and a high rate of false-positive cholangiograms, erroneously diagnosing choledocholithiasis.

Static cholangiography generally requires 15 to 20 minutes from the time the cholangiocatheter enters the cystic duct until the time the x-ray images are available for viewing on the light board. It is usually expected that 20% of the films will be inadequate due to overexposure, underexposure, misalignment, or failure to fill the entire biliary system and duodenum with contrast. In these cases, another 20 minutes will be required for repeating the study. In addition, experience has shown that, even if the static cholangiogram shows a filling defect that appears to represent a stone, the x-ray is misleading (falsely positive) in approximately 20% of cases. Consequently, 20% of common bile duct explorations are performed unnecessarily.[4] False-negative studies are probably more common than appreciated, but overlooked stones that become clinically significant are rare (< 1%).

With laparoscopic cholecystectomy, the difficulties in obtaining an adequate static cholangiogram are compounded by several factors. These include the laparoscopic instrumentation that may obscure the extrahepatic biliary system, the air-water interface at the hepatic plate, and the frequent inability to visualize the intrahepatic ducts with the patient in the reverse Trendelenburg position.

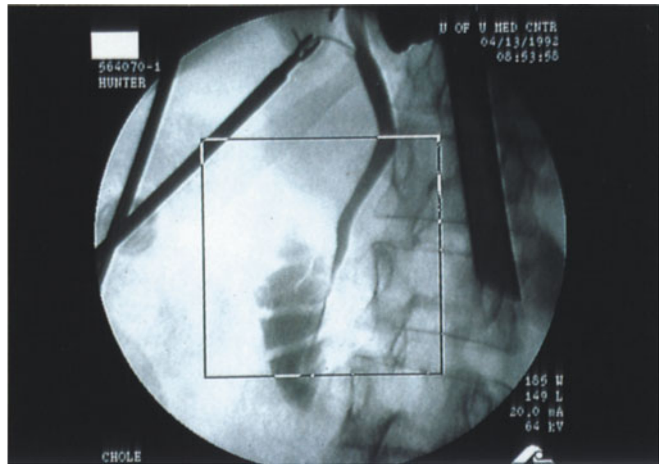
Dynamic Cholangiography

Computer driven, digitally enhanced fluoroscopic dynamic cholangiography is rapidly becoming the preferred modality for laparoscopic cholangiography. Since the 1970s, radiologists and gastroenterologists have relied on fluoroscopy during cholangiography to guide their examinations of the biliary system. Selected images are obtained with a *spot film* that demonstrates the biliary anatomy and pathology discovered. This system has been difficult to replicate in the operating room because it requires the ability to perform fluoroscopy, and intermittently, rapidly, place an emulsion film in line with the x-ray beam. Expensive operating tables, synchronized with a C-arm, are required to accomplish this goal.

Adequate film quality has been achieved by the use of computer driven, digitally enhanced fluoroscopy. This technology employs a standard fluoroscopic C-arm, which is connected to a computer that digitizes the information obtained. The image can be stored on a computer disk for review and further processing. In addition, state-of-the-art computer software can enhance the quality of the cholangiogram to approximate the resolution obtainable with emulsion film (Figure 36.3 A and B). Digital processing allows the magnification of any portion of the radiographic field to demonstrate fine detail. The image can be recorded on videotape or exported to a matrix or laser printer, which can produce an image quality rivaling static films. These images are used for documentation of the medical record and for subsequent examination by radiologists.

Technique

The patient is placed on a fluoroscopic operating table that has been turned around to allow access to the mid-abdomen. While the surgeon gains access to the biliary system, the scrub nurse drapes the C-arm with a sterile cover. Any metal trocars are positioned so as to be out of the x-ray path. The x-ray monitors are placed off the left foot of the patient and the C-arm is brought in from the left side of the patient (Figure 36.4). The surgeon dresses in a lead apron or stands behind a lead screen. The surgeon should be given the fluoroscopy pedal. Full-



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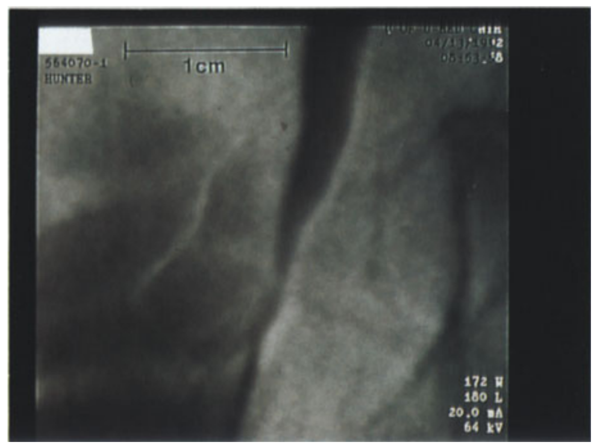

B

FIGURE 36.3. (A) Digital operative cholangiogram demonstrating normal anatomy. (B) Enlargement of the final tapered distal common bile duct gives resolution of features 1 mm and larger.

FIGURE 36.4. The operating room set-up with C-arm entering from the left, the surgeon behind a lead screen to the patient's right, and the monitor array positioned off the patient's left foot.

strength (60%) water-soluble iodinated contrast material is injected slowly through a long IV extension tube to allow mixing of contrast with bile, which will demonstrate small stones early in the cholangiogram.

With the patient in reverse Trendelenburg position, the flow of contrast is preferentially into the distal bile duct and duodenum. Filling of the intrahepatic ducts can be accomplished using one of three maneuvers. Frequently, a rapid bolus infusion will cause retrograde flow of contrast into the liver. If this fails, the patient may be placed in the supine or Trendelenburg position to encourage filling of the liver. As a last resort, morphine 1 mg IV can be administered to effect spasm of the sphincter of Oddi. Rarely is this last maneuver necessary. Nonfilling of the duodenum may be eliminated by the use of intravenous glucagon. Generally, glucagon 1 mg IV will produce complete sphincter relaxation within one circulation time (less than a minute), lasting for 10 to 15 minutes. If the duodenum still does not fill after glucagon administration, it is likely that a small stone or ampullary stricture (benign or malignant), is present. Lastly, the pancreatic duct will occasionally start to fill at the beginning of the cholangiogram. Real-time video monitoring during cholangiography can limit overfilling of the pancreatic duct and possibly reduce the incidence of postoperative pancreatitis. Several selected spot films can be obtained and stored on the hard disk during the cholangiogram for later review and printing.

Analysis of Findings

One of the most frequent difficulties encountered in fluoroscopic cholangiography is differentiating stones from air bubbles. Several techniques may be utilized to sort out this problem. One technique is to place the patient in the Trendelenburg position and flush the bubbles into the duodenum. Alternatively, if the patient is placed in a reverse Trendelenburg position, the air bubbles will float up into the liver, where they frequently will break into smaller bubbles in the segmental hepatic ducts. Clearly, stones will not do this. In addition, gravity helps to distinguish stones from air bubbles as stones tend to sink, while air bubbles rise. If the catheter is in the common bile duct and the common duct is capacious, it is occasionally possible to aspirate the air bubbles back into the cholangiographic catheter. Employing these techniques, we have only had one case in which the surgeon and radiologist reviewing the cholangiogram disagreed on whether the filling defect was a stone or an air bubble. (The resultant bile duct exploration proved the surgeon to be correct; there were no stones.)

Advantages of Fluoroscopy

The advantages of dynamic cholangiography compared with static imaging are many. The first advantage is that the time necessary to perform cholangiography can be cut in half. The length of time required to position the C-arm is no greater than that needed to place an x-ray cassette and position the overhead x-ray tube. As soon as the field is located, the contrast is injected, and the cholangiogram viewed as it is performed. This ensures a complete cholangiogram in 100% of cases and eliminates the waiting period for cholangiographic results, during which time common bile duct injuries may occur. In addition, the incidence of false-positive results may be reduced in fluoroscopic cholangiography through a number of maneuvers described previously that distinguish bubbles from stones.

A major limitation of real-time cholangiography is that it is necessary for the surgeon to be near the radiographic field at the operating table. Whatever system is used, the surgeon should be dressed in a lead apron or positioned behind a lead screen 6 ft from the C-arm collector. The necessary distance is obtained by using long extension tubing. Exposure risk is minimally improved by moving farther than 6 ft away from the x-ray unit.[13]

Cholangiography Results

In the first 100 laparoscopic cholecystectomies performed at the University of Utah, fluoroscopic cholangiography altered the operative course in 10% of cases.[14] In three patients, the finding of common bile duct stones prompted bile duct exploration. In three other cases, we found that the common or segmental right hepatic ducts were inserting into the cystic duct or low into the common hepatic duct. This increased our caution when applying clips to tubular structures in Calot's triangle. A third cholangiographic finding of interest was the phenomenon of unexpected proximity of the cystic duct dissection to the common bile duct. In one case, the presumptive cystic duct proved to be the common bile duct; in the second case, a clip on the cystic artery was compressing the wall of the common hepatic duct; and in a third case, the direct drainage of the gallbladder into the common bile duct (absent cystic duct) was identified and appropriately managed. With increased experience in laparoscopic cholangiography, we have found the variations in right hepatic duct anatomy to be more of a curiosity than a concern. However, a knowledge of the distance between the cystic ductotomy and the common bile duct provided by cholangiography has been very useful in placing cystic duct clips, to avoid narrowing a tented common bile duct. Presently, the most important feature of routine cholangiography is the identification of suspected and occult common bile duct stones, enabling their concurrent removal, thus obviating two procedures and a prolonged hospitalization.

The most frequent cause of unsuccessful cholangiography is failure to access the cystic duct, which usually results from inexperience in laparoscopic technique. If a policy of extremely selective cholangiography is used, or if a surgeon infrequently performs laparoscopic cholecystectomy, the rate of success may be 50%. During our initial experience with laparoscopic cholangiography, cystic duct cannulation was successfully performed in 88 of 99 attempts.[14] The instances of failure were predominantly among the first 20 cases and were attributed to a number of anomalies, including a small cystic duct, tenacious valves of Heister, accidental cystic duct transection, and excessive cystic duct incision (causing the duct to roll). With experience and the occasional use of guidewires, cholangiography can be successfully performed in 95 to 98% of cases.

In our early series, a cholangiogram demonstrating choledocholithiasis occurred in 6 of 99 laparoscopic cholangiograms,[14] but was falsely positive in two. To avoid leaving a stone behind, a protocol of transcystic bile duct exploration was utilized. Choledochoscopy or basket exploration through the cystic duct allowed bile duct clearance in all, and allowed primary cystic duct closure, obviating choledochotomy and T-tube placement. In the two cases where stones were not recovered, an air bubble and papillary stenosis were responsible for the filling defect.[15] The latter diagnosis was found on choledochoscopy.

To our knowledge, a false-negative study has occurred only once in 350 cases (0.3%). In this instance, the initial cholangiogram demonstrated two stones, only one of which was recovered at the time of bile duct exploration. It was felt that the second stone had been flushed into the duodenum since the completion cholangiogram did not show the stone. The patient passed the stone that evening. The cause of the error had been an excessively concentrated dye column. Full-strength contrast can be used during fluoroscopic cholangiography *if* the contrast is injected slowly so that mixing with bile allows detection of small stones.

Complications

The most common complication of laparoscopic cholangiography is perforation of the cystic duct. This may occur with the use of an excessively stiff catheter or with an unusually friable cystic duct. A perforation may be identified by visualization of the catheter tip in Calot's triangle or by extravasation of contrast on the cholangiogram. In these cases, it may be necessary to dissect the cystic duct down the common bile duct junction in order to obtain an adequate closure below the level of perforation.

We have experienced three common bile duct perforations during 350 cases (0.8%) of instrumenting the common bile duct. Two of these injuries were guidewire perforations through friable cholangitic common bile ducts. In neither case did a bile leak develop. Further occurrence of this complication has been avoided by the use of an extremely floppy-tipped guidewire. In the third case, a 5F whistle-tipped ureteral catheter failed to turn the corner into the distal common bile duct and penetrated the left wall of the common bile duct. This was repaired with a single interrupted suture and protected with a drain. There was no further leakage.

Alternatives to Cholangiography

Intraoperative ultrasonography has been utilized for evaluation of the common bile duct during open cholecystectomy.[16] Some argue that ultrasonography is more sensitive than cholangiography for detecting bile duct stones, and can be performed without the risk of bile duct injury, misidentification of anatomy, contrast reaction, or radiation exposure. The latter benefit is most relevant in pregnant patients. The use of ultrasonography in determining laparoscopic biliary anatomy appears promising.[17] It is unlikely that the current generation of surgeons will be as comfortable with ultrasonography as they are with cholangiography, but the prospect of defining biliary anatomy before performing potentially damaging dissection is enticing.

It is conceivable, but less likely, that choledochoscopy could supplant cholangiography. Conceptually, a choledochoscope no bigger than a cholangiocatheter is inserted through a cystic ductotomy into the common bile duct. The distal duct is then rapidly examined, and the endoscope is subsequently turned up into the liver via an articulating mechanism to examine the intrahepatic radicals. Flexible choledochoscopy is reported to be more accurate than cholangiography in successfully identifying retained stones after bile duct exploration. Just as upper endoscopy has largely replaced the barium examination, so choledochoscopy could replace fluoroscopy with future advancement in technology and skills.

Routine versus Selective Cholangiography

The benefits of routine fluoroscopic cholangiography are that it prevents bile duct transection by illuminating confusing anatomy; detects unsuspected stones; reduces unnecessary preoperative ERCPs; and facilitates training of surgeons in the performance of cholangiography, enabling them to become adept at accessing the common bile duct for stone extraction.

Digitally processed fluoroscopic cholangiography is generally capable of diagnosing all common bile duct stones 1 mm or greater, making it an extremely sensitive examination. It has been argued that routine fluoroscopic cholangiography is unnecessary because unsuspected stones will *always* cause ductal dilatation (as measured by ultrasound) or elevation of pancreatic or liver enzymes. The truth is that such preoperative indicators are present in only about one half of patients with common bile duct stones.[10] While the majority of these stones will be passed without clinically significant sequelae, some overlooked stones will cause cholangitis, biliary obstruction, or pancreatitis. It is impossible to predict which stones will be problematic. Thus, it seems prudent at the time of cholecystectomy to utilize routine cholangiography to aid in the identification and removal of all common bile duct stones 2 mm or greater in size.

The frequency of unnecessary preoperative ERCP falls dramatically when surgeons have the ability to confidently perform operative cholangiography. No matter how high the clinical suspicion of choledocholithiasis, half of all retrograde cholangiograms will fail to show bile duct stones.[18] Before surgeons became adept at performing operative cholangiography and bile duct stone extraction, the rate of unprofitable ERCP was as high as 85%.[19] Routine cholangiography offers the surgeon the opportunity to develop transcystic bile duct exploration techniques during easy cases so that unsuspected stones or large stones apparent preoperatively can be removed at the time of laparoscopic cholecystectomy. Routine cholangiography in training programs will ensure that residents become as facile with cholangiography as with cystic duct dissection and gallbladder resection. A surgeon who is incapable of performing a laparoscopic cholangiogram is capable of performing only half of a routine cholecystectomy.

The most persuasive arguments for selective cholangiography document the high expense of routine cholangiography (operating room time, radiologist, and equipment fees) and the infrequent revelation of useful information. It has been reported that, when cholangiograms are performed selectively, common bile duct stones and biliary anomalies are overlooked in $< 1\%$ of cases.[4–6] However, our experience demonstrates that the incidence of strategic information missed with selective cholangiography is closer to 5%.[14] A third argument for the selective use of cholangiography is the frequency of false-positive results (20%), obligating unnecessary duct exploration or ERCP. As previously discussed, fluoroscopic cholangiography largely eliminates the false-positive cholangiogram.

Conclusion

Laparoscopic surgery has offered us the opportunity to re-examine our approaches to many standard surgical disease processes. This examination has been extremely fruitful and has enabled us to look outside of traditional surgical practice to find new ideas applicable to the problems of laparoscopic surgery. From the radiologists and gastroenterologists we have discovered fluoroscopic cholangiography. Fluoroscopic cholangiography is safe, easily applied, and capable of revealing most biliary pathology. In justifying the acquisition of equipment to perform routine fluoroscopic cholangiography, it should be remembered that the cost of a single hepatic bifurcation bile duct transection, including medical and legal expenses, is at least twice as high as the cost of a digital fluoroscopic unit. If fluoroscopic cholangiography is capable of preventing even one of these injuries per machine sold, it is well worth the price of technology.

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37
Use of Intraoperative Ultrasound in Laparoscopic Liver Surgery

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Even intraoperative exploration of the liver can be difficult due to its large volume and the intrahepatic vascular pattern that is not represented on the surface. Tumors situated deep inside the liver are difficult to assess visually or by palpation. Understanding the topographical relationship of the Glisson's pedicles (portal triad and hepatic veins) is indispensable in modern hepatic surgery. However, the absence of corresponding resemblance between the portal triad and hepatic veins, and the lack of anatomical landmarks on the surface render the appreciation difficult.[1] These difficulties led to the rapid development of intraoperative ultrasound in conventional hepatic surgery.[2] Ultrasound is now being used in laparoscopic liver surgery.

Equipment for Laparoscopic Ultrasound Scanning

Ultrasound Probes

The presence of pneumoperitoneum precludes the use of percutaneous ultrasound examination during laparoscopy. To circumvent this, specially made ultrasound probes that can be passed through a 10- or 12-mm trocar (Aloka or Bruel and Kjaer probe) may be used. These probes must have a frequency of 5 MHz and the ability to be resterilized. Ideally, the transducer end of the probe should be modile in the sagittal plane (Bruel and Kjaer probe) in order to permit a snug application of the transducer to the liver. This would allow the "plane of cut" to be varied. Scanning can be done in the coronal plane.

Biopsy Needles

A 14-gauge needle is used that is 30 cm long and can be passed through a 5-mm airtight reduction sleeve. The main difficulty is determining the point of entry of the needle in relation to the position of the probe. One other difficulty is that the needle is often not visible ultrasonically. Its round surface causes reflection of echo in all directions with very little returning to the probe. However, the echo reflection can be improved by tarnishing the tip. The surgeon must follow the progression of the needle step by step to ensure that it penetrates the lesion.[6]

Anatomy

Anatomy of the Liver

The liver can be divided into eight segments that are functionally independent. They receive their own set of arterial and portal venous branches. They are also drained by their own hepatic veins and bile ducts. The arterial branches and the portal venous branches travel to their respective segments accompanied by a bile duct. These are called the Glisson's pedicles (portal pedicles), and each is surrounded by a fibrous sheath that is continuous with the hepatic capsule. This fibrous sheath penetrates into the liver with its vessels. The Glisson's pedicles provide vascular supply to the hepatic parenchyma. Their routes are different from those of hepatic veins, which are responsible for the vascular drainage. The separation of the liver into segments follows the division of Glisson's pedicles inside the liver parenchyma. Each of these segments can be treated independently without compromising the vascular supply and the function of other segments. This is the basis of modern hepatic surgery.

