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ADVANCED ENDOUROLOGY

THE COMPLETE CLINICAL GUIDE

Edited by

STEPHEN Y. NAKADA, MD

The University of Wisconsin Medical School
Madison, WI

and

MARGARET S. PEARLE, MD, PhD

The University of Texas Southwestern Medical Center
Dallas, TX

HUMANA PRESS
TOTOWA, NEW JERSEY

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Dedication

To our spouses, Deanna and Jack, who remind us that there is more to life than endourology.

Preface

Endourology is one of the most important subspecialties in the field of urology because of the widespread use of endoscopy for the diagnosis and treatment of a variety of upper genitourinary tract pathologies. Although most clinical urologists incorporate some basic endourology into their practices, complex upper tract pathology and anatomy require more advanced endoscopic skills and instrumentation.

Advanced Endourology: The Complete Clinical Guide is intended as a resource guide for all aspects of clinical endourology, particularly the more advanced procedures. This volume encompasses endourological applications for upper urinary tract calculi, strictures, and urothelial cancer. It will also serve as a comprehensive overview of available endoscopes and instrumentation.

Advanced Endourology: The Complete Clinical Guide is unique in that most of its individual chapters include videos that clearly illustrate critical portions of the techniques and provide tips and tricks from the experts. Every practicing urologist should have this book in his or her library, with the accompanying DVD kept near a DVD player, for quick access to detailed procedural instruction and immediate review of the videos.

Stephen Y. Nakada, *MD*
Margaret S. Pearle, *MD, PhD*

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Contributors

Murali K. Ankem, MD • *Division of Urology, Department of Surgery, University of Wisconsin-Madison Medical School, Madison, WI*

Dean G. Assimos, MD • *Department of Urology, Wake Forest University School of Medicine, Winston-Salem, NC*

Demetrius H. Bagley, MD • *Departments of Urology and Radiology, Jefferson Medical College, Thomas Jefferson University, Philadelphia, PA*

Ben H. Chew, MSc, MD, FRCSC • *St. Joseph's Health Centre, University of Western Ontario, London, ON, Canada*

David S. Chou, MD • *Island Urology, Honolulu, HI*

Ralph V. Clayman, MD • *Department of Urology, University of California Irvine Medical Center, Orange, CA*

Michael J. Conlin, MD • *Division of Urology and Renal Transplantation, Oregon Health and Sciences University, Portland, OR*

John D. Denstedt, MD, FRCSC • *St. Joseph's Health Centre, University of Western Ontario, London, ON, Canada*

Mahesh R. Desai, MD • *Department of Urology, Muljibhai Patel Urological Hospital, Nadiad, India*

Mihir M. Desai, MD • *Section of Laparoscopic and Minimally Invasive Surgery, Glickman Urological Institute, Cleveland Clinic Foundation, Cleveland, OH*

Steven G. Docimo, MD • *Department of Urology, University of Pittsburgh School of Medicine, Pittsburgh, PA*

Louis Eichel, MD • *Department of Urology, University of California Irvine Medical Center, Orange, CA*

Michael D. Fabrizio, MD • *Department of Urology, Eastern Virginia Medical School, Norfolk, VA*

Glenn S. Gerber, MD • *Section of Urology, Department of Surgery, University of Chicago Pritzker School of Medicine, Chicago, IL*

Inderbir S. Gill, MD • *Section of Laparoscopic and Minimally Invasive Surgery, Glickman Urological Institute, Cleveland Clinic Foundation, Cleveland, OH*

Khalid S. Hafez, MD • *Department of Urology, University of Michigan Medical School, Ann Arbor, MI*

Assaad El-Hakim, MD • *Department of Urology, Long Island Jewish Medical Center, New Hyde Park, NY*

Thomas W. Jarrett, MD • *The James Buchanan Brady Urological Institute, The Johns Hopkins Medical Institutions, Baltimore, MD*

Christina Kim, MD • *Pediatric Urology, Department of Urology, University of Pittsburgh School of Medicine, Pittsburgh, PA*

Samuel C. Kim, MD • *Indiana Kidney Stone Institute, Methodist Hospital Institute for Kidney Stone Disease, and Indiana University School of Medicine, Indianapolis, IN*

Jaime Landman, MD • *Division of Urology, Washington University School of Medicine, St. Louis, MO*

BENJAMIN R. LEE, MD • *Department of Urology, Long Island Jewish Medical Center, New Hyde Park, NY*

RAYMOND J. LEVEILLEE, MD • *Department of Urology, University of Miami School of Medicine, Miami, FL*

JAMES E. LINGEMAN, MD • *Institute for Kidney Stone Disease, Methodist Hospital, and Indiana University School of Medicine, Indianapolis, IN*