Ultrasound Anatomy

The Hepatic Veins

The hepatic veins can easily be seen converging and joining the upper end of the retrohepatic vena cava. Their walls are thin or invisible. Their positions define the sectors of the liver. The plane between the middle hepatic vein and the inferior vena cava can be easily located (main scissura dividing the two livers supplied by the left and right portal pedicles). The main scissura is almost sagittal, slanting slightly inward to the left. Behind the right hepatic vein, which is practically in the coronal plane, is the posterior sector. The anterior sector lies between the middle and the right hepatic vein. To the left of the middle hepatic vein is segment 4, which is limited laterally by the umbilical fissure. Anatomical variations occur frequently in hepatic veins. One of the more common variants (> 10%) with therapeutic importance is the presence of an inferior right hepatic vein. It joins the inferior vena cava below other hepatic veins, having run a parallel course to that of right portal vein.[5]

The Glisson's Pedicles (Portal Pedicles)

Glisson's pedicles can be found at the hilar region with their branches radiating toward the liver parenchyma. The pedicles are wrapped in a thick hyperechogenic expansion of the Glisson's capsule. The left and right hepatic ducts and their convergence can be seen in front of the portal bifurcation. They measure 5 mm in diameter at this level. Further up in the liver parenchyma, bile ducts are not normally visible. The branches of the hepatic artery can be detected only in the hilar region. The use of Doppler or Color Doppler can facilitate their detection. The branches of the portal vein are prominent and they are the element of the Glisson's pedicle, which can be followed deep into the liver parenchyma.

The left portal pedicle, after an initial transverse course, turns anteriorly at the posterior end of the umbilical fissure. It runs forward into the round ligament scissura and ends in a cuff that is continuous with the round ligament anteriorly. It is here where the branches are separated on the right side into segment 4 (there can be as many as four branches) and there is another branch to the left side of segment 3. The branch to segment 2 arises posteriorly as the portal pedicle turns forward. The right portal pedicle has a short segment of 3 to 4 cm, running more vertically It divides into an anterior and a posterior branch. The anterior branch gives off two branches: one inferior for segment 5 and a superior one that is often short and gives rise to three further branches for segment 8. The posterior branch divides correspondingly into two branches for segment 6 (inferior) and segment 7 (superior). These intrahepatic portal triads (Glisson's pedicles), in conjunction with the hepatic veins, enable the surgeon to define the segmentation of the liver. Recognition of these segments, therefore, plays a fundamental role in the study of anatomy.

The Hepatic Morphological Variation

In the cirrhotic liver, there may be segmental atrophy and hypertrophy simultaneously. This can cause a significant distortion to the liver anatomy. Knowledge of this particular variation is indispensable when surgical resection is being contemplated.

Tumor Detection

Deeply situated lesions are usually more difficult to assess as they may not appear on the liver surface. This may be equally difficult during laparoscopy even with thorough preoperative investigations. Intraoperative ultrasound scanning will allow the tumor to be detected, assessed, and more importantly, help to guide a biopsy needle for obtaining the histological diagnosis.

Clarification of the Relationship Between the Lesion and the Intrahepatic Vasculature

The study of the relationship between a tumor and the different intrahepatic vascular structures allows the anatomical topography of the lesion to be clarified. This segmental localization of the lesion is made by an accurate analysis of its position in relation to various intrahepatic vessels, the inferior vena cava, the gallbladder, and the round ligament.

Benign tumors never cause venous thrombosis but are often responsible for vascular compression with or without deviating the routes of the vessels. In addition to causing vascular compression, malignant tumors may invade vessels. Hepatocellular carcinoma can also give rise to tumor thrombus in the portal or hepatic veins that may grow against the flow in the lumen of the vessels and are easily identified on ultrasound scanning.[7]

Therapeutically, it is important to assess whether or not the lesion is close to, or invading, important vascular structures. For the posteriorly placed tumor, it is easy to assess accurately its position relative to that of the inferior vena cava, and the caval junction with the hepatic veins. These findings are important in planning the type of surgery and they allow the surgeon to anticipate potential difficulties during resection.

Detection of Unexpected Tumor

Intraoperative ultrasound scanning permits detection of lesions that may have passed unnoticed by the preoperative investigations. In a recent study, we found that intraoperative ultrasound examination is more sensitive than preoperative ultrasound scanning, computerized tomography scan, or arteriography.[8] This enhanced sensitivity comes from the fact that a higher frequency probe can be used that allows higher resolution, the ability to apply the probe directly to the surface of the liver, and more variable planes of cut, can be used to examine the liver.

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38
Future Developments

38.1 Retrieval Systems in Minimally Invasive Surgery

David Rosin

With the advent of video-assisted laparoscopic surgery, surgeons have started to perform all the operations that were performed during conventional surgery. One of the greatest problems encountered has been the difficulty of removing infected organs and bulky tissue. Laparoscopic surgery lends itself to reparative operations such as Nissen fundoplication when there is no need to remove any tissue. The removal of small organs is also easily performed through the usual port incisions of 5 or 10 mm. However, the need to enlarge these incisions to remove more bulky tissue has not been popular to "true laparoscopists" who feel "cheated" that they have managed to perform the operation through tiny incisions, then had to extend one of these to facilitate organ removal. Moreover, patients have come to expect that laparoscopic surgery means "keyhole surgery" and dislike the idea of any enlargement of the port sites. However, there is no doubt that in some operations the surgery is best performed in what has become known as "laparoscopic-assisted" operations. This is especially true in surgery of the large intestine where mobilization of the colon and rectum can be performed laparoscopically, but then a small incision must be made to remove the tumor. This is not only necessary for most colectomies but also oncologically sound.

It is vital that surgery for malignant conditions not be compromised by attempting to remove organs through inadequate incisions. There have been worrying reports of port site recurrences, and when removing left-sided colonic tumors through the rectum, of local seeding. However, it is possible to remove bulky tissue using retrieval systems, with or without morcellation.

Definitions

Laparoscopic surgery is when all surgery is done through ports, the number being dictated by the complexity of the operation. If an organ or tissue needs to be removed, then it must be removed via one of these port sites without extension. *Laparoscopic-assisted surgery* is an operation where the organ may be fully mobilized and then an incision made in the anatomical site most convenient for its removal. Examples include splenectomy and right hemicolectomy.

History of Retrieval Systems

When general surgeons took up laparoscopic surgery, the most commonly performed operations were cholecystectomy and appendicectomy. During the learning curve, many surgeons made holes in the gallbladder with a resultant escape of calculi, and they found it tedious to remove these particles, singularly or by suction. Therefore, various retrieval systems were used such as a condom, a sterile glove or the finger of a sterile glove, the sterilized bag in which the cholangio-catheter was packaged, and other available materials. The art of "bagging" the gallbladder, in some hands, became routine. For others, placing the gallbladder into the bag was only used after a hole had been made, or if the organ was rather bulky. The advantage of placing the gallbladder in a bag was that much more pull could be exerted on the bag without a rupture, when it was brought through the anterior abdominal wall. The use of a bag to retrieve the appendix became popular as the surgeon found that if he could not pull the freed appendix out through a 10-mm cannula, he was faced with bringing it through the anterior abdominal wall and possibly causing infection. Therefore many surgeons became practiced in placing the appendix into a retrieval bag and removing it.

Since these early days, many manufacturers have developed both small and large retrieval bags, with a variety of methods of closing them once the organ was placed inside. It is interesting that despite all these new retrieval systems on the market, there has been a recent article on the use of freezer bags. Dr. Glasser[1] has written about the use of everyday freezer bags, preferably the ones with "blue and yellow make green" seal. Dr. Glasser uses freezer bags because condoms, and the special bags commonly used to remove gallbladders, were too small for large ovarian masses. Secondly, he found that freezer bags, even with the cost of sterilization, were cheaper than manufactured bags. Dr. Glasser pointed out that there was a specially designed net for removing a large ovarian mass laparoscopically, but its cost was about $105. Glad freezer bags are not only much cheaper but they have a thick upper band that aids rolling for insertion into the laparoscope, and a zipper seal that is blue on one side and yellow on the other. The colors make the clear bag easy to see in the abdomen, and they are useful markings for the surgeon and the assistant. Gas sterilization is effective, and if done in large quantities, the cost is $1.35 per bag.

Present Retrieval Systems

There are many different types of retrieval bags that are produced by various companies in different sizes. Some bags are a simple, open bag in different sizes, while others have a prestrung suture at the opening so that once the organ has been placed into the bag, it can be closed in the same manner as a pre-tied Endoloop. Many bags are made out of plastic and are not very strong, so that traction can cause the bag to burst. When dealing with malignant tissue, it is vital that the bag used is impervious. This is also important when removing splenic tissue that could exude through the bag and implant into the omentum.

The use of a large 33-mm port has been described for removing an adrenal gland. However, this organ can be dissected using the normal ports and placed into a bag as previously described. Ethicon has developed an 18-mm port with a plastic container and flapper valve so that pneumoperitoneum is not lost when removing colonic and other bulky tissue.

The modified sigmoidoscope with valve has been described by Carey[2] and was first used for the easy removal of loose calculi, but can also be used for removing organs and bulky tissue.

Wolfe has manufactured a special operating rectoscope, with a large protuberant obturator, so that once the rectum has been cut across, this can be introduced without loss of pneumoperitoneum. The dissected free rectum and left-sided colon are brought down to the obturator, which is then removed. The specimen follows it out through this rectoscope. The obturator is replaced and the rectoscope withdrawn a little so that a staple can be placed across the rectum and an anastomosis effected.

Operations Necessitating the Use of a Retrieval Bag

1. Cholecystectomy
   If the gallbladder is very inflamed, or a hole has been made in it, or it is possible that there is a malignancy, then it should be placed in a retrieval bag prior to removal from the peritoneal cavity.
2. Appendectomy
   It is our policy to routinely place the appendix into a retrieval bag unless the appendix is thin enough to be extracted through a 10-mm port. The advantage of placing it in a bag is that wound infection should then not occur.
3. Splenectomy
   A small spleen is not very common but can occur with idiopathic thrombocytopenic purpura. The organ can be placed in a bag and the bag removed with the spleen intact. Usually, the spleen is markedly enlarged and then an incision has to be made to remove it once it has been dissected free. It can also be placed in a large, impervious bag and the neck of the bag brought out to the abdominal surface. It is then possible to morcellate the spleen using forceps, a finger, or the Cook morcellator. As the histology is not important, this is an acceptable practice. The surgeon must be extremely careful about spillage, as implanted splenic tissue can function later and cause subsequent problems.
4. Adrenalectomy
   It is preferable to place the gland in a bag, even though they are rarely malignant. However, the gland is quite fragile and it is better preserved in a retrieval bag.
5. Liver Resections
   When performed laparoscopically, this procedure is usually for small peripheral metastases. The danger of seeding is very possible and therefore the tissue must be placed in a bag.
6. Laparoscopic Nephrectomy
   When this is done for benign disease, rather like splenectomy, the organ may be placed in a bag and the organ morcellated within the bag. If performed for malignancy (it is debatable as to whether this is an oncologically sound operation), then the kidney must be placed in an impervious bag and if large, the incision will have to be extended to facilitate its removal.
7. Ovaries
   If removed as normal organs for the treatment of breast cancer, then they can be withdrawn through 10-mm ports. However, if there is any question as to whether there is malignant change, then they should be placed into an impervious bag and removed with

the bag. If the ovary is cystic, once in the bag, the cyst may be punctured to facilitate removal.

8. Uterus
Once dissected free, this organ may be either placed in the bag and morcellated within the bag, or passed through the vault of the vagina.
9. Gastric Resections
Whether for benign or malignant disease, the resected part of the stomach is best placed in the retrieval bag so that it can be examined histologically, even when a lesion is thought to be benign as in the case of leiomyoma. There is always a possibility that there may be malignant change (see complications).
10. Colectomies and Anterior Resection
We have changed our policy from performing these operations only by laparoscopy to performing laparoscopic-assisted resections. The real value of the laparoscopic approach for colonic surgery is mobilization, especially mobilization of the hepatic flexure in right hemicolectomies and the splenic flexure, when operating on the descending colon, sigmoid colon, or rectum. Occasionally, it is possible to do a colotomy for removal of a wide-based sessile polyp that cannot be removed colonoscopically. When this operation is performed, then it is possible to place the resected polyp into an impervious bag and remove it. The colotomy can be closed either by stapling or suturing laparoscopically.

    During a right hemicolectomy, the surgeon has to make a small incision, either in the right iliac fossa or right hypochondrium, depending on the situation of the tumor. Since the surgeon has to make a new incision anyway, we feel it is best to perform the mobilization laparoscopically and ligate the vessels if they are clearly seen. The division of the ileum and transverse colon and anastomosis is then performed extracorporeally, after the specimen has been removed. If the mesentery is very fatty and the vessels are not clearly seen, or it is difficult to tell if one is at the origin of the ileo-colic and right colic vessels, then these vessels are also dealt with through the small incision.

    When performing sigmoid colectomies and anterior resections, it is possible to bring the specimen out through the rectum. High ligation and division of the inferior mesenteric vessels is somewhat easier than vascular pedicles for right hemicolectomy. However, we do not feel it is oncologically sound to squeeze a malignant tumor out through the rectum and anus. For benign disease, it would be reasonable to remove the specimen through the anus but the common condition necessitating resection is diverticular disease and usually the bowel wall is thickened and the mesentery shortened. If the surgeon wishes to remove the specimen through the rectum and anus, it may be necessary to resect the sigmoid colon, then dissect it out to straighten it, so it can be passed out through the rectum and anus. We feel that a small incision adds little in the way of morbidity and is a much easier method that shortens the operating time needed to remove the specimen. In our unit, we perform only laparoscopically assisted colectomies and anterior resections.
11. Ilio-Obturator Lymph Node Clearance
This operation is performed as a staging procedure for prostatic carcinoma or as a clearance, for example, malignant melanoma. The dissected nodes are always placed in a bag prior to removal. A ligature should be placed at the proximal end to mark it for the pathologist.

Complications

There have been an increasing number of papers reporting incidences of port site recurrences and hernias. With the removal of bulky tissue through the port sites that are stretched and enlarged, especially in heavy people, it is difficult to close the fascia. If this can be done under direct vision, then port site hernias should not occur. The use of the Grice needle can make the placement of sutures under direct vision very much easier. It is our practice to use this method of placing the suture at the beginning of the procedure so that it can be ligated and ensure closure of the fascia at the end of the operation.

Even more worrisome is the rising incidence of implantation of malignancy in the port sites. There has always been implantation of malignancy into scars but these do not usually manifest themselves as quickly as malignancy within a small port site. In our unit, we have had two port site malignancies; the first was following laparoscopic cholecystectomy, when 18 months later the female patient returned with a hard swelling in the epigastrium. When removed it proved to be an ovarian cancer metastasis. The ovaries at operation had looked normal. The second case, which is more relevant to this chapter, followed resection of a leiomyoma that histologically was found to be a leiomyosarcoma. The resected gastric specimen with the tumor, was placed into a glove, which was then brought out through one of the 12-mm port sites. Unfortunately, with the tumor lodged in the port site, the glove burst. The gastric specimen with the tumor was retrieved with forceps but had been in contact with the abdominal wall. Seven months later, the patient re-presented with a large metastasis in that port site, which when resected was shown to be a leiomyosarcoma. It is imperative that when dealing with malignant tissue, the bags used are much stronger than those manufactured at the present time. It is vital that they be impervious. During this early phase of laparoscopic oncological surgery, there will probably be more cases of port site metastases.

The Future

Instrumentation and retrieval systems will continue to improve. The use of the culdoscope in female patients (placed through the posterior fornix) may be a future method for removal of bulky tissue. The possibility of placing a resected specimen into a large bag within the peritoneum and then performing laparoscopic surgery within that closed bag may be something for the future. If a right hemicolectomy specimen, for example, was placed into a bag and the neck tightened around the telescope and instruments, then the surgeon might be able to dissect out the mesentery of the colon and withdraw the lymphatic tissue in a second bag used for staging. It might then be possible to morcellate the colonic specimen and remove it in the bag. However, the retrieval bags will have to be much stronger before this sort of surgery can be performed. The time taken to perform laparoscopy in the bag may not be justified. Inflicting a small incision to facilitate removal of a malignant organ is a small price to pay to ensure a proper cancer operation. It is imperative that surgeons do not abandon the well-laid principles of oncological surgery in an attempt to perform the operation laparoscopically.

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38.2
Stereoscopic Imaging for Laparoscopy

David Southgate

There have been rapid advances in the ability of surgeons to perform fine laparoscopic procedures over the last few years. One of the major factors that made this possible is the availability of high-sensitivity, high-resolution miniaturized video cameras, together with displays of a matching quality. The surgeon now has the ability to see fine detail with an accurate color rendering. Artificial enhancements are also available, if needed. Color, contrast, or the appearance of boundaries can be changed to improve visibility of various features. Missing, however, is the direct perception of depth. With practice, the effect of camera motion, or the change of appearance due to the limited depth of camera focus, can be used to give some depth information; but the depth perception that is given by stereoscopic vision has not been available. This feature can be of enormous advantage. Emergency action often requires an immediate perception of depth; without stereoscopic vision, such quick action could involve increased risk of morbidity and mortality.

The situation has now changed. A number of manufacturers have recently developed systems that can provide fully stereoscopic displays. Work has proceeded on three components of the total system—the camera and optical system that provides an image pair, the signal processing, and the image display. Some of these systems are now commercially available.

Several issues should be considered in evaluating a stereoscopic presentation. Ideally, such a presentation should give an accurate replication of the internal organs, at least those within the camera field of view. The magnification should be adjustable, without distorting the shape of the objects. The display must be bright, and must have high resolution (that is, capable of showing fine detail). The means of viewing the display should not substantially interfere with the visibility of the surroundings. A completely convincing representation should also have motion parallax; that is, as the head of the viewer is moved, it should be possible to "see around" the various organs, at least to some extent. The display should be autostereoscopic, that is, not requiring any special glasses. Needless to say, stereoscopic displays that have recently become available do not have all these features. They have good basic depth perception and high resolution, the main requirements for fulfilling the essential needs of stereoscopy. They do, however, require special glasses, and are not as bright as ideally desirable.

We use the term *stereoscopic* to indicate the generation of a complete illusion of depth. The term *3-D* (three-dimensional) is often used, but in medical terminology, it more frequently implies the rendering of a two-dimensional picture to appear solid by appropriate shadowing and perspective. It can also mean the presentation of a complete set of tomographic slices. Fully stereoscopic presentation of the type we are considering here creates separate images in each eye that differ according to the parallax effect. Systems also exist that create enhanced depth perception by exploiting special lateral motion effects or by giving low-frequency alternate image presentation on a screen. These are not suitable for high-quality laparoscopic presentations.

There are two ways in which stereoscopic systems can operate so that each eye sees only the appropriate image—sequential and concurrent.

Sequential Viewing

The most economical way to implement stereoscopic displays is based on field sequential viewing. This mode is the one favored for commercial products. Systems of this kind involve light shutters that employ liquid crystal (LC) films. A cathode ray tube (CRT) display screen is arranged so that it alternately shows left and right eye views; the light shutters are alternately switched on and off in synchrony. In this way, each eye receives the correct view for half the time and is cut off for the other half. If the frame rate of the display is fast enough, with a period that is short compared with the integration time of the eye, then a continuous image is seen.

Figure 38.2.1 shows the glasses used for one version of

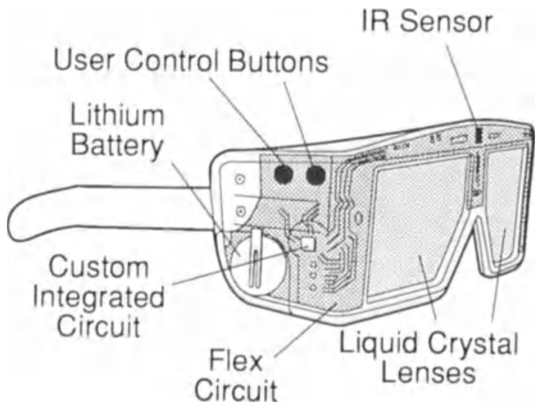

FIGURE 38.2.1. Eyewear for viewing sequential stereoscopic presentation. (Courtesy of Stereographics Corporation.)

the system, as supplied by the Stereographics Corporation. The light shutters are contained within the glasses and they can be switched on and off in time periods as short as several milliseconds, which is much faster than the eye can perceive transitions. The glasses need to be activated, requiring both a small amount of power and a synchronizing signal from the display system. A convenient way of sending this signal is by an infrared beam, in the way that a TV remote control operates. A pulse is transmitted, following the scan of one frame on the screen, which then closes one eye shutter and opens the other. Although the glasses contain a battery and electronic circuits, they can be quite light; current versions weigh about 3 oz.

An alternative version of sequential display uses an active polarizing sheet that covers the whole screen. The viewer then wears glasses that are passive; they can be lightweight and can easily be combined with prescription glasses or safety goggles. The active sheet contains an LC film that can switch so that it passes light alternately polarized in different directions. Either linearly or circularly polarized light may be used. For linear, the directions of polarization are orthogonal, while for circular, the rotation directions are opposite. The effect on the viewer, if operation of the components is ideal, is identical to that obtained with active glasses. A display of this kind is marketed by Tektronix, Inc. The active sheet that switches the polarization is known as a pi-cell, which is a type that can switch sufficiently fast to follow alternate fields. Circular polarization is employed. The display is in full color and has satisfactorily high resolution, but is much less bright than an equivalent standard monitor that would be used for a two-dimensional display.

Sequential stereoscopic systems require the use of displays that have fairly rapid response. If they do not, one display frame will persist so that it overlaps the time of the following frame. In this way, it can become visible to the wrong eye. This produces an annoying phenomenon known as "ghosting," which is particularly noticeable if a bright object is presented on a dark background. For a high-quality picture, the ghost should be $< 1\%$ of the brightness of the true image. This means that in CRT displays, the phosphor must have short persistence. Special CRTs are needed; the phosphor used in most television tubes, for instance, has too long a persistence. A technique developed by Tektronix uses an LC shutter divided into horizontal bands, with only the band covering the travelling spot open at any time. Much of the delayed phosphor emission that could appear as a ghost can be blanked out in this way.

It is usual in sequential displays for two cameras to be used, both operating continuously. The frames generated by these cameras are then interleaved, so that they alternate with a combined frame rate of twice that of each camera. To enable this, it is necessary to provide a memory frame store for each camera. The display is then arranged to have a fast vertical scan rate, typically 120 Hz, which is twice the camera speed. The information in each frame can then be fully displayed. The eye sees alternate frames at the original rate so there is no added flicker. A system with reduced performance can also be constructed. The display runs at standard TV rate, switching from one camera to the other so that alternate frames are discarded. This produces an acceptable effect only in dim displays; with a brightness desirable in an operating room, a distracting flicker is very evident, so that such reduced performance systems are not acceptable for laparoscopy.

Concurrent Presentation

A second type of display uses two separate sources that continuously generate both left and right eye images. Presentations of this type have been used in specialized movie theaters for the better quality 3-D presentations. The two images must be combined so that they appear on the same screen. This is done either by projection or by viewing one image in reflection from a partly reflecting mirror and the other directly through the mirror. Such arrangements are shown in Figure 38.2.2. The two image displays each have a polarizer in front and the images are selected for each eye by glasses that have the corresponding polarization. Either linear polarizations in orthogonal directions, or circular polarization having opposite rotations, may be used. Again, the passive glasses may be used in conjunction with vision-correcting glasses.

The two-monitor display is more cumbersome than the one monitor required for the sequential display. It does however have some advantages. There is no need for special short-persistence phosphor tubes, and ghosting will not be generated from phosphor persistence or from light shutter delay. Standard scan rates can be used so that

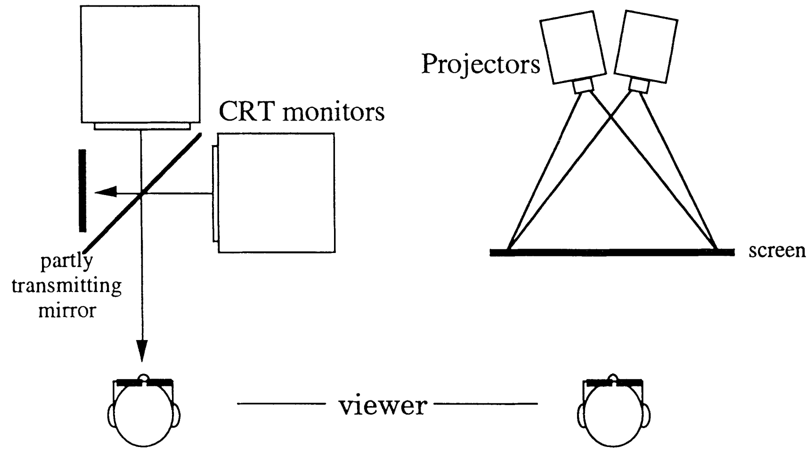

FIGURE 38.2.2. Two types of concurrent stereoscopic displays.

cameras can be directly connected with no intermediate signal processing. The total system cost is therefore not necessarily higher than for a sequential system.

The projection display, as shown, requires good registration of the two images. Current high-brightness projectors use CRTs and the problem of obtaining and maintaining registry between the two sets of CRTs is quite difficult. In the future, this problem may be alleviated, since liquid-crystal-type projectors, with high resolution and moderate brightness are now becoming available. These are easier to align than CRT projectors. An image-splitting mirror arrangement, which makes the incidence of the two projectors coaxial, may be needed to avoid the problem of image mismatch due to the different screen angle incidence of the two projectors.

Liquid crystal projectors have the added benefit of generating light that is already polarized, so no light need be thrown away by an additional polarizer. The distinction between left and right images is achieved by a polarization-rotating sheet, which does not absorb light. If adapted for projection on a relatively small screen, say 2 ft wide, the display will be bright, so that even after reduction by the viewing glasses the perceived brightness can be 100 foot-lambert. This compares with a brightness of about 40 foot-lambert for paper in a well-lit office area.

Comparative Merits of Displays

Both the sequential displays and the concurrent polarized displays have the potential for high resolution. As the resolution is increased, the cameras that form the images must have an increasing number of picture elements, and the spot that scans the display must be reduced. Both cameras and color CRTs will permit a high enough resolution to see all the features that are needed for surgical procedures. When shown on a screen 18 in. across, viewed at 6-ft distance, the limitation on resolution is then that of the eye rather than that of the display. There is, however, a limitation on brightness. This is so even for directly viewed monoscopic displays. The small spot size associated with high resolution implies low electron beam current. High-resolution color CRTs therefore typically have brightnesses that do not compete well with the illumination in an operating room.

As mentioned previously, for a stereoscopic display, brightness is reduced from that of a directly viewed CRT. Similar losses occur for both sequential displays and for many concurrent displays. The initial selection of polarized from unpolarized light typically passes only one-third of the light generated by the display. The second polarizer, when in open orientation, may only pass about two-thirds of the remainder, and there is a further factor of one-half, since each eye only views half the time, or because the beam-splitting mirror only passes half the light.* The net viewed brightness is 12% of the original. The situation holds even for light-shutter glasses; they also operate on the principle of crossed polarizers. Somewhat more efficient polarizers have been used in the glasses, illustrated in Figure 38.2.1, for which the net viewed brightness is about 16% of the original.

Efficiency values of this magnitude result in rather dim displays. High-resolution color displays have a maximum directly viewed brightness of 40 foot-lamberts; the stereoscopic filtering will reduce this to about 5 foot-lamberts. This compares with about 50 foot-lamberts needed to give good visibility in a well-lit room and 200 foot-lamberts, a goal for high-resolution medical displays such as transmission x-radiographs. An order of magnitude increase in tube brightness is therefore needed to produce a fully acceptable display. Unfortunately there are many tube design considerations that make this unlikely in the

*It is possible that this factor could be increased by use of polarizing reflectors. Unfortunately such polarizers currently do not have a sufficiently wide color band or range of viewing angles to be acceptable.

near future. In contrast, projection displays based on liquid crystal or other pixel-based technologies do not have this limit.

If the surgeon is wearing glasses that pass only part of the light, the ambient room lighting must be increased to maintain the optimum visibility of the environment. If the glasses are passive polarizers, a threefold increase is needed. The shuttered glasses, as mentioned before, have a smaller average transmission factor, and consequently, the ambient lighting needs to be increased by a factor of as high as six to maintain ambient visibility. It seems more likely that ambient brightness would be increased by a smaller amount and that some reduction in visibility would be tolerated. Careful consideration must be given to this trade-off when installing such a system.

There are further, possibly limiting, features of displays using polarizing glasses. One is the need of the viewer to always hold his head level. If a linearly polarized system is used, then a tilting of the head begins to produce the ghosting referred to before. Ghosting does not exceed 1% until the head tilt reaches about 8°, which is not a severe restriction on freedom of movement. For both linearly and circularly polarized systems there is also a problem of mismatch between the direction of image disparity and the interocular direction. Mismatch increases with head tilt and becomes troublesome beyond about 5°. A second feature of linear polarization is that real objects, particularly those that are partly reflective, can have a different appearance when viewed in the different polarized light presented to each eye. This difference can be distracting. The sequential display using active shuttering glasses does not have this limitation.

Ghosting is also an effect that has not been completely eliminated from the displays which use active filters on the CRT face. The problem becomes apparent when the screen is viewed from the side. For direct normal viewing, the ghosting is $< 2\%$, approaching the ideal maximum, but it becomes considerably greater when the view angle exceeds about 20°.

The relative performances of the three CRT systems that have been discussed are summarized in Table 38.2.1. Ambient light loss factor is the ratio of perceived room brightness without glasses to that with glasses. All values shown are only approximate. There is some room for improvement of performance, for example, by development of more efficient polarizers or polarization-sensitive reflectors.

TABLE 38.2.1. CRT stereoscopic system comparison.

	Sequential presentation		Concurrent presentation
	Shutter glasses	CRT face filter	Image-dividing mirror
Display brightness reduction factor	6	8	8
Ghosting %—normal view	1	2	< 1
angled view	1	> 2	< 1
added by head tilt	n	n	y
Ambient light loss factor	6	3	3

Projection displays show similar ghosting effects. If back-projection is used, the screen material and the type of polarization must be chosen so that no polarization change occurs by passage through the screen. Brightness, however, is not as limited as it is for CRTs of the shadow-mask type. It is possible that a stereoscopic display that approaches the ideal, using LC projectors, may be developed in the future. The cost of such a display, however, will probably be considerably more than that of the CRT display.

Camera Systems

The lenses of a stereoscopic camera need to be held with a well-defined spacing and orientation. For this reason, as well as to minimize insertion incisions, the optical paths for both stereoscopic channels are combined to pass through the same cannula. With a maximum diameter of 12 mm, to include both paths and also the illuminating fiberoptics, there is a challenge for the designer of the optical system.

There are a number of optical systems that have been developed by companies such as Olympus, Richard Wolf, American Surgical Technologies, and Welch-Allyn. These can involve optical relays with a number of sequential lenses in the endoscope tube; or coherent fiber optic bundles, with prisms at the endoscope tip, combining two images in one optical path; or they can involve separate miniature cameras in the endoscope tip.

Systems using relay lenses or fiberoptic bundles may have problems of reduced resolution or light transmission. Placing cameras within the endoscope overcomes these problems, although the arrangement incurs the cost of developing a specialized camera sensor. An endoscopic tip of this kind, soon to be available, is shown in Figure 38.2.3. As an alternative system, one camera can be used, rather than the two embodied in current designs. Image-combining shutters are employed to present alternate frames, the camera being run at twice the normal speed. An arrangement of this kind may allow higher resolution to be obtained.

As discussed later, it may be desirable to have a lens spacing of greater than the 12 mm that conveniently fits within the cannula. However, the provision of such extra spacing complicates the design. Moving parts and folded optics are needed to achieve this; such structures are likely to degrade the image. A clear need must be demonstrated before such designs become acceptable.

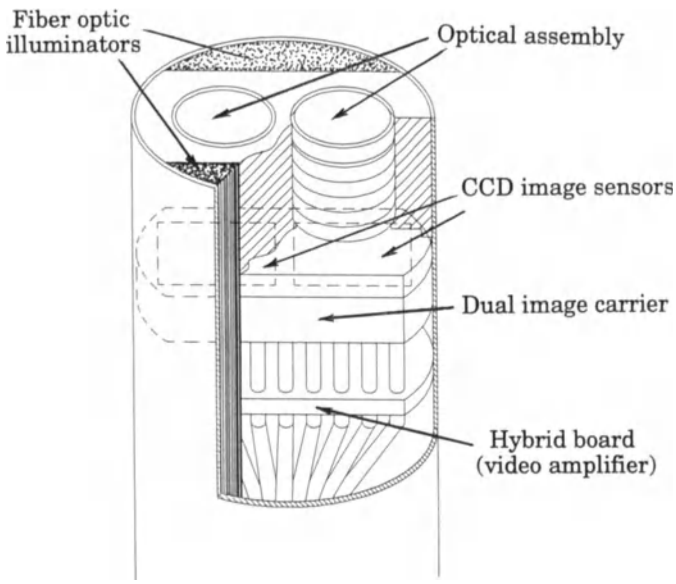

FIGURE 38.2.3. Endoscopic tip incorporating miniaturized video cameras. (Courtesy of Welch-Allyn Inc.)

Any of the endoscopic camera optical systems can be combined with any of the display systems, given a suitable electronic interface. Different commercial vendors have chosen systems having the particular merits they wish to emphasize.

Effigy Distortion

In all the displays discussed so far, each eye is presented with an image that does not change as the viewer's position changes. This produces artifacts in the appearance of the three-dimensional object as perceived by the viewer, often referred to as the *effigy*. The simplest of these is the apparent *shearing* of the effigy as the viewer's head moves from side to side. During an operation, it is not likely that this effect would cause much of a problem since the surgeon's head motion is not large. More severe can be the image distortion that occurs due to differences between the camera and the viewer's angular field of view, the convergence points of the camera and the viewer, and between camera spacing and interocular distance. If all dimensions in the viewer space are scaled up uniformly from those in the camera space, then the effigy will appear scaled up. In general, however, the camera field of view will be greater than that presented to the viewer. A usual angular field for a laparoscopic camera is 60°, while if a 15-in. high video screen is viewed at a distance of 6 ft, the angle is only 12°. Effigy distortion in this situation is unavoidable and the system needs to be designed to minimize the distortion.

Figure 38.2.4 shows the distortion of field that can occur for a display with the viewing parameters just quoted. The camera spacing is 5 mm, converged to a point 150 mm away. This illustration assumes a distortionless camera lens system, in which a flat uniform checkerboard pattern will be imaged as a uniform checkerboard pattern. The upper field shows the real scene as viewed by the camera, and the lower as perceived by the viewer. The crosses on the left side represent the positions of the camera lenses, or of the viewer's eyes. The crosses nearer the center are located at the edge of the plane on which the cameras converge and at the edges of the display screen. Distortion of this kind can be reduced by increasing viewing angle (increasing screen size or standing close to the screen) and by increasing lens spacing until the relative proportions of the camera field and the viewing field are similar. Convenience of insertion of the camera optics, however, dictates a reduced lens spacing.

In practice, wide angle lens systems used in laparoscopy also have very pronounced field distortions and the effigy distortion will be more extreme than shown in Figure 38.2.4. Reduction of this component of the distortion may require image warping, using electronic image processing. For instance, the peripheral parts of the image may be stretched. Although this is technically feasible, it would add substantially to system cost and is not being incorporated in any of the commercial products announced so far.

Although the distortion shown in Figure 38.2.4 appears in this presentation to be quite severe, it must be remembered that the human observer is capable of considerable corrective adaptation. The amount that can be tolerated depends to some extent on the familiarity of the object. For instance, if it is known to be a room with a rectangular floor, even a distorted representation can be perceived as rectangular. Less well-defined shapes, on the other hand, will be more difficult to correctly interpret and manipulation of such shapes as viewed in the distorted display may be difficult. In the design of a laparoscopic stereoscopic system, it is best to aim for the least distortion. Such design should be done in the light of research on the ability to manipulate objects viewed with distortion.