BRIAN R. MATLAGA, MD, MPH • *Department of Urology, Wake Forest University School of Medicine, Winston Salem, NC*

EDWARD D. MATSUMOTO, MD, FRCSC • *Division of Urology, Department of Surgery, St. Joseph's Hospital, McMaster University, Hamilton, ON, Canada*

ELSPETH M. MCDOUGALL, MD, FRCSC • *Department of Urology, University of California Irvine Medical Center, Orange, CA*

STEPHEN Y. NAKADA, MD • *Division of Urology, Department of Surgery, University of Wisconsin-Madison Medical School, Madison, WI*

MARGARET S. PEARLE, MD, PhD • *Department of Urology, The University of Texas Southwestern Medical Center, Dallas, TX*

GLENN M. PREMINGER, MD • *Division of Urology, Duke University Medical Center, Durham, NC*

DAVID E. RAPP, MD • *Section of Urology, Department of Surgery, University of Chicago Pritzker School of Medicine, Chicago, IL*

OJAS D. SHAH, MD • *Department of Urology, New York University School of Medicine, New York, NY*

DAVID S. SHARP, MD • *Section of Laparoscopic and Minimally Invasive Surgery, Glickman Urological Institute, Cleveland Clinic Foundation, Cleveland, OH*

FARJAARD, M. SIDDIQ, MD • *Department of Urology, University of Miami School of Medicine, Miami, FL*

ARTHUR D. SMITH, MD • *Department of Urology, Long Island Jewish Medical Center, New Hyde Park, NY*

DOUGLAS W. SODERDAHL, MD • *Department of Urology, Eastern Virginia Medical School, Norfolk, VA*

W. PATRICK SPRINGHART, MD • *Division of Urology, Duke University Medical Center, Durham, NC*

BENG JIT TAN, MD • *Department of Urology, Long Island Jewish Medical Center, New Hyde Park, NY*

VÉRONIQUE TRAN, MD • *Division of Urology, Washington University School of Medicine, St. Louis, MO*

IOANNIS M. VARKARAKIS, MD, PhD • *The James Buchanan Brady Urological Institute, The Johns Hopkins Medical Institutions, Baltimore, MD*

RAMAKRISHNA VENKATESH, MD, FRCSC • *Division of Urology, Washington University School of Medicine, St. Louis, MO*

J. STUART WOLF, JR., MD • *Department of Urology, University of Michigan Medical School, Ann Arbor, MI*

Companion DVD

The companion DVD to this volume contains video segments in support of the book, organized in sections corresponding to the book. The DVD can be played in any DVD player attached to a NTSC television set. The DVD may also be viewed using any computer with a DVD drive and DVD-compatible playback software, such as Apple DVD Player, Windows Media Player 8 or higher (Win XP), PowerDVD, or WinDVD.

I

DIAGNOSIS AND INSTRUMENTATION

1 Endoscopic Imaging and Instrumentation

David S. Chou, MD *and Elspeth M. McDougall,* MD

CONTENTS

SUMMARY

With the advancement of materials science and optics, endoscopes have undergone major refinements since Bozzini's lichtleither, leading to the development of the modern endoscopes. This chapter presents the basic physics and characteristics of both rigid and flexible endoscopy. Included is a discussion on video systems and the integrated operating rooms. The future of cystoscopes, ureteroscopes, and nephroscopes for both rigid and flexible devices is presented. In addition to presenting the present-day endoscopes and delineating their features, this chapter includes discussions of the limiting factors of some of these fragile instruments and future trends to look forward to. It is important for the urologist to have a clear understanding of the characteristics of these highly technical instruments in order to make appropriate choices when purchasing these devices, and in understanding the nuances of handling them in their clinical practice. In addition, discussion of care and sterilization has been presented with recent research data reported to help in the decision-making process of acquiring these endoscopes and using them clinically. With the availability of a wide range of rigid, semi-rigid, flexible endoscopes, and specifically designed working instruments, most of the upper urinary tract lesions encountered in urology can be effectively diagnosed and treated in a minimally invasive approach. Continued refinements may potentially improve the optics, durability, and efficacy of these instruments as technological advances are incorporated into the design of endoscopes and accessory instruments.

Key Words: Endoscope; optics; light source; ureteroscopes; video imaging system; integrated operating room; cystoscopes; nephroscopes; rigid; flexible; semi-rigid; working channel; irrigation channel; deflection; sterilization.