Autostereoscopic Displays

The ideal display is the autostereoscopic display because it does not require any headgear. Until now, those that show static photographed scenes have the best resolution and freedom from ghosting. Within a limited region, the viewer can move from side to side or forward and back; the effigy will not shear or distort. These displays provide a different image over a range of viewing angles. The images are interleaved in strips and viewed through a fine

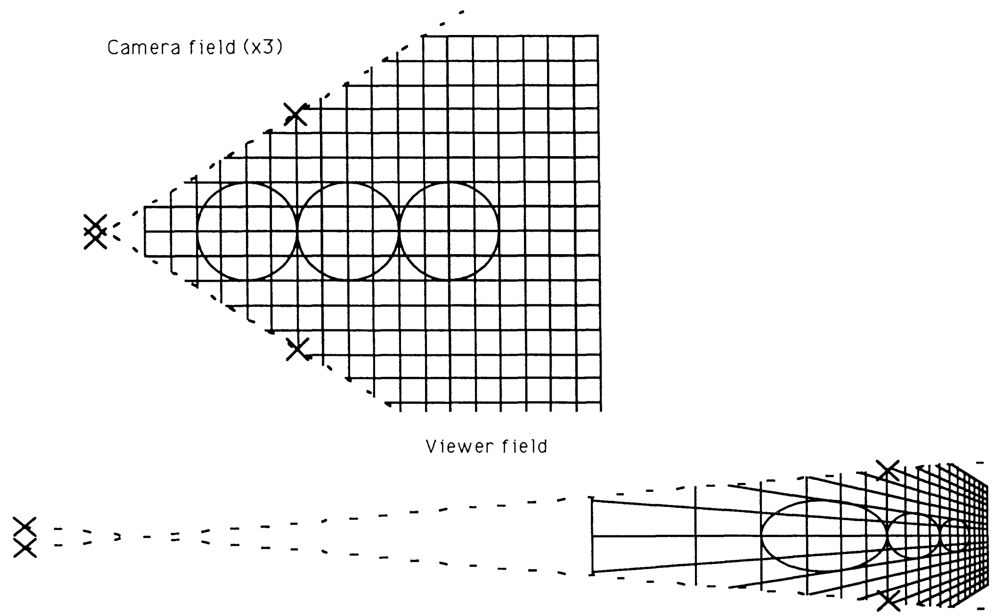

FIGURE 38.2.4. Field distortion of stereoscopic effigy.

grating or array of parallel cylindrical lenses, so that only one is seen at a time by each eye.

The ideal autostereoscopic design can be achieved only by substantially increased system complexity. If an image resolution is required that is comparable to that expected in two-dimensional displays, an extremely large number of images is required. As the depth of the effigy needed is increased and as the desired range of head motion is increased, the number of required images increases. For a high-quality presentation suitable for laparoscopic work, more than 50 images may be needed. Development work is currently proceeding on methods of generating all these intermediate images from a stereoscopic pair of cameras and on methods of presenting the images. Although there is no immediate prospect of providing such a system at a reasonable cost, the continuing drop in cost of complex image processing and display technologies gives hope that practical systems may be developed in the future.

Telepresence

One interesting use of stereoscopic imaging, currently under development, is combining the imaging with remote-controlled surgical instruments. If an effigy is produced within a volume, which is surrounded by various handles that remotely control the instruments, the illusion can be given that the handles are directly connected to the effigy; the operation is conducted on a virtual patient. A telepresence system could then consist of a worksite module, containing the instruments, cameras and other sensors, and the operator module. The surgeon can reach into a virtual operating space and work as if the patient were actually there.

Again, there are some special requirements. If the display is generated from a direct left and right image, the cameras must be accurately held in a fixed position if the virtual operating space is to connect to the instrument controls. The surgeon's head also cannot move much, otherwise the effigy location will be displaced. Decisions on the advantages of this kind of telepresence display will depend on the outcome of studies on the relative difficulties, if any, that a skilled operator has in adapting to operating with a standard stereo display.

Head-Mounted Displays

Head-mounted displays are widely used in various military applications. Special goggles that have small CRT or flat panel displays embodied can allow the presentation of a wide-angle stereoscopic view to the surgeon. This view can be dominant, or it can be seen on a transparent screen, so that is superimposed on the real world. The problems of image distortion due to limited viewing angle can now be circumvented, if appropriate warping is applied to the image.

At this point, we can begin to enter the world of fantasy, if we suppose that the display which is viewed is no longer a direct representation of the camera view, but can be highly processed. When this display is combined with other sensory inputs, such as touch from force-feedback instruments, the situation is known as virtual reality. One form of processing is that of image stabilization. This can be done by attaching head position sensors to the headset that locate the position relative to fixed external signal sources. It is now possible to present the internal body view, as seen by the cameras, in a transformed representation superposed on the direct view. This gives the illusion that the body has become transparent. Other modalities can also, in principle, be presented. For instance, a thermal camera might show the temperature of the organs.

The success of these developments in the near future is speculative. Unlike some military applications, where the image created is a fairly simple structure, the surgical image needs to be of high resolution. Information on image content cannot be lost during processing. It may be needed to re-create a stereoscopic view from a different angle or head inclination. Techniques of processing are still the subject of basic research. One might conceive of this work as leading to the ultimate display: a virtual reality situation where the surgeon can apparently walk inside a greatly enlarged body cavity, and using signals delivered through sensory gloves to the actual operating instruments, manipulate body organs. Such science fiction may eventually be attainable, but it is very difficult to make predictions on when it might become economically practical in routine surgical situations. Until such time, further study is needed to decide the potential value of such techniques and determine the optimum form of presentation.

Conclusion

Stereoscopic imaging for laparoscopy has now become a reality, at an acceptable cost. The images presented in systems now available will greatly enhance manipulative ability in critical procedures such as knot tying and dissection of closely underlying tissues. There are, however, some drawbacks, such as reduced display brightness and interference with normal vision due to the need to wear glasses. It is probable that brighter projection displays will be developed, at increased cost. However, the need to wear glasses will not be easily overcome. Looking further to the future, it is evident that the continuing decrease of cost of elaborate image processing techniques will make a wide range of transformed presentations available. It will ultimately be possible for a surgeon to call up any view of the operative region that is accessible to a camera and present it stereoscopically in any size or orientation, superimposed on past images taken in other modalities. It is for the medical community to decide which of these many imaginative possibilities will contribute most to effective surgical procedures.

38.3
Interactive Computer Training

Aly Sabri

Introduction

Dr. X is working on a simulation program for cardiovascular emergency treatment in a quiet phase during his weekend duty. His virtual patient has just suffered from ventricular fibrillation, visible from the change of the real-time ECG that is running in a window on the screen. Now he can choose from a series of treatment possibilities the one he feels is best. Even after repeated dose adaptation, the medicine does not show any effect. Dr. X decides on defibrillation.

With this program, Dr. X is able to further his education and learn with realistic situations. The computer stores the physician's actions and analyzes them. Looking at the patient record on the program, Dr. X can receive feedback of his treatment strategy at any time. The results of the simulation can be stored and used for maintaining Credits of Medical Education (CME). What is computer-based training (CBT)? In this example—which is not fictitious—the two main features of computer-based training programs are the combination of several media (multimedia) and the interface between user and program.

The considerable increase in performance of computers and the resulting software developments allow physicians to work simultaneously on text, graphics, pictures, animation, simulation, video, and audio. The software allows the user to enter into a dialog with the machine while controlling the programs and then seeing the results of his actions immediately. As a consequence, the unidirectional learning path offered by the book has become a bidirectional, like the format of seminars and discussions. Lower prices have made this technology available to everyone.

A Program Example

The "LapChole" trainer is a program that explains the fundamental principles of laparoscopic cholecystectomy. The program is designed as an electronic book to make the navigation and orientation for the user as easy and intuitive as possible. It runs on Windows and Macintosh computers without any additional hardware. The "book" contains chapters on epidemiology, anatomy, physiology and pathology of gallstone disease, comparative representation of the conventional and laparoscopic surgical procedure, as well as a quiz and a vocabulary section. An extensive introduction to this new surgical procedure is given on 130 screen pages with text, pictures, animation, and digitalized video clips. The user can choose his learning path freely.

Through the use of the computer, it is possible to show complex facts such as the preparation of the gallbladder. Apart from the description by text, the action is shown by a schematic animation and by a video sequence in real pictures. A speaker explains what is happening. Graphically enhanced still pictures emphasize details in the video. Extended pieces of information can be retrieved from the vocabulary section via mouse click. Figure 38.3.1 shows a page of the LapChole trainer.

In order to carry out successful laparoscopic surgery, it is crucial to know topographic anatomy. The laparoscopic methods have added new, topographically more complex, views of the surgical situs to the traditional anatomical views. In addition, the view through the laparoscope is somewhat limited. In the CBT program, the learner himself, contrary to working with an atlas or a video, can select his view of the anatomical structure in the 3-D model via mouse click and can study the corresponding

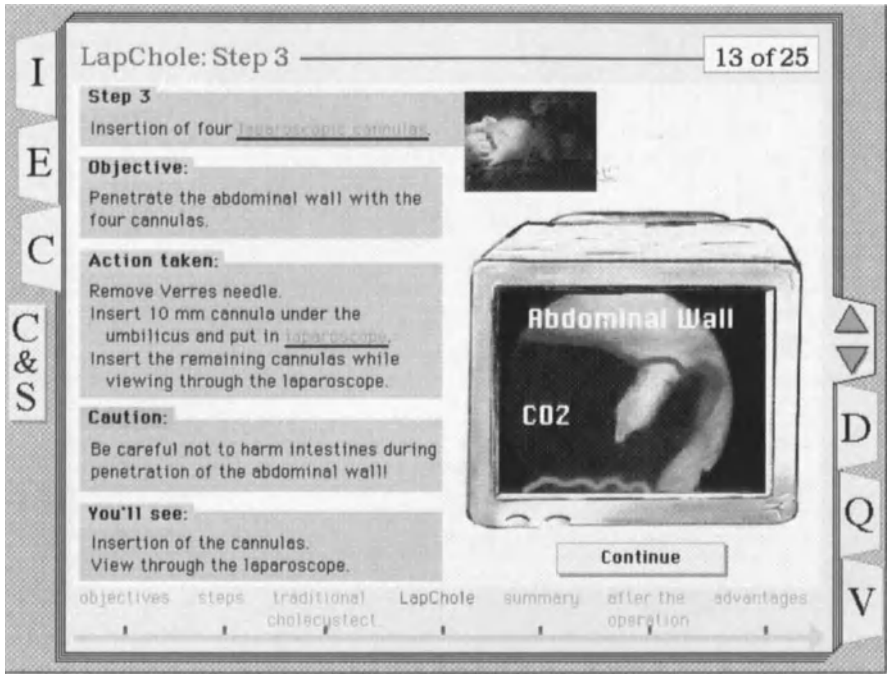

FIGURE 38.3.1. A screen page of the LapChole trainer. The subject is the penetration of the abdominal wall. The text explains what is happening, and the underlined text leads to the vocabulary section via mouse click. A still picture can be seen in the video window.

two-dimensional view through the laparoscope. In further applications, the sequence of the numerous surgical steps, the instruments and their use, as well as the frequent complications and their mastery, can be learned. These programs can be produced with different levels of individual difficulty for medical doctors, nurses, and medical students.

User Interface and Media

User interface is defined as the interface between operator and computer. This interface contains, on the one hand, the operation elements (keys, menus) that are operated with a mouse; on the other hand, it displays the reactions of the computer (in a dialog box). The graphical user interfaces have made the PC an easy-to-use tool for a broad level of non–computer-literate users.

Contrary to a book, where the reader knows where he or she is situated, and how long the volume is, the amount of information and the structure of the digital data remain concealed from the computer user. The difficulty lies in creating the user interface in such a way that navigation and orientation in the space of knowledge are made easier for the user. *Navigation* is the movement within the space of information (comparable to page turning in a book). *Orientation* shows where the user is situated within the space of information, and which pieces of information are available (comparable to the page number and a book's index).

The development of graphical user interface made the simultaneous use of text elements, graphics, images, animation, simulation, digitized video, and audio possible. Texts, images, and graphics show the classical media which are known from the print medium in order to impart information. In CBT programs, these elements have to be transformed in a way that facilitates interactivity, thus using the computer's versatility. When using these elements, the computer is only able to make use of its advantages over the print medium if the main attention is given to interactivity.

By means of animation generated by the computer, complex facts can be shown in a graphic way. Animated graphics that visualize defined facts are moved. Digitalized video enables the integration of, for example, real surgical sequences. Simulations have a special position within the mentioned elements as they are dependent on the action of the user. During simulation the user can, for example, set the blood pressure and pulse within a circulatory model and then receive the dependent parameters of the system that have been calculated by the computer. Audio is used for further explanation of animations and video.

This media mix brings up two problems: How are the mentioned elements connected and which facts can be shown with which medium in an optimal way? These questions have to be solved for each application individually as they depend very strongly on the contents. It is expected that, analogous to the book, a certain typology will develop for the respective CBT application.

Functionality

The functions of CBT programs can be divided into two groups: navigation and interaction. With browsing, the easiest form of navigation, one can proceed in a linear fashion from one information unit to the next one. Hyperlinks connect associated information units, that is, their contents are related. As an example, the histology of certain anatomical structures can be shown to the user while he is working on the operating room situs. With the help of search functions the user can "jump" directly to the desired information unit. Depending on the programming of the software, it is possible to search for individual key words or the full text. Figure 38.3.2 shows the various types of navigation.

Interaction converts the book's unidirectional way of learning into a bidirectional one. Each action of the user leads to a reaction of the computer. Easy forms of interaction help to operate the program (for example, browsing back and forth). In CBT programs, the aim should be to create content-related interaction (for example, choosing the right therapeutic strategy for a situation presented by the computer). For this, simulation is an example. Through the change of, for example, physiological parameters that are controlled by the user, the effects on the circulatory model can be displayed graphically in realtime. The quiz is an additional form of interaction during which, in the most simple case, answers have to be chosen. More complicated programs facilitate the identification of a particular structure (for example, in an x-ray) with the help of mouse sensitive hot spots. Future systems will approach reality more and more and also may have a playing character ("Gameboy").

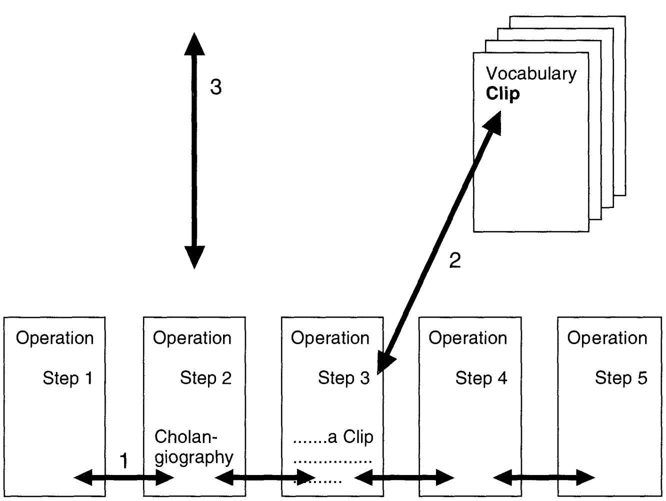

FIGURE 38.3.2. Three types of navigation between single information units (for example, steps of an operation). 1 = Browsing, 2 = Hyperlinks (in this example the term "Clip" is being looked up in the vocabulary section), 3 = searching (in this example "Cholangiography" is being searched).

Further Elements of CBT Programs

Artificial intelligence, neural nets, and three-dimensional simulation programs are further software technologies already available that could be useful for computer-based learning systems. They will allow the user to experience virtual reality. Artificial intelligence programs can give a certain amount of decision support. These systems are called expert systems as well, because a large data bank stores the pieces of information that have been entered by experts. A corresponding retrieval software transmits the user's questions to this data bank, retrieves the relevant entries, and then displays the results on the screen. For example, the physician enters three to four findings on his patient into the system and receives from it a selection of diagnoses with their respective probability appropriate in this constellation of findings. Expert systems could be incorporated, for example, in CBT programs on differential diagnostics or differential therapeutics. However, the application of medical decision making is still in its infancy and the validity of these systems has to be judged very critically.

Technology that is often confused with expert systems are neural nets. A *neural net* is a specific programming technique that allows the computer to learn from user entries and to give "intelligent answers" after an appropriate input phase. A neural net can be described as a pattern recognition system. For example, character recognition programs are using neural net structures. With this, the user must enter the individual characters repeatedly, in his own handwriting. The system remembers the individual handwriting and is able to recognize even variations of this person's handwriting with a certain probability. While the expert system depends on the multiple and time-consuming entries of a so-called expert, the neural net is able to make a reliable statement after only a few entries. These statements will become more and more precise with increasing entries, as the neural nets can learn from their decisions. For example, neural nets could be used in CBT programs in order to recognize a certain error pattern of an individual user. According to his error pattern in the quiz, the user could be referred to specific sections of the learning program. Such a system could be described as an "intelligent training system" as the system adapts to the errors of the user and shows specific reactions.

The technology of virtual reality cyberspace programming, which is increasingly popular, provides a new dimension to the interface between man and machine. With the help of a data glove, the user is able to immerse himself in a realistic way in the action simulated by the computer. Therefore, the surgeon can, for example, wander about the purulent "virtual" appendix in order to remove it later in the operating theatre. Regarding the computer-based interactive training programs, the possibility of virtual reality will again lead to a new horizon in information technology. The possibility of actively entering a space of knowledge and acting within it will open a completely new dimension for visualization of information. Even if at present special hard- and software requirements are still needed to offer virtual reality of good quality, we believe this technology will be at everyone's disposal within the next three to five years. A further dimension of this technology will be the possibility of simulating tactile perception of the touched structures, therefore giving the surgeon the opportunity to practice manual training as well as dexterity.

Conclusion

CBT programs offer an interesting alternative to established training possibilities due to their interactivity, the combination of different media, and the possibility of a specific reaction to the user's actions. The possibility of running CBT programs on standard Windows and Macintosh computers and easy updating of the training programs will make this kind of learning interesting for a growing circle of medical doctors, nurses, and students. CBT programs try to show reality in the computer and to create it according to pedagogical criteria. With the introduction of virtual reality, the barrier between man and computer will continue to disappear and the creation of new worlds using the computer will become possible. LapChole will then be a system within which the surgeon will be working, using different pieces of information from a base of knowledge for visualization and moving within the surgical situs.

38.4
Computer Simulation Training Devices

Mark D. Noar

Introduction

Minimally invasive surgical and endoscopic techniques have been changing the face of medicine for the past 25 years. These new techniques, which are introduced each year, represent potential for reduced costs and improvement in the standard of patient care. As new advances occur, the demand for training of increasing numbers of physicians and other allied health professionals overburdens traditional resources.

While there are no fully proven solutions at this time, a possible solution is the development of computer simulators. The computer simulators would operate independently and not require the presence of more experienced surgeons or endoscopists. In addition to training, simulators would be able to test and perhaps even certify skills, based upon objective performance criteria. These devices could closely duplicate any particular procedural experience and provide benefits that could include, but not be restricted to: (1) a more rapid transferal of information; (2) standardization of technique; (3) rapid dispersal of knowledge; (4) saving of instructor time and cost; (5) savings in equipment costs; (6) avoidance of complications; (7) practicing new procedures on the computer before trying them on humans; and (8) improvements in operator knowledge and skills.