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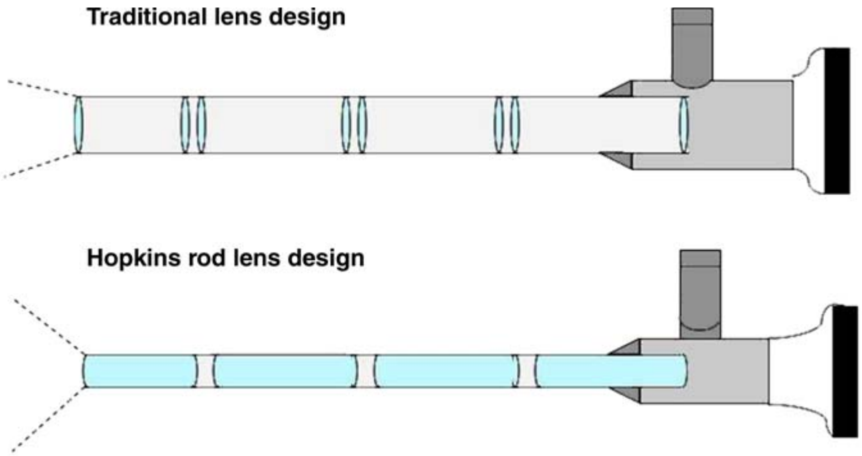

Fig. 1. Traditional and Hopkins rod–lens designs.

INTRODUCTION

The goal of endoscopy is to access and treat organs, through natural or artificial orifices in the body, with a telescope. The gradual evolution toward the modern endoscopes began with Philipp Bozzini's construction of the "lichtleiter" in 1806 for direct inspection and treatment of the uterus and bladder *(1)*. These early endoscopes were cumbersome and impractical, made of hollow examining tubes with illumination by candle light directed by a mirror. With the advancement of material science and optics, endoscopes have undergone major refinements since Bozzini's lichtleither, leading to the development of the modern endoscopes.

Optics

The first major improvement in optics was made by Nitze in 1877 by using a series of precisely aligned thin lenses within a tube *(1)*. The optical image is relayed from the distal end of the scope to the ocular lens where it can be viewed. The next breakthrough in optics did not occur until 1960 when Harold Hopkins developed the rod–lens system (Fig. 1) *(2)*. A more durable and smaller diameter scope was made possible by replacing the conventional thin lenses with long, contoured glass rods. The rods now served as the transmission medium and the thin pockets interspersed between the glass rods acted as lenses. The light reflecting off an object is detected by the objective lens at the distal tip and the image is transmitted via the rod–lens system back to the ocular lens where it is viewed by the surgeon's eye or captured by a camera. The rod–lens system offers better light transmission, reduced image distortion, wider viewing angle, and improved image brightness by nine fold. The size, or the degree of magnification, of the image is dependent on the diameter of the lenses, therefore a smaller caliber telescope, such as a ureteroscope, would have a smaller image than a larger caliber cystoscope. Although the Hopkins lens system provides excellent visualization and clarity when the shaft is straight, in straight cystoscopy and nephroscopy, significant deterioration can occur when torque is placed on the scope, as during passage through the ureter. The lenses and air spacers may come out of alignment, and up to half of the image may disappear, leading to a crescent field defect, or a "half-moon" appearance. Further stress on the shaft may lead to permanent lens damage or misalignment. Therefore, as demands for ureteroscopes increased, semirigid ureteroscopes or miniscopes that incorporate flexible fiberoptics within rigid shafts were designed to circumvent optical problems encountered during passage through a tortuous ureter.

Light Source

Throughout this period, the light source also underwent considerable modification. Trouve in 1873 moved the light source from the outside to the inner tip of the endoscope using a glowing hot platinum wire *(1)*. This was later replaced by a small incandescent light bulb. A major step toward modern endoscopy was made in the 1960s with the introduction of fiberoptic cable that enabled the transmission of light from an outside source. Fiberoptic cables provided more illumination with a cool light which made cystoscopy safer; it also made smaller profile scopes with larger irrigation and working channels possible. The fiberoptic cable may be built into the design of the scope, or it may be attached via a light post to the scope.

INSTRUMENTATION

Early endoscopic procedures were limited by the lack of accessory instruments to treat disease. As the optics of rigid endoscopes underwent continuous refinement, more sophisticated accessory instruments evolved to broaden their therapeutic potentials. The first true endoscopic procedure was performed by Desormeaux in 1853, extracting a papilloma from the urethra through an urethroscope. The usefulness of electrocautery was demonstrated in 1874 when Bottini performed blind electrosurgery of the prostate. A lever was introduced by Albarran in 1897 allowing the ability to control the electrode. This was improved by Freudenber in 1900 with the addition of an endocope for visualization. High-frequency current was introduced by Beer in 1910 which revolutionized the field of therapeutic endoscopic procedures. Subsequently, the first resectoscope was constructed in 1926 by Stern. It was modified by McCarthy in 1931, with the addition of a lever to move the cutting loop. This basic design is still used today for modern resectosopes. Subsequently, surgeons developed different loops, catheters, and wire baskets that could be passed through the endoscopes for the treatment of stone disease. Today, these instruments have become increasingly more powerful, with the development of ultrasonic, pneumatic, electrohydraulic, and laser lithotriptors.

Ureteroscopes

In 1912, Hugh Hampton Young performed the first ureteroscopic procedure using a pediatric cystoscope in a 2-month-old child with posterior urethral valve *(3)*. Our modern day concept of enodoscopy of the ureter and renal pelvis was made possible first by Marshall in 1960 with the advent of a 3-mm flexible fiberoscope *(4)*. Similarly, in 1968, Takayasu and Aso developed the first flexible pelviureteroscope with an operating channel *(5)*. The first rod–lens ureteroscopy was performed by Lyon to explore the distal ureter with a 11-Fr pediatric cystoscope in 1977 *(6)*. Ureteral orifice dilation was performed cystoscopically with Jewett sounds prior to insertion of the scope. The original ureteroscope was made by Richard Wolf Medical Instruments (Vernon Hills, IL) in 1979, modeled after a pediatric cystoscope, and was available with 13-, 14.5-, and 16-Fr sheaths *(7)*. The first practical ureteroscope was developed in 1980 and 1981 by Enrique Perez-Castro and the Karl Storz Company (Culver City, CA) *(8)*. However, these ureteroscopes utilized the rod–lens optical system and were limited by their size and the lack of adequate instrumentation for stone fragmentation and removal. They were purely instruments for diagnosis and not for therapeutic efficacy.

The application of fiberoptic technology was the next major step in the development of ureteroscopes. This was based on the principle of total internal reflection; light traveling inside of an ultrathin glass fiber surrounded by a cladding with a lower refractory index can be transmitted over a long distance with minimal degradation. A coherent fiberoptic bundle contains thousands of individual fibers with identical orientation at the ends of each bundle so the exact image is transmitted to the eyepiece. Therefore the image obtained by fiberoptic bundles is not a single image but a composite matrix of each fiber within the bundle, giving it a "honeycomb" appearance (Fig. 2A). The early flexible ureteroscopes were limited by the lack of irrigation, active deflection, or instrumentation. Continuous refinements have led to the 7.5-Fr flexible ureteroscopes with high pixel densities today. These ureteroscopes contain two coherent bundles for light transmission and one noncoherent bundle for image transmission, a working/irrigation channel to allow both irrigation and insertion of instruments, and active dual deflection, as well as secondary passive deflection. As demands for reliable rigid ureteroscopes grew, the fiberoptic technology was applied to a new generation of "miniscopes" or semirigid fiberoptic uretroscopes. The flexibility of the fiberoptic bundles allowed for the metal shaft to be flexed up to 2-in. off the vertical axis without significant image distortion. It also allowed a significant reduction of the outside diameter of the endoscopes, while maintaining larger working channels and greater irrigation flow rate compared to the rod–lens system. Semirigid ureteroscopes with small distal diameters of 4.5 to 8.5 Fr became available, making the inspection of the distal to midureter possible without routine dilation of the intramural ureter. At the same time, a host of new graspers, baskets, biopsy forceps, and laser fibers were also developed specifically for ureteroscopic procedures.

Video System

The images transmitted by the endoscopes may be viewed directly from the eyepiece or indirectly on a television monitor using a video system. A video system offers a large viewable area for binocular vision that can be viewed by multiple persons simultaneously, and with greater surgeon comfort and ergonomics. Specially designed cameras may contain "beamsplitters" (Fig. 3) to accommodate urologists who are more comfortable using direct visiualization through the endoscope eyepiece while projecting the same image on a television monitor for viewing by the operating assistant. A video system may include a camera and control device, television monitor, printer, and a video capture device. At the heart of modern digital imaging is the charge-coupled device (CCD), an integrated circuit designed to respond to light. A digital image is composed of millions of tiny dots of information or pixels. Each pixel corresponds to a charge generated by the CCD proportional to the intensity of the light striking it. Although single CCD chip cameras are still common, newer cameras for endoscopic procedures contain a prism-based 3 chip (multisensor) system to create a high-resolution image. Light from the image is split by a prism into the three primary colors: red, blue, and green to generate three CCD arrays. The information from each of the CCD is then merged by a computer into a single color pixel. The information is converted into a signal that is processed and refreshed up to 60 times per second and transmitted to a television monitor to form a complete image. New digital filters can be built into the camera system to eliminate the "honeycomb" appearance of the endoscope image at the expense of resolution (Fig. 2B). Continuous refinements in the video system are ongoing with the advancements in digital technology.