The value of simulators has already been proven in many fields, including aviation and nuclear reactor operation. To date, there have been many efforts to extend simulator technology to the fields of medicine and surgery with the development of prototype endoscopy and laparoscopy simulators. The progress made in the field of medical/surgical simulation in the past eight years has been painfully slow, owing to limited funds and antipathy found in the medical community.

Despite these seeming impediments, simulator development continues to advance. The field is complex; a number of important issues need to be addressed. This chapter will provide insight into the simulators that exist, address controversial issues in the field, and provide a projection of where simulation is going and how it may affect the field of endoscopy and minimally invasive surgery.

The History of Medical and Computer Simulation

One of the first medical simulator developed, during the Ming Dynasty, was the Chinese physician's doll. This device was used by proper Chinese physicians when referring to the female body. Over time, additional anatomical models were developed that have sought to duplicate the appearance and feel of human organ systems. These models varied in sophistication from rudimentary hand-drawn organs to highly realistic rubber or plastic models, such as the one first developed and published in 1971 by Heinkel. While the appearance of many of these models was realistic, the feel and behavior of the "tissue" was unable to even remotely duplicate the real-life situation.

Prior to the endoscopy simulator era, several medical simulators were developed. One example was the Sim-Aid Medical Simulator, which was developed in 1980 at the University of Southern California. This was a realistically configured human body that would interact with students and was controlled by the instructor. The Cardiopulmonary Resuscitation Simulator was developed in 1982 by the American Heart Association. In this simulator, for the first time, computer simulation was coordinated with tactile response, providing both didactic and psychomotor training. Since the perfection of this simulator, it has become a highly regarded tool in the instruction, testing, and certification of CPR (cardiopulmonary resuscitation).

In 1984, the Shock-Trauma Simulator was introduced, which required instantaneous response to developing patient situations. This simulator was capable of changing the situation in response to users' actions. Similar simulators exist that duplicate the emergency department or intensive care unit environments, training teams of nurses and physicians to react swiftly and accurately to changing patient care needs.

In 1989, several anesthesiology computer teaching devices were introduced. One such simulator, developed by Good at the University of Florida-Gainesville, makes use of an actual anesthesia machine with all the usual feedback equipment and a full patient surrogate. This unit is fully developed and is currently employed to train residents in how to properly respond to routine and unusual situations in the operating room.

The first endoscopy simulation device was introduced in 1986. Since that time there have been as many as four major groups working in the field and the field has progressed steadily. The specifics of these changes and details of each system will be covered subsequently.

Simulation Terminology

As expected, the birth of endoscopy simulation was accompanied by the creation of new terminology. A working knowledge of the general technical jargon is essential to develop an understanding of the different computer simulation devices. Technical terminology native to each simulator will be explained within the specific section on each device.

Simulation
: A participatory experience. Significant aspects of a given procedure must duplicate the reality of the procedure as closely as possible.

"Visual Feel"
: A realistic synthesis of observation and tactility that occurs during a procedure, in other words, a way of feeling what one sees.

Internal Landscape
: A mosaic of views in motion that creates a complete visual environment, or literally, everything one sees during a procedure.

Seamless Images
: Images that are realistically linked, without any gaps or visual jumps between images.

Real-Time
: Images that appear and change in response to a given action, faster than the human eye is capable of detecting, so as to appear seamless.

Interactive Video Technology (IVT)
: A simulation system that uses actual endoscopic images stored on a videodisk, and later displayed in real-time, in response to users' actions.

Computer Graphics Simulation (CGS)
: A simulation system that uses computer graphic images to portray endoscopic images which are reproduced in real-time in response to users' actions.

Video Graphic Tool Technology (VGTT)
: A simulation system that uses a hybridization of IVT and CGS to portray movement of catheters or other devices in several planes over actual endoscopic images, in real-time in response to users' actions.

Simulation Technology

Imaging Methods

Endoscopy and minimally invasive surgery operate in an intensely visual medium. The quality of the images portrayed is an important part of the simulation. Initially, image processing was fraught with problems associated with the use of videotape. These problems have been largely overcome with the development of the laser videodisk and with improved computer graphic image technology. CD-ROM also offers exciting new potential in this area.

Laserdisk Technology

The laserdisk used in IVT has made it possible to perform simulation using actual endoscopic images, but there are certain limiting factors. A videodisk may store up to nine gigabytes of information or roughly 54,000 video-frames, which are displayed in response to computer commands. However, one limitation of this imaging method is related to the time required for the laser "reader" to search and display the desired images. Rapid accessing of images was initially a major problem. Early videodisk players were linear, meaning that a particular segment could be played, but in order to change to another image the machine had to stop, move the laser head, and then find the other footage. The resulting gap or glitch did not allow the seamless presentation of images. However, advances that occurred in 1987 resulted in technology capable of frame jumps of up to 250 frames in less than 1/30th of a second. Thus, it became possible to achieve seamless real-time simulation, all but eliminating gaps. Another advance in laserdisk player technology will take place with the development of zero wait-state machines. Due to be released in the next one to two years, these super-laserdisk players will make total instantaneous access of images possible and eliminate all gaps between images.

CD-ROM

CD-ROM is another type of laserdisk that makes use of a smaller disk or CD. While it offers the advantage of small size, the technology to date is still incapable of playing high-quality images in real-time. Once this shortcoming is corrected, CD-ROM has the potential to become the ideal imaging system, especially because it can be integrated into existing computers.

Computer Graphics

Portraying images that employ computer graphics relies upon computer-generated images, which are stored in the computer memory and later called forth in response to the computer commands. The limitations of this technology are related to the large amount of memory needed for storage, and the slow speed at which highly detailed images may be drawn from memory and reproduced. CGS initially used only crudely drawn figures in order to portray real-time movement. There have been major improvements in this technology. With the development of more powerful and faster computers, more sophisticated graphic cards, and larger hard drives, it has become possible to add coloring and texture to the graphic images and retain the real-time effect. In real-time simulation, CGS images are still far from the quality of IVT images, but advances promised in the future may narrow this gap. For the time being, it is possible to capture a computer graphic image of a *nonmoving* endoscopic picture that is indistinguishable from the actual picture. However, to date, CGS is unable to display actual *moving* endoscopic images in real-time without the use of larger and more expensive computers.

Digital Video Graphics

Digital video graphics (DVG) is another technology that shows some promise in simulation applications. In this method, actual images of an endoscopic or surgical procedure are gathered and then digitized and stored in computer memory. Using special software, portions of the images may be modified or moved and subsequently superimposed upon other images. In this manner, images may be constructed in a desired sequence. While this technology does use actual digitized images, it is still hampered by the same memory and access limitations of computer graphics. New technology currently being developed will benefit DVG by allowing compression of data into smaller memory space and more rapid recall of images.

Video Graphic Tool Technology

VGTT is a hybridization of IVT and CGS. Joining these two technologies may be the preferred imaging method. VGTT uses actual endoscopic or surgical images from the instant jump videodisk player or digitally compressed images, which are played in a background video-plane. Using computer graphic images of catheters, sphincterotomes, or other instruments that operate in an overlaying plane, it is possible to manipulate the device over the face of the moving video pictures playing in the background. In this manner, multiple tools in multiple planes may be portrayed to allow performance of cannulation, sphincterotomy, or organ manipulation. The computer graphic tools are under total user control. The scope of application of VGTT is still largely unperfected and until recently, in-depth capabilities have been limited. However, even with limited use, this technology has already demonstrated the ability to make real-time computer simulation of endoscopic and minimally invasive procedures a reality.

Physics-Based Graphic Modeling

Physics-based graphic modeling (PBGM) is a newly developed method employed to image internal body organs. The benefit of this technology is that organs are seen as they really are. There are also mobility and movement capabilities that respond to manipulation in close to real-time. This represents a major advance in imaging methodology. Detailed, high-resolution background images are also used as the backdrop to the PBGM images. The entire visual landscape is then welded together via specialized video plane programming and image projection for a startlingly realistic, action-sequenced visual experience.

Sensing Devices

The sensing devices used to construct simulators are extremely important to the functioning of the systems. These devices are the nervous system of any simulator and must function as the tactile, directional, and visual collection devices of the computer. Sensors provide signals to the computer concerning the activation of instrument controls and movement of the instrument through and around the surrogate patient. In some instances, it is possible for sensors to provide reversed tactile feedback to the user. Many of the recent advances in this area have come courtesy of the declassification of military hardware and advances in miniaturization.

Some examples of sensors include: (1) basic electrical switches or simple potentiometers or analog pots, which send off and on signals; (2) light-emitting diodes, which send a beam of light, usually infrared, which when broken indicates the passage of an object; (3) plastic laminate pressure-sensitive capacitors that may be sprayed onto a surface and sense extremely light touch or heat; and (4) optical sensors, which detect edges of moving lines in order to provide information concerning the movement of catheters or endoscopes throughout the simulator. Optical sensors are both the simplest and most sophisticated sensors and offer many advantages, including no radiowave interference. This is extremely important if these devices are to pass electrical emissions standards.

Tactile Feedback Devices

One of the most important elements of any simulator is the ability to duplicate the same tactile cues found in the actual procedure. The initial device developed for this purpose was known as the variable resistance device (VRD). Until the introduction of the VRD, the necessary tactile feedback in simulation systems was either nonexistent or relied upon complex mechanical or structural sphincters in the surrogate patient. With the initial VRDs, variable resistance was exerted on the instrument by using computer-controlled opposing rollers in coordination with the virtual position within the simulator. Thus, if the instrument was perceived as impacting against the bowel wall, there would be resistance exerted to simulate this feeling. Initial VRDs have been large, crude, and slow to react, but the latest devices are smaller, and more rapidly respond, providing more realistic tactile feedback. One very obvious advantage of the use of VRDs is that once perfected, there would be no need for complex mechanical or structural sphincters to simulate tactile feedback in the surrogate patient. More recent advances in VRD technology have given birth to a new class of resistance device known as the nonmechanical variable tactile response device (NVTRD). NVTRDs employ still proprietary methods to simulate the feel of tissue resistance normally found when pulling, pushing, or cutting tissue.

Patient Surrogates

There have been many "patient" surrogate types employed in the past, ranging from anatomically correct molded structures to metal and rubber boxes. Currently, there are three different varieties of patient surrogate employed. The simplest is the molded manikin, a department store mannequin that has been outfitted with many sensors in order to track the movement of the endoscope in a forward or backward direction. While it looks human, it actually has very limited function and sensing capability.

A more advanced patient surrogate is the externalized patient. This consists of a geometric box, replete with complex sensors and sensing capabilities, to track actions like tip motion, shaft pistoning, or rotation. While not realistic in appearance, it does provide improved sensing and feedback, with the addition of a VRD.

The ultimate patient surrogate is the molded robotics patient. This surrogate is molded from a human and may be covered with a synthetic skin to simulate puncture resistance. It contains multiple sensors, enabling precise tracking of instruments and the corresponding positions within the robot. Tactile feedback in the robotics patient employs either mechanical, structural-spatial, VRD, or more advanced NVTRD sensors.

Simulation Instrumentation

One of the most difficult tasks in developing a computer simulator for endoscopy or surgery is to build instruments that are realistic in feel and function, and have the sensing capability required to interface with the computer. Initially, sensors were very large and could not be placed into the confines of a normal endoscope. Small surgical instruments could not be outfitted with sensors at all.

This forced early computer simulators to make use of an isolated endoscope head without the shaft. The dials and buttons were fully functional, but the reality of the fully functioning endoscope was missing. Another endoscope employed in simulators is the "mock" endoscope, which features a functioning endoscope head with moving buttons and dials and a short shaft, with no allowed movement or tip deflection. The mock endoscope does allow the user to at least handle the shaft of the endoscope naturally. Continued advances in miniaturization and the use of optical sensors and readers allowed sensing capability to fit into a "regular" appearing endoscope, providing tracking of all aspects of endoscope movement. The most advanced simulation systems currently make use of this type of fully functional endoscope, with minor differences that are mostly cosmetic.

With regard to instruments used in the simulation of minimally invasive surgery, the instrumentation utilized is far more complex. A series of eight different instruments are available, including two trocars. Sensing is not yet integrated directly into the instrument. Instead, external devices through which the instruments pass are employed to provide the full compliment of necessary sensing. The "force feedback" generated by these devices, which are still highly proprietary, provide the feel of grasping, tugging, and probing.

Computer Hardware

Nothing has changed more rapidly than the actual computer hardware. Current simulator systems are dependent on hardware advances for future improvements. Basic differences do exist in the demands required by each simulator. The differences in required computing power are directly related to the imaging system employed. As a general rule, CGS-, or DVG-based systems require faster, more powerful computers with larger amounts of memory to run their applications. IVT systems run on slower and less expensive computers with smaller memory requirements. On the other hand, minimally invasive surgical simulators require the most sophisticated computing capability because of the underlying physics-based interaction with graphically modeled images.

New computers with different internal architectures are being developed and made available. Very important advances in standard computer technology have been made. They include improved methods of handling video and audio integration functions and the multiplicity of video functions possible. These new computers will also simplify the way different media are handled, and while initially very expensive, market-driven economics will lower the prices. These units will eventually find their way into the simulation systems. The image handling capacity of the new computer hardware will revolutionize how simulators work.

Concomitant with the release of new hardware, will be the development of new software programming capabilities that will be simpler and more powerful. New software methods already exist that are able to powerfully handle multimedia materials in ways never dreamed of two years ago. A prime example of this technology is the relatively recent introduction of CD-ROM.

Pedagogy of Endoscopy Simulation

Pedagogy is the study of what must be taught and how to teach a particular subject for maximum effect. The pedagogical methodology employed by the simulation device is vital for successful transmission and mastery of the material being taught. Pedagogical issues are perhaps the most important and, unfortunately, the last issues to be considered. Research into the best way to teach endoscopy or minimally invasive surgery is sorely lacking and has traditionally been assigned a low priority.

Endoscopy and surgery are multitask learning situations. Visual recognition skills must be developed and mastered. Manual dexterity is essential in order to be able to perform various maneuvers automatically. The final synthesis of visual and manual dexterity skills is the development of complex psychomotor skills and reflexes. Once this stage is reached, the trainee will then be able to concentrate more on perfecting complex techniques and observation skills.

There are two basic approaches in the pedagogy of endoscopy education. Learning methodology may be either close-ended or open-ended. These two methodologies differ in how learning opportunities are presented to the student. A close-ended learning system requires deductive reasoning; a certain calculated response must be elicited to a given situation. If the response is incorrect, another attempt must be made, thus halting the learning process temporarily.

The open-ended learning system is a totally free environment. Open-ended learning is purely inductive and allows active participation and learning via experimentation. A range of different responses is acceptable in a given situation, which in turn gives rise to another range of acceptable actions created by the changes of the first situation. This open-ended methodology closely duplicates the actual learning environment experienced in endoscopic or minimally invasive procedures.

Finally, there is the concept of staged learning of skills. Developed by Noar, this recently conceived pedagogical technique considers the sum total of skills required to perform a complex procedure, such as laparoscopic cholecystectomy, and deconstructs out the component skills into individual skill stations. The student then masters multiple individual visual and tactile skills independently. Once mastery of the deconstructed skills is achieved, the skills arena is then reconstructed allowing the trainee to use already perfected skills in concert to complete a complex operation. This pedagogical methodology is the key to learning in simulators teaching minimally invasive surgical procedures.

Endoscopy Simulators

In the past eight years, there have been eight endoscopy and minimally invasive simulation systems introduced and displayed at various international meetings. These devices represent major advances and innovations in the field of endoscopy simulation. Each system is unique in its approach and demonstrates the wealth of divergent opinions and directions that the field has taken. While some are pure simulators, others are complex and complete teaching systems, employing the most up to date pedagogical methods, computer technology, and simulation hardware.

CATE Simulator

The CATE (computer-assisted training in endoscopy) simulator represents the first published and presented attempt at endoscopy simulation.[3] It was developed by the group led by Beer-Gable and is used in teaching upper gastrointestinal endoscopy. The system consists of a standard noninstant jump videodisk player, a monitor with touch screen, a desktop 386 PC computer, a mock endoscope, and a molded manikin. Potentiometers and basic optical sensors were employed to read scope positions and travel through the patient surrogate. User actions are recorded in computer memory for later use by instructors.

The educational learning system is a close-ended system. Dialogue between student and machine is accessed via the touch screen and is in the form of graphic messages or printed text. The user may obtain location or guiding information, if requested. The level of expertise may be preselected as beginner or expert.

Users who pilot the endoscope are expected to perform a prescribed action for passage through each segment of the upper gastrointestinal tract. Maneuvers that do not fit the predetermined pattern of action result in nonmovement of the video picture. The user then asks for assistance and is instructed as to which actions will be required to advance. Due to the use of the standard videodisk player, the images of contiguous segments are not seamless and are played as sequences of video, with short pauses between segments.

One of the most significant additions to this simulation system is the development of the *Medical Encyclopedia.* This is a multimedia interactive encyclopedia designed to demonstrate a variety of pathology with accompanying verbal and written explanations. Information is available in multiple languages. Employing digital synthesis of images and compression technology, pathological findings may be added to normal anatomy. Users may ask to see pathological variants or may elect to solve clinical problems leading to endoscopic image display. With the addition of the learning material, the system is transformed into a complete endoscopy learning station, teaching endoscopy and recognition of pathological states.

Digital Mapping Simulation

The simulation work being performed in this area has been pioneered by Barde and his group, who began with interactive simulation, using actual endoscopic images on a standard videodisk player and an isolated endoscope head.[5] Employing topological image modeling techniques, this method used endoscopic images that were captured, mapped, and transferred to videodisk. While the system had rapid access of high fidelity images, there was a significant loss of user freedom. In order to avoid this loss of freedom, Barde changed the system design to employ a larger image in the database and to use digital modeling. This allowed images to be altered by moving and blending pixels, providing the flexibility to import pathology, and measure performance (Figure 38.4.1).

The process involves the digitalizing of actual images of the colon and creation of larger virtual images. By moving pixels from one image to another, pathology may be introduced and subsequent images matched, to avoid changes in visual registry as the endoscope moves from one centimeter to another. Images are held in a buffer for later recall, permitting seamless travel. Motion of the tip of the endoscope is simulated by moving the mask framework of the endoscopic view instead of the picture itself.

The total system has yet to be demonstrated in an integrated manner. There is some loss of degree of image fidelity and artistic ability is required to develop and perfect the images. As with all systems using graphics or digitized images, image storage and recall is dependent on speed and memory size. However, one advantage and the unique feature of this system, is the concept of moving the visual overlay or mask, rather than having to reconstruct images for all directions of tip motion, which may be more computationally economical.

Endoscopic Retrograde Cholangiopancreatography (ERCP) Computer Graphic Simulation

Initially presented in 1989, the simulator is largely the result of the collaborative work of Gilles and Baillie. It is a CGS simulation device initially composed of a desktop PC, a special Key Med externalized surrogate patient that monitors rotation and pistoning, and a mock endoscope.[4] The educational programming is open-ended. Simple line, wire frame modeling is used for images. While giving the images a stick figure appearance, anatomically the view is correct.

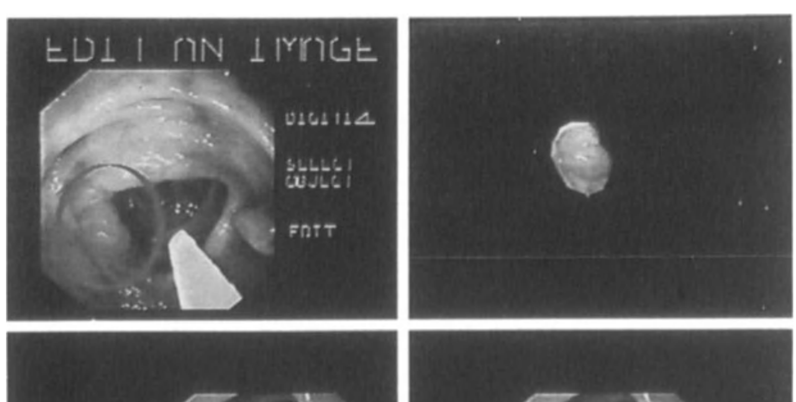

FIGURE 38.4.1. Digital mapping simulation system production of images. (A) An original image is digitized and a polyp identified. (B) The polyp image is cut out for later use. (C) The polyp is blended into a normal segment of colon.

The original simulator demonstrated only cannulation and movement within the duodenum; however, recent refinements now allow insertion through the stomach, straightening maneuvers, and improved feel of cannulation. Successful cannulation results in a cholangiogram or pancreatogram. Despite the primitive nature of the images, the simulation is real-time and seamless. The externalized patient now makes use of a VRD for improved tactile endoscope feel and permits the use of a fully functioning, modified Olympus endoscope. New programming allows precise tracking and scoring of performance indicators. Other than the simulation capabilities, no additional teaching material is presented.

Colonoscopy Computer Graphic Simulation

The colonoscopy simulation system stems from the work of Williams and Gilles, which was first reported in 1987.[4] The original system was a CGS simulator, using a desktop PC computer, VGA graphics with an externalized Key Med surrogate patient, and mock endoscope. Imaging is achieved using a three-dimensional ring model, known as a generalized cylinder. The 3-D models were extracted from multiple-angled x-ray images of the colon, which reproduce internal architecture accurately. The only problem noted with this technique is the loss of axial symmetry. Improved realism is provided by adding Lambertian shading to the images. Heuristic modeling is employed to simulate the interactive relationship between the endoscope and colon (Figure 38.4.2). The ring model also permits flexibility and the creation of multiple colon configurations of varying levels of difficulty. Pedagogically, the system is open-ended and varying degrees of difficulty may be preselected. No teaching material is presented or available beyond the simulation action.

Improvements made recently include the use of a VRD in the externalized patient, a fully functioning endoscope, and enhanced graphics. Users are able to access full views of the colonic ring structure for assistance. Although the images are not of the same fidelity as actual endoscopic pictures, the simulator is definitely real-time and seamless. Pathology is present and audio feedback is provided to indicate patient discomfort. The program is capable of demonstrating problems such as spasm, lens debris, and various types of looping within the colon. User actions are monitored and evaluations are made based upon level of difficulty and skill. Audio feedback, such as complaints of pain, requests to stop, and the passage of flatus, is provided to simulate patient reactions to trainee maneuvers. Corresponding image changes add to the reality of this feature.

Flexible Sigmoidoscopy Computer Graphic Simulation

The flexible sigmoidoscopy simulator is an offshoot of the work begun on the ring-modeled colonoscopy simulator noted above. Pioneered largely by Baillie, the system is a CGS system, running on a desktop 486, 50 MHz computer with an 800 mb hard drive and Texas Instruments Graphic Architecture card.[1] Initially a simple externalized surrogate patient was used, employing a mock endoscope, but this has been upgraded with a VRD and fully functioning endoscope. The unique software designed specifically for this application is known as object-oriented programming, which allows for simultaneous display of multiple, independent graphic routines. Pedagogically, an open-ended learning system is employed.

The computer-generated images of the endoscopic images of the colon are based upon tubular mesh models and represented as planar polygon surfaces, similar to the imaging used in aircraft simulators. The images run

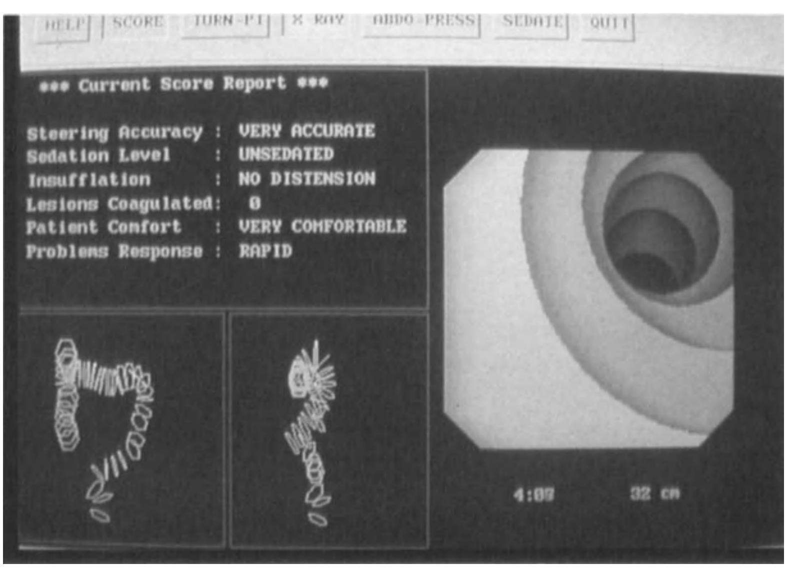

FIGURE 38.4.2. Computer graphic colonoscopy simulation showing Lambertian shading and 3-D modeling of the colon.

seamlessly and in real-time, thanks to a double-buffering technique. Gouraud shading, which for each polygon averages shading at the corners, weighted inversely by distance to the corner, has improved the realism of the images, albeit at the cost of increased computing power (Figure 38.4.3). The images with Gouraud shading are now in the process of being integrated in order to run real-time. The realism of the images is limited only by computer memory and speed, and begins to approach the quality of actual endoscopic images. A special software adaptation, EndoEdit, allows the construction of multiple colon models and shows peristalsis, looping, and pathology. Audio feedback to the user of the pulse oxymetry beeping has been developed. Performance indicators are measured and recorded for each trainee.

Robotics Interactive EGD Endoscopy Simulation

First introduced in 1989 and pioneered by Noar, the robotics interactive EGD simulator is the first of the complete interactive teaching simulators using IVT simulation[2,7]. The system consists of a 286, 16-MHz desktop PC, an instant jump video player, a high-intensity video monitor with an infrared touch screen, printer, and fully functional endoscope with optical sensors. The patient is a molded robotics patient with multiple optical sensors and functioning sphincters. The head and neck are movable and control the position of the upper esophageal sphincter and trachea. A VRD is being developed to improve tactile sensation. One of the distinguishing features of this simulator is the detailed teaching materials available in addition to simulation tasks (Figure 38.4.4).

From its inception, the simulator was built to duplicate the realities of the actual patient-endoscopist-instructor environment. Visual recognition, manual dexterity, and complex psychomotor skills are developed separately, and in concert, using an open-ended learning pedagogy. The user interacts with the system via the touch screen. The student may ask for assistance at any point in the program and receives digital audio instruction, appropriate to the given situation. Objective evaluation functions are provided to assess mastery of developing skills, prior to advancing to more complex tasks.

The educational program is divided into four sections. The orientation to the anatomy section allows the user an opportunity to master the visual anatomy of the upper gastrointestinal system while being instructed in methods of passing the endoscope. Tip position and landmark anatomy discussions are provided. A test of the user's visual anatomy skills documents learning. The orientation to the endoscope section allows the user to manipulate the endoscope and see the effects of the action, so as to develop automaticity and manual dexterity. A manual dexterity test is provided to document automaticity in the use of endoscope controls. The coaching and practice section is for initial practice of endoscopy in a totally open environment. All actions normally permitted during a real endoscopy are possible, with remediation provided if dangerous maneuvers are attempted. Audio coaching is available upon request. Assessment of endoscopy skills is performed in the evaluation section.

The images used are actual endoscopic pictures. All possible permutations of views are recorded on the videodisk and accessed in accordance with the actions taken by the user. The instant jump videodisk player allows images to be portrayed in less than 1/30th of a second, al-

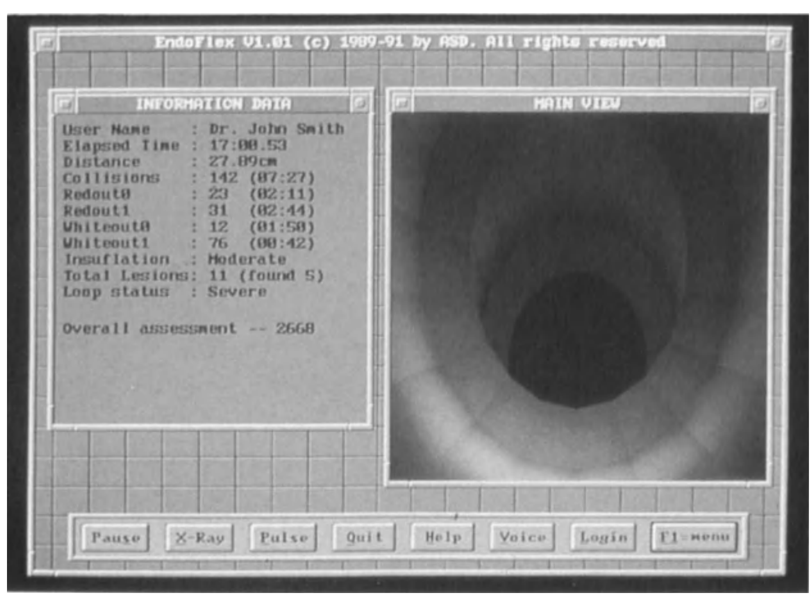

FIGURE 38.4.3. Computer graphic flexible sigmoidoscopy simulator image showing Gouraud shading of colon.

lowing real-time seamless simulation. There are occasional glitches in images that are the result of loss of register of reference point changes. This problem is being solved by using frame capture programming, which provides transition frames of images.

Robotics Interactive ERCP/Sphincterotomy Endoscopy Simulation

First released in 1990 by Noar, the robotics interactive ERCP/sphincterotomy simulator uses the same educational format and theory, equipment, and principles as the robotics EGD simulator[6,7]. The same hardware is employed, with the exception of the addition of fluoroscopy and cautery foot pedals. This device teaches and simulates passage of the side-viewing endoscope to the papilla, the straightening maneuver and selective cannulation of the major papilla, minor papilla cannulation, and biliary sphincterotomy. A complete teaching simulator, pedagogically, the main difference from the EGD simulator is the ability to preselect beginner, intermediate, or expert degrees of difficulty. In a curious turnabout in educational practice, the system teaches mastery of cannulation skills prior to passage of the endoscope and straightening technique. This is done to pretarget ideal positioning of the papilla prior to learning passage of the endoscope.

This system is unique in that it is the first hybrid CGS/IVT simulator. VGTT technology was developed, and is the basis of image management, for cannulation and sphincterotomy. Using VGTT, in the section on therapeutic and diagnostic cannulation, actual endoscopic images are played, showing the natural respiratory and peristaltic variation of the duodenum. A computer graphic cut-out of the catheter moves as an overlay superimposed on the video. The angle of the catheter and length of the catheter is controlled by the use of the elevator or by pushing or pulling the catheter inside the endoscope (Figure 38.4.5). Once the catheter is properly positioned, the control of the images returns entirely to video footage from the laser player. The catheter movement, cautery results, and fluoroscopy function are under real-time operator control. X-ray images are fluoroscopy sequences. Planned improvements in programming and graphic catheter images will eliminate visual change in reference points and limitations in catheter travel. The system is capable of projecting multiple variations in digestive system and fluoroscopic anatomy; planned extensions will simulate stenting and stone removal.

Both the EGD and ERCP robotics simulators may be combined and run from the same simulator. A supplemental teaching program is available with either the ERCP or EGD robotics systems, known as the Medical Detective. This is an interactive audiovisual program that teaches laboratory, x-ray, diagnostic and therapeutic endoscopy, and histology features of different disease states. The user acts as a medical detective, trying to unscramble mixed-up patient data. Audio assistance may be requested in the form of a consultation. Successful workups are automatically videotaped for the user.

Laparoscopic Surgical Skills Simulator

Under development since 1990, this simulator is the newest addition to the endoscopic simulation family. Developed as an intensive collaborative effort by Ixion, it represents a unique new simulation device. While it stems from the original simulation work of Noar, it is far more advanced than the EGD and ERCP simulators.

Introduced in 1993, the Laparoscopic Surgical Skills

FIGURE 38.4.4. Robotics interactive endoscopy simulator showing robot patient, endoscope, touch screen monitor, and endoscope.

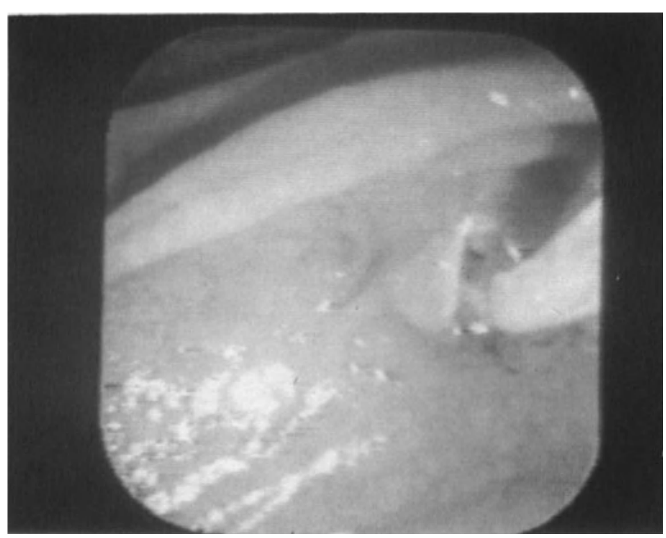

FIGURE 38.4.5. Endoscopic sphincterotomy performed on the robotics interactive ERCP simulator.

Simulator (LSSS) is a complete interactive teaching simulator that employs open-ended learning with the newer staged skills pedagogy. The instruments available to students include two trocars and eight different laparoscopic tools, including scissors, grasping forceps, clip appliers, cautery probes, and dissection instruments. The patient is a molded robotics type. There is tactile feedback provided by the latest nonmechanical variable tactile response (NVTR) technology. The computing power is provided by NeXT computers, which run a specially developed, proprietary software (Figure 38.4.6).

The LSSS exposes trainees to three different patients with 11 different pathological states, which are introduced by the computer. The student may play either the main surgeon role or the role of the assistant. The simulator is designed to familiarize and evaluate the student on the five major skills of mobilization, exposure, dividing, ligation, and anastomosis. Skills are practiced individually, and finally, in concert during a full operation.

Images are provided in virtual real-time. The visual landscape is composed of layers of video images that are made up of multiple planes of moving images. Organs are sophisticated computer-generated and controlled representations that move and react to touch and manipulation from instruments. This computer graphic anatomy is based upon the physics of motion and light reflection, which is essential to coordinate with the "force feedback" NVTRs that achieve what is known as "tactile graphics" (Figure 38.4.7). In its current format, the LSSS concentrates on the colon, but is extendible with the introduction of additional anatomy and instruments, to other operations and areas of the body.

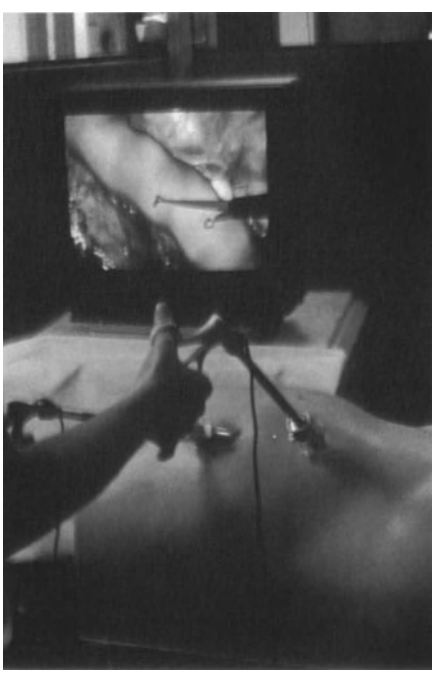

FIGURE 38.4.6. Laparoscopic surgical skills simulator showing patient and instruments in place and internal view of abdomen during performance of the procedure.

Endoscopy Simulation Issues

The ultimate question remains: Will endoscopy simulation succeed in training endoscopists and surgeons? There are many issues that must be addressed before this question may be answered. There must be careful study of the pedagogy of endoscopy and minimally invasive surgical training. Close cooperation between endoscopists, independent professional educators, and equipment manufacturers will be needed. Once it is known how to teach maximally, simulators can be made to reflect this knowledge. The simulator will never be better than teaching methods employed to construct the programs. One unusual benefit of current simulators is that performance data collected from simulator use may yield this information.

For those still working in the field of simulation, it is evident that validation of simulation methodology must be conducted. There are initial indications that simulators may be able to shorten a typical three-month learning curve to as little as two weeks. Formal studies must be carefully conceived, especially as imperfections in simulators may introduce errors into the trial data. Studies are now either planned or underway to at least begin to gather some initial data on whether or not simulation might be beneficial.