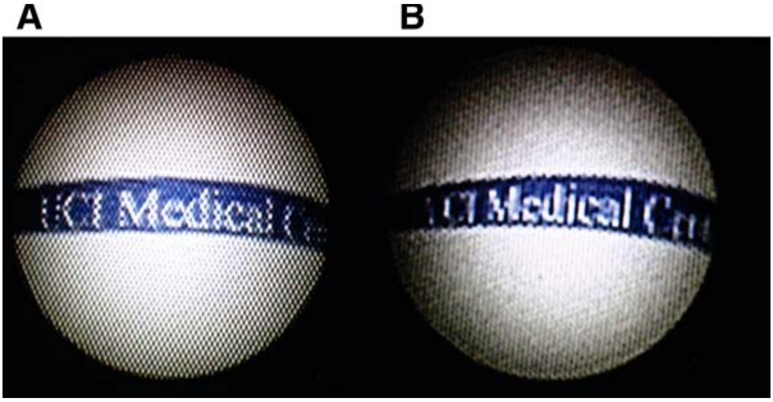

Fig. 2. **(A)** Honeycomb appearance of the modern fiberopotic endoscope image. **(B)** The use of a digital filter eliminates the honeycomb effect, but also reduces the resolution of the image.

Fig. 3. Beamsplitter camera (Karl Storz Inc, Culver City, CA).

Integrated Operating Rooms

As the equipment for endourology has become more sophisticated, the trend is now toward integration of all operating room functions and equipment controls into one central control unit which may even have touch screen or voice control capabilities, such as the OR 1™ system by Karl Storz or the Endoalpha™ Centralized OR system by Olympus (Melville, NY). Thus, the management of multiple complex systems can be simplified. Recent studies on surgeon fatigue and discomfort during minimally invasive surgeries has brought attention to the ergonomics of endoscopic procedures *(9)*. The surgeon's comfort, hand–eye coordination, and visualization can be greatly improved by using flat-screen, liquid crystal display monitors mounted on booms placed in close range to the surgeon's direct line of vision, the surgeon's hands, and endoscope. The integrated operating room provides an efficient and ergonomic work environment for the entire surgical team. This also provides a multidisciplinary, minimally invasive surgical suite. Single flat-screen monitors accommodate laparoscopic surgery, whereas the triple flat-screen monitors, on a single boom, provide simultaneous endoscopic and fluoroscopic visualization during endoscopy (Fig. 4).

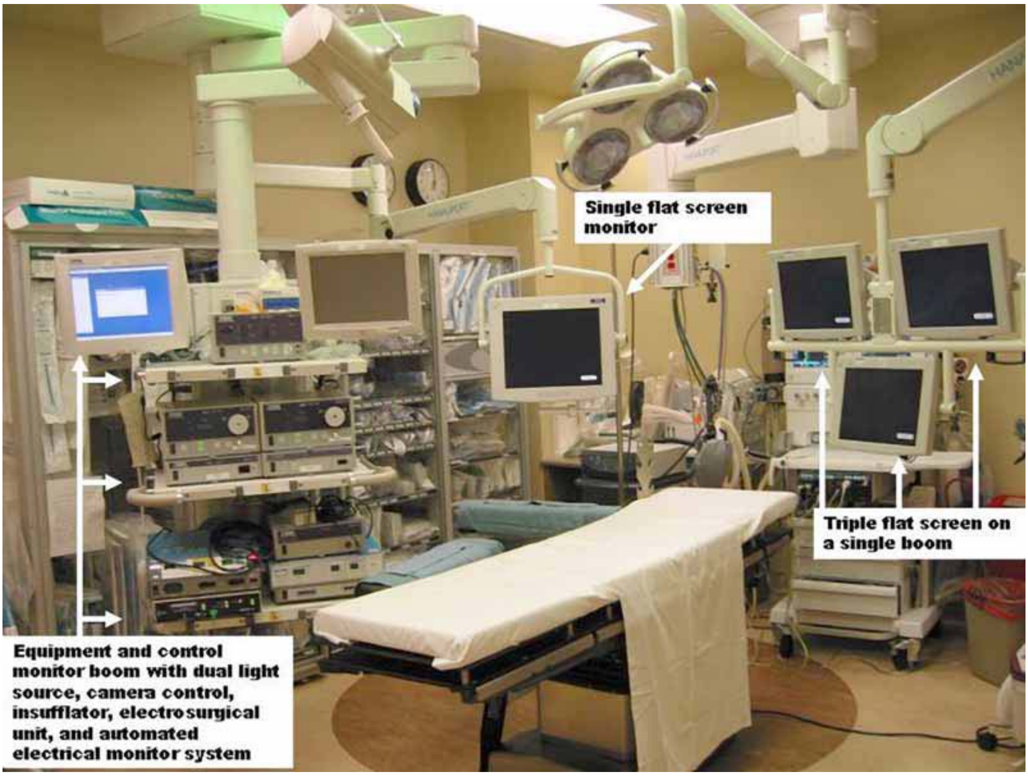

Fig. 4. Storz OR1™ at University of California Irvine Medical Center.

Future Trends

New development in video technology has allowed the cameras to become increasingly miniaturized with high resolution image output. Despite the advancements in traditional optical systems, they may eventually be replaced by digital and electronic imaging without a viewing lens. A small CCD chip can be mounted at the distal tip of the scope to transmit digitized information via a single fiber to a processor that can reconstruct the image on a television monitor. This will allow for a smaller scope profile with larger working channels while producing a superior image. Three-dimensional imaging may become possible if two CCD chips are used to create a stereoscopic vision. Finally, although still in its infancy, noninvasive virtual endoscopy from emerging computed tomography techniques may be used for surveillance of the entire urinary tract in the future *(10–12)*.

Rigid Cystoscopes

A rigid or flexible cystourethroscope may be used for direct visual inspection of the bladder. The rigid scopes offer a better image quality, larger working channels, and greater control, whereas the flexible scopes offer better access to visualizing all areas of the bladder and greater patient comfort. Basic components of the modern rigid cystoscope include the sheath, bridge, obturator, and telescope. The size of the sheath is expressed in French (Fr), which is a measure of the outer circumference of the scope in millimeters (1 mm = 3 Fr). Available sizes range from 8 to 12 Fr for pediatric endoscopes and up to 16 to 25 Fr for adult endoscopes. The bridge attaches to the sheath and allows for the attachment of irrigation tubing and the passage of the telescope and instruments. A deflecting Alberans bridge may be used to control deflection of flexible instruments as they pass through the distal portion of the instrument. The obturator may be inserted into the sheath to create a smooth tip for insertion. Viewing obturators allow the zero degree telescope to be inserted to enable direct visualization for passage of the instrument into and through the urethra. The standard telescopes available are 0 (direct), 12 (operative), 25 or 30 (forward-oblique), 70 (right angle), and 110 to 120° (retrospective). The telescopes contain the rod–lens system for image transmission and provide illumination via fiberoptic fibers.

Flexible Cystoscopes

The flexible cystourethroscope can also be used as a percutaneous nephroscope. The basic components include fiberoptic bundles, within a flexible shaft, to provide illumination and image transmission to the eyepiece, and a large, 6.4 to 7.5 Fr, channel to accommodate irrigation and ancillary instruments. The tip of the scope can be deflected in either direction from 180 to 220° with a thumb control. There are a wide variety of long, flexible instruments that can be passed through the working channel including grasping forceps, biopsy forceps, lithotripsy and electrocautery probes, and basket entrapping devices. A new digital cystonephroscope (Fig. 5) made by American Cytoscope Makers, Inc. (ACMI; Southborough, MA) has recently become available and is the first scope to address some of the unique demands of flexible nephroscopy. Besides the improvements in image quality, the digital cystonephroscope is capable of additional flexion perpendicular to the traditional up and down axis of deflection of the flexible cystoscopes. This may facilitate easier access of the calyceal system from the percutaneous nephrostomy tract sheath.

Semirigid Ureteroscopes

The newer generation of semirigid ureteroscopes contain fiberoptic bundles larger than those in a flexible ureteroscope. Therefore the image is comparable to those derived from a rod–lens system, and the “honeycomb” effect is further reduced by new fiber-packing techniques and an advanced camera system. A straight working channel for passage of a rigid instrument is possible in scopes that take advantage of the flexibility of fiberoptics and have an offset eyepiece. Most of the available semirigid ureteroscopes have round or oval tip designs, but scopes with smooth, triangular tips have recently become available, designed to ease insertion into the ureteral orifice. The shafts of these scopes are tapered such that they gradually enlarge from 5 to 8.5 Fr at the distal tip to 7.8 to 14.5 Fr at the proximal shaft. This design increases the proximal strength of the scope while providing a gradual dilation of the ureter as the instrument is advanced. The distal and lower middle ureter in men and the renal pelvis in women may be accessed using a 31-cm ureteroscope, whereas a 40-cm ureteroscope may be needed to reach the renal pelvis in male patients. The scopes may be designed with one large channel for both instrumentation and irrigation, or with two channels to separate instrumentation and irrigation. A single, straight, large working channel is possible in ureteroscopes with an offset eyepiece. In contrast, two channel scopes allow passage of a working instrument without diminution in the flow of the irrigant fluid. They usually have a 3.4-Fr working channel that can accommodate a standard 3-Fr instrument and a 2.1- to 2.4-Fr irrigation channel. Some of the currently available semirigid ureteroscopes and their features are listed in Table 1.