It is still not known exactly which skills must be taught by a simulator for it to be optimally effective. Endoscopy and minimally invasive surgery are complex tasks involving independent visual and manual skills and combined psychomotor skills. Whether a simulator that teaches only hand-eye coordination is sufficient, or if full teaching

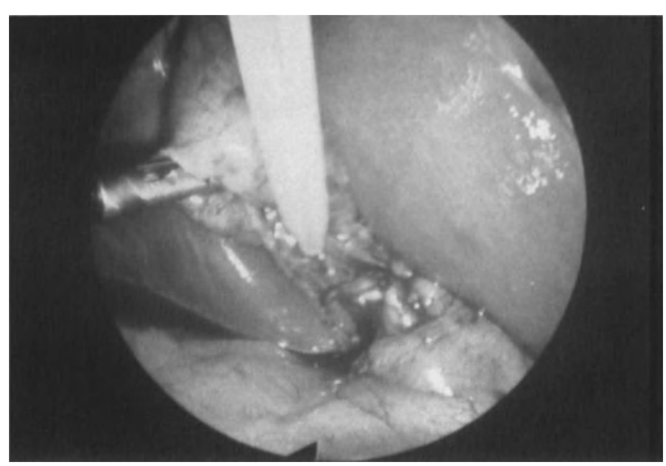

FIGURE 38.4.7. Laparoscopic surgical skills simulator: view during diagnostic peritonoscopy.

simulators with interactive teaching materials are needed, is not yet known.

Simulation design is refreshingly divergent. It is difficult to ascertain whether one design is superior to another with respect to teaching capacity. According to the First Rule of Endoscopy Simulation, "an endoscopy simulator must faithfully duplicate the reality of an actual endoscopy in all aspects."[8] None of the current simulators satisfy this rule, and it is not known how much reality will be important in achieving the ultimate goals of simulation. If the experience from other fields that use simulators may be translated to endoscopy, the more realistic, the better.

Imaging technology is still very controversial. The procedures are intensely visual, so images must be as realistic as possible, and must appear in real-time, in order to have a high degree of skill transference. IVT images are clearly superior to those images currently available in CGS. Although the fidelity of images is less sophisticated, CGS has the advantage of being closer to true real-time, compared to pure IVT. VGTT is another issue entirely, and while not yet perfected, may offer the best of both systems. Yet, the image manipulation found in the LSSS, which makes use of fused video planes, is by far the most flexible and powerful to date.

Another vital issue that will ultimately control the further development and use of simulation technology, is the support or disregard from within the medical field and government. The cost of learning on humans for the first time is still very low. Until the cost of the human portion of the training equation escalates, there is little to drive simulation technology forward, other than a few courageous health product companies who see simulation more as a promotional tactic than an essential part of training. The American College of Surgeons is the only organization to date to begin to seriously consider simulation as a future part of surgical training programs. The American Board of Internal Medicine is likewise beginning to explore the possible use of simulation devices to document basic levels of endoscopic skills. However, for the most part, medical and surgical societies have been suspect, and very slow to demand the integration of simulation devices into training programs.

Finally, some very specific questions will need to be answered. Some of these queries include: Will simulators limit complications or patient discomfort? Will two weeks (or more) of simulator study replace the typical learning curve of three months or more? Will simulator training save (or just postpone) valuable instructor time? Will simulation truly standardize training? What performance level or result on the simulator is equivalent to competency in a specific endoscopic or surgical procedure? Should simulator-developed skills be required prior to work on humans?

Future Directions of Simulation

Assuming that simulation will do for endoscopy and minimally invasive surgical training what it has already accomplished in aviation and nuclear fusion technology, the potential for these devices is intriguing and infinite. Endoscopy simulation will become procedure specific. At this time, other simulators for bronchoscopy, endoscopic ultrasound, and angioscopy/angioplasty are already being developed. In addition, simulators will become expert specific. Subtle nuances of master endoscopists and surgeons will be taught and conditioned via the simulator, so that for a given technique a unique set of images and programming will be available.

The format of the ideal simulator will be decided in the next several years. This simulator will probably be a combination of IVT and CGS technologies and fused video plane images with complete teaching capabilities. Once this is accomplished, all procedures will be learned on simulators, prior to allowing performance on humans.

With the development of new techniques and instruments, manufacturers will conjointly produce simulation programs to allow mastery of new skills prior to use on patients. Simulators may actually be used to help develop new products without the need for animal or human experimentation. Simulation training centers will be developed, most likely in universities or in the private sector. Individuals who desire to learn a specific technique will be able to gain valuable experience and training prior to their first human experience.

The process of certification and recertification is another issue being investigated by agencies, both in the government and in academia. Once validated, some simulators may be able to document the criteria necessary to allow certification and recertification of endoscopist/surgeon skills. A basic level of skill with standardization of instruction and practice in the field might then be assured.

Another exciting prospect is that currently existing hybrid technology now used in simulators will be placed into actual endoscopes. This would allow the simulators to learn and self-program experts' actions during a procedure. So called "second stage simulators" would allow users to ask for assistance during the performance of an endoscopy on a patient.

Finally, the next logical and futuristic step will be what Noar has called the development of "intelligent endoscopes and instruments." These instruments will be capable of automatic steering and guidance, if requested, and will have the ability to recognize pathology or present information from a visual database. It would even be possible to review a particular technique prior to performing the maneuver. Help modes may be able to provide on-the-spot advice, such as suggesting the direction and size of an incision of the papilla. It is even possible that physicians may be situated in a remote location from the patient, guiding procedures from a control panel.

While this may be alarming and sound impossible, the technology already exists and work has already begun that will make these projections a reality in the very near future.

Conclusion

The development of the current prototype simulators represents a giant leap forward into the future of endoscopic and surgical education. Despite what seems like significant progress, there is still a long path to travel. Conservatively, 10 to 15% of the potential has been explored and developed. Further progress in the field will depend on the financial support from private industry, the advance of computer technology, and most importantly, the endorsement of these efforts by the endoscopic organizations and government regulatory agencies. Assuming that these conditions are met, simulators will continue to become more sophisticated and less expensive. The ultimate result will be the standardization of education, improved quality assurance, uniformity of performance, and rapid dispersal of new techniques and expert variants of well-known techniques in the medical community.

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38.5
Virtual Reality and Surgery*

Richard M. Satava

Virtual reality is a new computer science that has its roots in both simulation technology and advanced graphics displays. Although there is no single agreed upon definition, *virtual reality* is the creation of a three-dimensional computer graphics drawing, referred to as a "world," which a person can enter, move around, and interact with objects as if the world actually existed.

Historically, what has become known today as virtual reality, began with an effort by National Aeronautic and Space Administration (NASA) to find an ideal means of allowing astronauts to train and perform complex actions using remote control, such as maneuvering the robotic arm on the Space Shuttle or remotely driving a lunar rover on the moon from earth. Borrowing from the vast experience in aircraft flight simulators and robotics, a system was created that allowed interaction by the astronaut with the manipulators through a computer. This interaction, known as human factors engineering or human interface technology, employed the helmet-mounted display (HMD). HMD has a pair of miniature televisions mounted directly in front of the eyes. While wearing the helmet, the real world is blocked out and only the artificial, virtual world is seen, giving the illusion that the person is inside of the three-dimensional drawing; when the wearer turns around he or she sees what is "behind." In order to provide interaction, a glove with fiberoptic sensors called a DataGlove is worn. By pointing in a direction, the operator moves around or "flies" in the world, and by making a grasping gesture, objects can be picked up and moved around (Figure 38.5.1). There are two broad categories of virtual reality: immersive (or egocentric) in which the person feels as if he were totally immersed inside of the world; and "through the window" (exocentric), in which the feeling is like looking into the world from an outside vantage point. Each has its strengths and weakness and, depending upon the application, is more suited for one application or another. Virtual reality has brought *Alice in Wonderland* to life, one can build an imaginary world, crawl into it, and travel around in it.

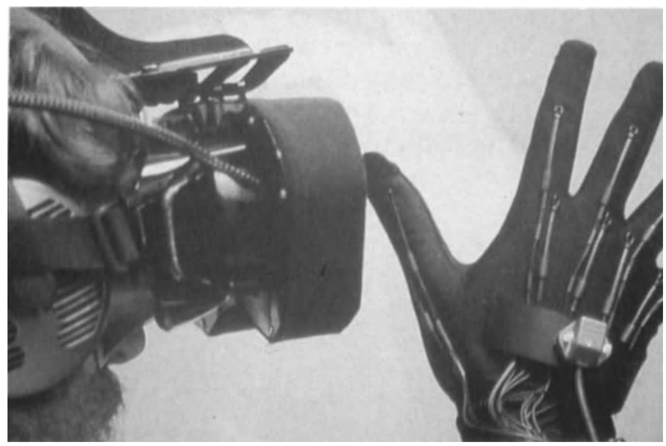

FIGURE 38.5.1. Virtual reality. The helmet-mounted display and DataGlove being used on the prototype Virtual Reality Surgical Simulator.

For surgery, there are two applications that would benefit from this remarkable new technology: learning surgical anatomy and training in surgical procedures. For these purposes, a prototype Virtual Reality Surgical Simulator (VRSS) of the abdomen has been created.[1]

When learning anatomy, a teaching or demonstration mode can be used that allows a predetermined flight through and around the organs to illustrate specific points of anatomy. For example, a tour of the upper gastrointestinal tract takes the student down the esophagus, into the stomach and duodenum, through the ampulla of Vater, up the bile duct, and out the gallbladder. What this

*The opinions or assertions contained herein are the private views of the author and are not to be construed as official, or as reflecting the views of the Department of the Army or the Department of Defense.

provides is a perspective of the internal arrangement of organs, similar to that seen with endoscopy. Once the didactic teaching is complete, the student can enter into the learning or exploration mode. For example, the student might choose to fly from behind the pancreas, then along the common duct between the pancreas and duodenum, and follow the common duct as it enters the duodenum. In this manner the student learns anatomy by discovering inter-relationships of organs in a way not possible even with cadaver dissection. The power of this approach to education is that it combines the elements of didactic instruction with explorative learning in a highly interactive, visual format. Since the graphics are computer generated, the learning system has the potential for being correlated with other information in a multimedia system, similar to the University of San Diego system.[2] Thus, while the student is touring the gallbladder, he could touch the mucosa and view a histologic slide labeled with the cells and layers, see a videotape of the formation of gallstones, watch a video of laparoscopic cholecystectomy being performed, or ask for a short history of biliary surgery, which includes photographs of famous hepatobiliary surgeons.

In the training mode, a surgical resident can learn and practice surgical procedures. Similar to anatomy education, there is a demonstration mode in which the resident can watch a surgical procedure being performed on the organs; then he can grasp the virtual instruments, which look convincingly like a real scalpel or clamp, and actually begin performing a surgical procedure. In addition to conducting elective surgical procedures on normal anatomy, congenital abnormalities, diseases, or battle injuries could be created. The ultimate simulator would allow for a very large encyclopedia of abnormalities or injuries.

The current status of virtual reality simulation for surgery has two demonstration projects. The first is the VRSS by Satava.[1] This simulator uses an immersive approach with HMD and glove (Figure 38.5.1). The abdominal world is a torso with the esophagus, stomach, duodenum, pancreas, biliary tract, gallbladder, liver, and colon; also included are a scalpel and clamp. All of these objects are very crude and stylized, however they are anatomically correct and provide accurate information for surgical concepts. The power lies in the fact that it is a totally interactive system in real time, providing the opportunity to explore as if the organs actually were present. There is no single perspective or view, no limited approach to the anatomy. The student can fly inside, around, behind, and through the organs, get a view from above or a view from inside. While some aspects are not realistic (for example, a microscopic view inside of the bile duct), it demonstrates some of the unique qualities of immersive virtual reality.

The second current virtual reality surgical project is the Virtual Reality Laparoscopic Simulator by Woods and colleagues.[3] In this prototype, there is a typical laparoscopic "black box" simulator with the handles of laparoscopic instruments protruding. The video image on the screen is replaced by a virtual abdomen with the liver, biliary tract, stomach, and duodenum. This is a "through the window" approach, mimicking the way laparoscopic procedures are currently performed. These instrument handles have a limited force feedback and range of motion. The advantage to this simulator is that it is identical to the way laparoscopic procedures are actually performed, preserving the same hand-eye axis and coordination used during the procedure.

Both systems represent initial steps. No one would believe that the graphic representations on the monitor are the real organs; however, the simulators provide a method of acquiring fundamental knowledge and basic surgical techniques in a manner not currently available, except through expensive cadaver dissection or animal training models. The current limitations to the realism are the limitations of computing power. As their power and speed increase, so will the accuracy and value of the training. Organs will look more realistic, be able to be deformed or change shape with gravity, and will bleed when cut. Sensory feedback to the surgeon such as pressure, tactile, and force feedback will be added. Over 40 years ago, Edwin Link's flight simulator was a modest beginning on a carnival ride airplane modified with hydraulics and instruments. Today, every military and commercial pilot must spend hundreds of hours in a flight simulator before risking the perils of flight. In the future, surgeons may well undergo the same rigorous training on a simulator before performing their first surgical procedure.

Even as these simulators are developing, the next generation is being considered, based on an innovation that will succeed laparoscopic surgery: The Green Telepresence Surgery system.[4] This is a remote control system developed to answer the three main deficiencies of laparoscopic surgery—the absence of 3-D vision, poor dexterity, and lack of sensory feedback. Telepresence surgery is accomplished by having a remote operative site with a dexterous manipulator and stereoscopic camera. Adjacent to the operative site is the surgical workstation with a 3-D monitor, and instrument handle controllers with dexterity and sensory feedback similar to instruments used in open procedures. This permits the surgeon to operate as if it were an open surgical case, regaining his sense of touch and dexterity, while having the feeling of actually being at the operative site (telepresence) instead of in front of a video monitor. This system not only would allow the surgeon to operate with the patient nearby, but even to use the equipment in a remote site such as space station or Third World country. In addition, other images, such as CT scan or MRI, could be imported during the procedure and overlay the video image, giving the surgeon a visualization of tumors or structures deep within the organs. This technology is not limited to surgical procedures, but also can be applied to endoscopic or microscopic procedures.

To accommodate this new telepresence technology, a virtual reality abdominal simulation can be imported to the workstation instead of using an HMD and DataGlove or laparoscopic trainer. This would provide the ideal teaching environment in the sense that exactly the same instruments and workstation would be used for both the simulation and the actual telepresence surgery procedure. The resident could practice on the virtual computer image, and with the flip of a switch, begin operating on the real patient.

While these technologies are in prototype stage and will soon become available, their implementation into the mainstream of surgery may well depend upon social, financial, or political forces. Yet, the fundamental technologies that underlie these innovations will form the framework that will propel surgery boldly into the twenty-first century.

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38.6 Surgical Robotics

Michael R. Treat

The acceptance of laparoscopic surgery opens the door to further changes in the *surgical interface.* Surgical interface consists of an *afferent limb,* which brings information about the patient to the surgeon. There is also an *efferent limb* by which the surgeon manipulates the patient's tissues. Before laparoscopic surgery, the surgical interface was the surgeon's unaided eye and hand, operating on the patient by means of fairly simple instruments. Laparoscopic surgery has taken the interface up one incremental level of sophistication, in that the surgeon is no longer directly looking at the patient's tissues but is operating via an optical system. The optical system, consisting of a videocamera, telescope, and a viewing monitor, provides the surgeon with a better view of the operative field than he could have had without resorting to a large incision.

Surgical Robots

Although the video-optical portion of the laparoscopic surgical interface is a net improvement over the surgeon's unaided eye, the same cannot be said of the efferent limb (output side) of this interface. The tools that the surgeon uses to manipulate tissue in the laparoscopic environment are simple, rigid, sticklike instruments. The surgeon's hand is certainly the most sophisticated tool in terms of dexterity, sensitivity, and flexibility. Unfortunately, to allow that hand to approach intracorporeal pathology requires a fairly large incision, which imposes undesirable consequences on the patient. These simple, sticklike laparoscopic instruments need to be replaced with devices that can more closely match the flexibility and dexterity of the surgeon's hand, while maintaining the advantage of a minimally invasive approach.

It is easy to imagine more complex instruments that have multiple joints or degrees of freedom that would permit more humanlike motions. However, it would be difficult for the surgeon to actually use these instruments if he had to adjust the position of each of these joints at every step of the operation. It would make more sense if the multijointed instrument were motorized and incorporated a computer "brain" to adjust its joint positions. With a computer brain interpreting the surgeon's command, the surgeon would not have to directly specify the position of every joint of the instrument, but would issue a single overall positioning command ("Move there") that the computer would break down into individual joint motions. In order to ensure that this motorized device does not harm the tissues, it should ideally incorporate some kind of force feedback sensor that can be monitored by the computer brain to keep the exerted forces within safe limits. These considerations lead us directly to the concept of surgical robotics.

Definition of a Surgical Robot

In the most general sense, a *surgical robot* is a machine that can perform surgery or assist at the performance of surgery. This machine should possess some degree of onboard computer intelligence in order to be aware of the spatial position of its various parts and of any effects that it is causing to the tissues. As is the case with industrial robots, we can imagine a spectrum of surgical robots, ranging from simple to complex. At the complex extreme, the surgical robot may be a partially autonomous entity that has a hierarchical relationship to its human supervisor. In this case, the robot functions quite independently in the tactical sense, but communicates at intervals with its human supervisor, and defers to that supervisor for input regarding major goals and overall guidance in achieving them. At the simple extreme, a robot may be considered as a servomechanism or "slave" that precisely follows the actions of its human controller. The term *controller* as opposed to *supervisor* implies that the machine is being constantly directed by the human. In this case, the robot is essentially an extension of the human controller's senses, reflexes, and muscles. While this simple robot may well be equipped with special sensors that can enhance its controller's knowledge of the surgical situation, the robot contributes nothing in terms of tactical or strategic planning. This type of "dumb" robot is only concerned with faithfully following the actions of its human controller. Achieving faithful servomechanical slaving is by no means trivial, since the robot will have to receive tactile or other input from its controller and then translate that input into motions of its mechanical systems that result in the desired action at the tissue level. Even in this servo mode, a great deal of intelligence (computing power) would be required for the robot to compute the solution to replicating even a simple hand motion of its controller. Another generally accepted term for such a "dumb" robot is *teleoperator.*

For the purposes of this chapter, we will simply use the term *robot,* but one should bear in mind that there is a spectrum of complexity and autonomy that the machine might have. A generic surgical robot is shown in Figure 38.6.1.

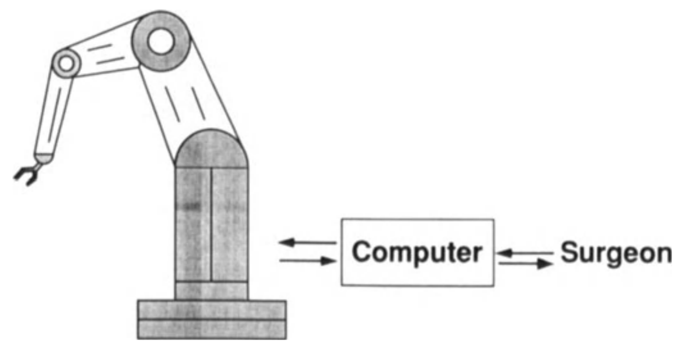

FIGURE 38.6.1. Schematic depiction of the generic surgical robotic system. Mechanism for producing motion is indicated by the multiaxis industrial positioning device. Effector device, shown here as a two-digit grasper is being positioned by the mechanism. Arrows indicate data flow, not only from the surgeon to the computer and the mechanism, but also in the reverse direction back to the surgeon. Closing of the data loop is essential for the human surgeon to exercise overall control of the surgical robot.

The Technologies

The following technologies will be involved in surgical robotics. They can be grouped into three areas: (1) sensory input; (2) manipulators; and (3) control and coordination.

Sensory Input Technologies

Machine Vision

Sensory input can be provided to the robot in various ways. One way would be the ability to interpret visual information provided by a video camera. The problem of machine vision has been studied for many years, by many high-powered researchers. Machine vision can do a good job in well-structured, predictable environments as might be found in assembly line manufacturing processes involving a limited variety of objects and shapes. They are presented to the robot's optical scanner in a few well-defined ways. The problems involved in reliable machine vision are greatly increased by the type of environment encountered in the operating room. In the surgical environment, there are many more subtle variations in the shape and presentation of tissue structures. The presence of varying amounts of blood and other tissue substances that can color or shade tissue structures would also compound the difficulties for the machine vision program. If the robot is being used in a slave or teleoperator mode, then the problem of machine vision does not exist. The teleoperator would carry video devices whose output would be presented to the human controller for interpretation. Given the difficulties in solving the problem of reliable machine vision in the unstructured surgical environment, in the next 5 to 10 years we probably will see the clinical deployment of surgical teleoperators, but not of more autonomous surgical systems. Such systems would need to perform their own interpretation of the video data.

Force Sensors

Besides visual input, a surgical robot or teleoperator would benefit from the incorporation of sensors that can input tactile information about the tissues. Currently, there is a wide array of strain gauges and pressure transducers that may be used in the surgical environment. These various strain gauges and force sensors can be constructed using micromachining technologies. In other words, it is now possible to build strain and force gauges that are small enough to embed into the working surfaces of surgical instruments, just as the human hand has many sensors embedded in the skin, especially the fingertips.

Chemo Sensors

Although human beings do not have chemo sensors on their fingertips, there are numerous examples from nature, chiefly from the insect world, in which the creature has a multimodal probe or tentacle that incorporates not only the usual tactile type of sensor but also chemo sensors (taste buds, for example). These chemo sensors could be used to assess tissue pH, oxygen tension, and lactate content. Measuring these factors might help the robot to distinguish diseased from normal tissue and might also help the robot to optimally adjust the tension of sutures ("Tissues should be approximated not strangulated.").

Active Sensors

Sensors need not be limited to passive devices that react to the presence of something in the tissue. Unlike the usual sensors, an active sensor would emit an energy signal into the tissue, and then record the response of the tissue to the probing energy. Active sensors can operate using probing signals that are optical, acoustical, and mechanical.

A familiar example of acoustical probing is ultrasound. The idea behind ultrasound is to use very high-frequency sound waves to construct an architecturally detailed view of the target tissue. High-frequency sound is needed because the resolution of detail that can be obtained is inversely proportional to the wavelength of the incident sound wave. Simply put, it is necessary to use short wavelength (that is, high frequency) in order to visualize small physical structures. Unfortunately, the depth of penetration of short wavelengths into tissue is less than that of longer wavelengths. Conventional extracorporeal ultrasound devices use wavelengths that are a compromise between acceptable resolution and acceptable depth of penetration. Placing the ultrasound transducer at the end of the robotic surgical instrument, which is in contact with the tissue, is advantageous. The distance between the transducer and the tissue is minimal, allowing the use of very short wavelengths with resulting high resolution.

A familiar example of mechanical probing is percussion, as practiced clinically. Percussion is essentially the use of a mechanical impulse to elicit an acoustical response from the target tissue. In a robotic embodiment of percussion, there would be a low-frequency emitter that would send mechanical impulses into the tissue. The resulting tone could be received by a sound transducer (microphone) and analyzed to reveal features of the tissue composition. This technique could be used to ascertain whether the target structure was hollow or solid and also to determine its mechanical characteristics (that is, stiff or flexible). This type of sensing would enable the surgical robot to mimic some aspects of the human sense of touch.

Another type of active sensor is optical. An example of this is the use of laser-induced tissue fluorescence to diagnose the presence of neoplastic tissue. In this type of system, a low-powered laser emits a pulse of light that is conveyed to the target tissue via a fiberoptics. After emitting the diagnostic pulse, the laser is shut off and the fiber is used to collect the reflected light coming from the tissue. This reflected light has a spectral distribution or "signature" that is characteristic of the target tissue. Mathematical analysis of this spectrum can be used to determine various things about the tissue, such as whether or not it is neoplastic.

Sensory Fusion

Opportunities exist to improve the teleoperating or telesupervising surgeon's grasp of the surgical situation by combining the sensory data from different "channels" (that is, video, x-ray, force sensors) into a single, comprehensive and integrated display. In this scenario, the human surgeon is immersed in a truly multimedia sensory experience that gives him a compelling and detailed representation of the surgical scene. This multisensory display need not use the human surgeon's senses in the same way that he would use them outside of the teleoperating environment. For example, the human operator's sense of hearing might be used to receive data about the degree of force that the robot was exerting on tissues (a low-pitched sound for a light grasp and a gradually increasing pitch as the force of the grasp was increased). Although this redefining or scrambling of the human operator's senses opens up possibilities, it would increase the learning time and would be somewhat counterintuitive. Multisensory displays that would parallel the normal human experience would probably be more desirable.

Manipulator Technologies

There are many technologies that could be employed as part of the "efferent limb" for the surgical robot. These technologies span a size range from the microscopic to the size of industrial robots. The most crucial aspect of different manipulators is the actuator that moves it. Actuators can be made using electromagnetics, fluidics, shape metal alloys, piezoelectrics, and electrostatics. The choice of actuator mechanism largely depends on the size and strength of the motion desired.

Electromagnetics

For large applications, conventional electromagnetic motors are probably the best choice. This type of technology is employed in industrial robots such as the PUMA type machines that are ubiquitous to the manufacturing process. Recent developments from Japan promise to provide electromagnetic motors in the millimeter size range. The availability of motors in this size range would greatly expand opportunities for using this technology in small surgical instruments.

Another potentially useful electromagnetic technology is the solenoid, which is basically an electromagnetic coil that acts on a piston or plunger. Solenoids are best suited for larger applications that require "on-off" positioning and are not suited for incremental positioning applications. A more versatile electromagnetic technology is the *voice coil,* which is similar to the mechanism of audio speakers. Voice coil technology has found wide application in computer disk drives and in CD players. This type of technology is relatively inexpensive, compact, and capable of high precision when coupled to appropriate driver electronics.

Fluidics

Fluidic actuators include hydraulic and pneumatic devices. Hydraulic devices range from high-pressure systems using oil as the medium to low-pressure systems employing water. Pneumatic systems are generally confined to smaller scale applications where a great deal of force is not required. Although fluidic systems are very versatile in the way in which they can be configured, conventional fluidic systems are not suitable for very small applications. There is a new class of fluidic actuators being developed that are in the millimeter size range and that would be suitable for finer surgical applications.

Shape Memory Alloys

Shape memory alloys (SMA) are materials that have a dual crystalline structure. When heated, these materials can be induced to undergo a transition from one crystalline structure to the other, resulting in a change in shape or length. These materials can be formed into wires that undergo up to a 5% change in length, when an electrical current is passed through the wire to cause heating. The prototypical material is Nitinol. Nitinol was discovered by Buehler and Wiley in the 1960s at the Naval Ordinance Research Laboratory. Since then, modifications and improvements in this original material have been discovered. Although the amount of force that a typical SMA wire can exert is limited, the wires can be arranged in parallel to produce more powerful actions, similar to the way in which skeletal muscle fibers are grouped. Another disadvantage of SMA actuators is that they are relatively inefficient. Therefore, these actuators dissipate a fair amount of heat, and provision for heat sinking them must be made, in order to keep them at temperatures that will not harm tissue. On the positive side, SMA actuators can be readily coupled to driving electronics and can be driven in a proportional mode to produce a graduated response.

Micromechanical

The above-mentioned actuator technologies are suited to a size range down to a few millimeters. However, if we wish to challenge the human hand in terms of dexterity and flexibility, we need to consider actuators that are an order of magnitude smaller. Such actuators can be made using micromachining techniques. *Micromachine technology* refers to the etching on a silicon chip, of not just electronic circuits, but also structures that are capable of physical motion. These micromachine actuators employ the piezoelectric effect and the effects of electrostatic attraction and repulsion. The piezoelectric effect refers to the fact that certain crystalline materials will undergo a change in physical dimension when subjected to an electric field. We are familiar with this effect from ordinary earphones that employ a piezoelectric diaphragm. Electrostatic actuators employ the familiar phenomenon of like charges repelling and opposite charges attracting. These, too, can be etched on a silicon substrate to make a wide variety of interesting configurations. Besides the very tiny sizes that are attainable with silicon micromachining techniques, another advantage of this technology is that the driver electronics can be etched onto the same chip. Using extensions of the very large scale integration (VLSI) technology that is used to construct very complex computer chips, it should be possible to construct an entire micro-robot on a single chip that would incorporate a computer "brain," microactuators, charge couple device (CCD), video chip, and perhaps even a diode laser. This chip level of integration also implies that these devices could be made quite cheaply, as is the case with many other silicon chip-based consumer products including computer chips and watches. Cheapness and small size means that these devices could be used in great numbers to produce surgical devices with unprecedented flexibility and dexterity.

Control and Coordination Technologies

Even the very simplest of "dumb" surgical robots require the presence of computing power to translate the human operator's input into machine manipulator output. This is so because of the fact that the manipulator mechanism is physically quite different from the human surgeon's hand-arm mechanism, and therefore a computer is required to translate the human's input motions into the detailed motions of the machine manipulator. It is the job of the computer to free the human operator from the task of having to micromanage the positioning of every joint and every degree of freedom that the robot manipulator possesses. In a real sense, the computer functions as an extension of the human's cerebellum. Just as our cerebellum allows us to walk without having to concentrate on explicitly moving every muscle in the legs, the computing element in a surgical teleoperator would allow the human operator to indicate an overall goal or movement (for example, "grasp that piece of tissue"). Once this overall goal has been specified, the computing element would figure out (compute) the detailed positioning solution of the joints and actuators of that manipulator to achieve the desired physical motion.

Training the surgical robot to execute certain repetitive or fairly stereotyped actions would be possible. This type of training is employed in assembly line robots. These robots can be taken through a complex series of motions by the human operator and then will be able to re-execute this series on command. This is similar in concept to the *macro* that is employed in word processing and spread-sheet programs. A macro is a series of steps that, once defined, can be called up by means of a single command. For the *surgical macro,* the human operator would indicate the tissue to be acted upon and then specify the macro to be executed. An example of a surgical task that could be called up as a macro would be knot tying. The human surgeon would designate (perhaps by a laser pointer) to the robot or teleoperator, the tissue locations for the entry of the suture, the exit of the suture, and what kind of knot should be tied. The robot would have in its memory a list of other parameters that are part of the suturing process, such as how firmly to grasp the tissues, how much tension to put on the tissues when pulling them together, and how much force to use when tying the knots. The robot would then execute the suturing task, according to these parameters. The human surgeon is able to inspect and evaluate the results of the robot's actions. The advantage of having the robot do the suturing is that it would be able to do it faster and more reproducibly than the human surgeon. In this scenario, the patient gets the best of the human surgeon's overall strategic planning and judgment and the robot's ability to precisely and accurately execute the surgical plan.

Neural Networks

In manufacturing situations, the parameters for actions can be well defined and very uniform. For example, an assembly line robot that is supposed to tighten a particular screw on a particular part can "expect" that the part will always be presented to it in the same position, at the same angle, and at the same time interval. Surgical tasks are likely to be much more varied in their presentation to the robot. Currently, human beings are the only "machines" that have enough flexibility to deal with such variability. There are developments in machine intelligence that will change this. One of these developments is the concept of the neural network. Neural networks are learning systems that consist of a set of possible inputs, a set of possible outputs, and a set of possible relationships between these inputs and outputs. At the beginning of its training, a neural network has basically random connections between the inputs and the outputs. The network is trained by having it give its responses and then telling it whether it was right or wrong. It modifies its responses based on this feedback. Eventually, it will learn to produce the correct responses. A powerful advantage of a neural network is that the human supervisor does not have to program every possible response. For simple systems, it would be practical for the human to program every step, but for complex systems this is no longer the case. In addition, the network is capable of continued learning and adaptation. The sophistication and subtlety of its responses is a function of the number of computing elements in the network.

Parallel Computers

Parallel computing systems are well suited for the implementation of neural networks. These systems employ many small microprocessors that attack many aspects of a problem simultaneously, instead of the more conventional computer, which through its programming, breaks a problem up into sequential tasks that are executed one at a time. Real-time problems involving machine vision, pattern recognition, and the position of complex multi-degree of freedom actuators are well suited to parallel computing approaches.

Clinical Applications

There are several current clinical examples of the use of surgical robots. The first of these is the orthopedic surgical robot known as ROBODOC.

ROBODOC

ROBODOC is a surgical robot employed in orthopedic operations involving the placement of a prosthetic device (Figure 38.6.2). The initial development work on this device was a collaborative effort between a team at the University of California at Davis and Russell Taylor, PhD, at the IBM Thomas J. Watson Research Laboratory. The machine involves a fairly standard industrial robot that is coupled to a computer. The computer has in its memory

FIGURE 38.6.2. ROBODOC system in action. System was first used clinically by Dr. William Bargar in November 1992, in Sacramento, CA.

a CT scan image of the bone to be fitted with the prosthetic device. Tactile sensors on the robot enable it to acquire the spatial position of the bone that is to be drilled. Once the spatial coordinates of the bone have been read by the robot and computer, the robot then uses the CT image in the computer's memory to guide it while it drills out a near perfect hole to accept the prosthesis. The strength and precision of the robot cutter exceed that of any human surgeon. The result is a cavity that is almost perfectly drilled to accept the prosthesis.

The AESOP Laparoscopic Camera Positioning Robot

AESOP is an Automated Endoscopic System for Optimum Positioning of the laparoscope (Computer Motion, Inc.). This device (Figure 38.6.3) takes footpad or joystick input from the surgeon and positions the laparoscope accordingly. It is capable of remembering positions or views that can be recalled simply by pressing a button. It has received FDA approval and has been praised by Dr. Johnathan Sackier and other initial clinical evaluators. This device does meet the minimal criteria in our definition of a surgical robot, but its real importance is as an evolutionary step forward in the introduction of active, computer controlled mechanized devices into the operating room. Hopefully, this seminal device will be the forerunner of a whole line of more advanced surgical robots.

The Gastrointestinal Micro-Teleoperator

In its initial embodiment, this device could be a fairly "dumb" teleoperator that would be capable of propelling itself along the bowel lumen under direct human control, sending back a video image of what it encounters. Such a device would be able to replace conventional flexible endoscopes that need to be pushed into the bowel. Eliminating the pushing required by conventional endoscopes would greatly decrease the discomfort associated with this type of examination.

Ultimately, the device is intended to be a semiautonomous robot that could explore the luminal aspect of the gastrointestinal tract. It would embody diagnostic technologies such as reflectance spectroscopy via an on-board diode laser to sense abnormal tissue. Such a video-bug could make automated mass screening of the entire gastrointestinal tract a possibility. More sophisticated versions of this device could incorporate therapeutic devices such as more powerful diode lasers or micromanipulators to ablate or excise abnormal tissue. Obviously, application of such a device is not limited to the gastrointestinal tract.

Ideally, this would be built as a "robot on a chip" employing micromechanical technology. However, working prototypes (Figure 38.6.4) of such a device are being evaluated that incorporate more conventional actuator technology.

Blueprint for the Future

Many people believe that the future of surgery will become a partnership between man and machine. On the "afferent" side, the sensors of the machine can gather a spectrum of data that will extend the range of the unaided human's senses. This extended data spectrum will include

FIGURE 38.6.3. AESOP laparoscopic positioning system. Device accepts real-time input from the surgeon.

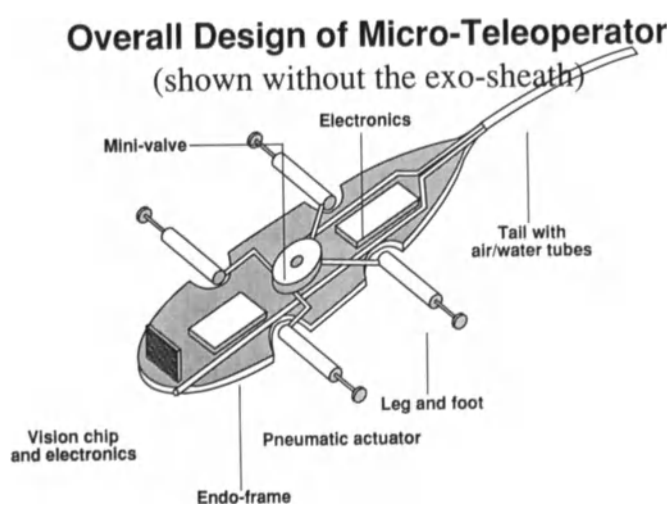

FIGURE 38.6.4. Micro-teleoperator is intended for use within the lumen of the gastrointestinal tract. It propels itself by means of four legs that are actuated by pneumatic piston cylinders. This version has a tether, which, in addition to supplying air and water, could be used to convey video data from the teleoperator to the human operator, and control signals from the human back to the teleoperator.

the usual video input and could also include radiographic, magnetic resonance, sonographic, and other data sets. The information from these other data sets can be overlaid onto the basic video data to provide the human surgeon with a literally "in-depth" view of the operative field. The laparoscopic experience has made us aware, by reducing our tactile abilities, of the limitations of being able to look at only the visible surfaces of the anatomy. What the machine will enable us to do is combine sensory modalities that see below the surface of tissues. For example, in the course of a difficult biliary dissection where one does not really know where important structures are, the human surgeon could ask his machine partner to find the ducts ("Computer, show me the ducts please") using ultrasound, and then display their location on the stereoscopic heads-up display on which he is observing the operative field ("Also, computer, would you please color those ducts green . . ."). The machine partner can help on the "efferent" side as well. To continue the previous example, once the ducts have been found, the human surgeon can request that the machine assistant expose them ("Computer, expose the cystic duct–common duct junction please").

In this model of the future, the human surgeon is still the one in charge of the operation. He supplies the judgment and overall decision making. The machine partner functions to extend and enhance his surgical abilities.

Suggestions for Further Reading

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