Flexible Ureteroscopes

Several state-of-the-art flexible ureteroscopes are available with a small distal diameter ranging from 4.9 to 11 Fr, and a relatively large working channel up to 3.6 Fr. These

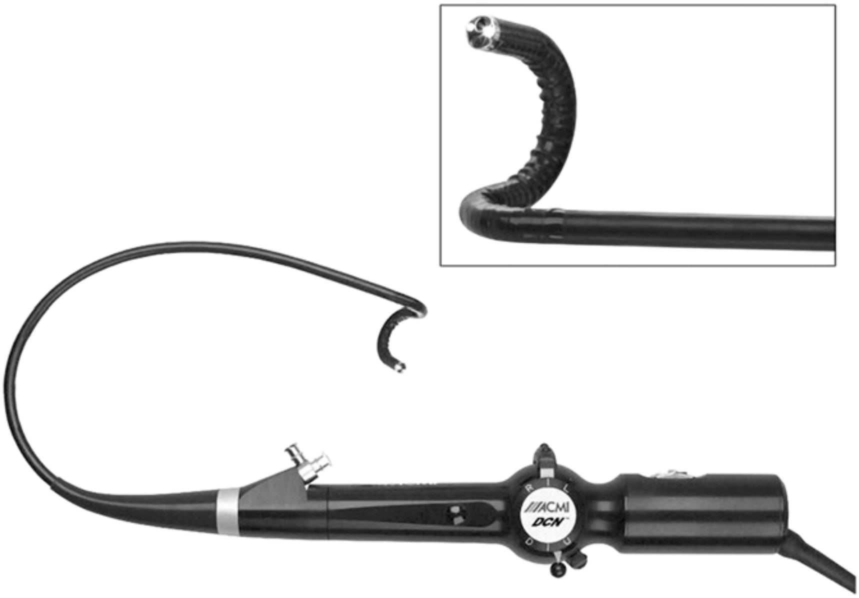

Fig. 5. Digital Cystonephroscope (ACMI, Southborough, MA).

scopes all contain imaging and light transmission fiberoptic bundles, a working channel, and a deflecting mechanism. However, each may have variations in dimensions, image transmission, working channel size, degrees of active deflection, the deflection mechanism, and tip design depending on the manufacturer. The newer scopes have working lengths between 54 and 70 cm. As in the semirigid scopes, they have tapered shaft designs with the proximal shaft size between 5.8 and 11 Fr. The smaller tip design has greatly reduced the need for ureteral dilation and decreased the ureteral complication rate. Some of the currently available flexible ureteroscopes and their specifications are listed in Table 2.

Optics

Each scope contains a coherent fiberoptic bundle for image transmission and one or two larger noncoherent light transmitting fiberoptic bundles. In general, two sets of light transmission bundles provide a more even illumination and decreased shadowing. The light cord which carries light from the lightsource to the ureteroscope may be incorporated into the design of the scope, or it may be attached onto a connecting post on the scope. The former uses a continuous bundle from the lightsource to the tip of the scope to provide a better illumination and relatively better visibility, whereas the latter offers the ability to replace the light cord separately if it should become damaged. In vitro evaluation of select, available ureteroscopes was undertaken at University of California-Irvine to compare the resolution and distortion of the ureteroscopes using test targets lined with dots of varying diameters at preset distances. The images of the test target, viewed through the ureterscopes, were analyzed. Resolution was defined as the imaging system's ability to distinguish object detail, measured in line pairs per millimeter. Distortion was defined as an optical error (aberration) in the lens that causes a difference in magnification of the object at different points in the image. It is calculated as [(Actual distance–Predicted distance)/Predicted distance] × 100. This was expressed in terms of a percentage. These studies have demonstrated the

Table 1
Specifications of Rigid and Semirigid Ureteroscope

Model	*Eyepiece design*	*Working length (cm)*	*Tip shape*	*Tip size (Fr)*	*Mid segment size (Fr)*	*Proximal size (Fr)*	*No. channels*	*Channel size (Fr)*	*Angle of view (degrees)*
ACMI									
MR-6/ MR-6L	Straight	33/41	Beveled/triangle	6.9	8.3	10.2	2	3.4, 2.3	5
MRO-633/ MRO-642	Offset	33/42	Beveled/triangle	6.9	8.3	10.2	2	3.4, 2.3	5
MRO-733	Offset	33	Beveled/triangle	7.7	9.2	10.8	1	5.4	5
MRO- 742	Offset	42	Beveled/triangle	7.7	—	10.8	1	5.4	5
Olympus									
A2940A/ 2941A	Offset	43/33	Oval	6.4	—	7.8	1	4.2	7
A2942A	Offset	43	Oval	8.6	—	9.8	1	6.6	7
A2948A/ A2949A	Straight	43/33	Oval	6.4	—	7.8	1	4.2	7
A2944A	Offset	43	Triangular	7.5	—	9.0	2	3.4, 2.4	7
A2946A/ A2943A	Straight	33/43	Triangular	7.5	—	9.0	2	3.6, 2.5	7
Storz									
27410SK/ 27410SL	Straight or offset	34/43	Triangular	7.5	9	10.5	2	3.6, 2.5	0
27430K/ 27430L	Offset	34/43	Oval	8	9	10.5	1 + 2 irrigation	5	0
27023SA/ 27023SB	Straight	34/43	Oval	10	12	13	1 + 2 irrigation	5.5, 3	0
27830A	Straight	25	Triangular	7.5	9.0	10.5	2	3.6,2.5	0
Wolf									
8702.402/ 8712.402	Straight	31/42.5	Oval	6	7.5	—	1	4.2	0
8702.533/ 8702.534	Offset	31/ 43	Oval	6	7.5	11	1	4.2	0
8703.402/ 8707.402	Straight or offset	42.5/ 31	Oval	8	9.8	11	1	5.2	10
8708.51	Straight or offset	31.5/ 33/ 43	Oval	6.5	8.5	11	2	4.2, 2.5	5
8704.401/ 8714.401	Offset	31/ 42.5	Oval	8.5	11.5	14.5	1	6.2	10
W8703.534/ 8703.533	Offset	31.5/ 43	Oval	8	9.8	14	1	5.2	10
8721.402/ 8721.401	Straight	31/42.5	Oval	4.5	—	—	1	2.5	0

Table 2
Manufacturers' Specifications of Flexible Ureteroscopes

Model	*Working length*	*Tip diameter*	*Midshaft diameter*	*Proximal diameter*	*Tip design*	*Active primary deflection (degrees)*	*Active secondary deflection (degrees)*	*Deflecting mechanism*	*Working channel size (Fr)*	*Angle of view*	*Comments*
ACMI											
DUR-8	65	6.75	9.4	10.1	Beveled	170/180	—	Both	3.6	9	
DUR-8E	64	6.75	9.4	10.1	Beveled	170/180	0/130	Both	3.6	9	
AUR-7	65	7.2	7.4	11	Beveled	170/180	—	Both	3.6	9	
Olympus											
URF-P3	70	6.9	—	8.4	Tapered	180/180	—	Counter-intuitive	3.6	0	Integrated Lightcord
Storz											
11274AAU	70	7.4	8.5	8.9	Round	120/170	—	Intuitive	3.6	0	
11274AA	70	7.4	8.5	8.9	Round	170/120	—	Counter-intuitive	3.6	0	
11274SP	70	7.4	8.5	8.9	Round	120/170	—	Intuitive	3.6	0	Integrated Videohead
11274SPU	70	7.4	8.5	8.9	Round	170/120	—	Counter-intuitive	3.6	0	Integrated Videohead
11278AU1	65	6.7	7.5	8.4	Round	270/270	—	Counter-intuitive	3.6	0	
11278AU	65	6.7	7.5	8.4	Round	270/270	—	Intuitive	3.6	0	
Wolf											
7325.172/ 7325.152/ 7325.122	70/45/20	7.5	7.5	7.5	Tapered	130/160	—	Intuitive	3.6	0	
7330.072/ 7330.052	70/45	7.4	9	9	Tapered	130/160	—	Intuitive	4.5	0	
7331.001	60	7.4	9	9	Tapered	130/160	—	Intuitive	3.6	0	

Table 3
Resolution and Distortion of Flexible Ureteroscopes

Resolution	
Wolf 7325.172:	25.39 lines/mm (BEST)
Wolf 7330.072:	22.62 lines/mm
Olympus URF-P3:	12.70 lines/mm
ACMI Dur-8:	14.30 lines/mm
ACMI DUR-8E:	11.30 lines/mm
Storz Flex X:	9.54 lines/mm (WORST)
Distortion	
Wolf 7330.072;	11.9% (Lowest distortion)
Olympus URF-P3:	13.6%
Wolf 7325.172:	18.4%
ACMI Dur-8:	28.8%
ACMI DUR-8E:	34.2%
Storz Flex X:	38.1% (Highest distortion)

Distortion (%) = [(Actual Distance – Predicted Distance)/Predicted Distance] × 100.

Wolf flexible ureteroscopes to have the best resolution with the least amount of distortion compared to the other commercially available flexible ureteroscopes (Table 3).

Tip Design

In general, most of these ureteroscopes have a 0° angle of visualization. However, some have a 9° angle for the visualization of instruments as they are advanced out of the working/irrigation channel. The majority of the flexible ureteroscopes have flush tips, however, some of the flexible scopes have a beveled, triangular tip which in theory may facilitate insertion into the ureteral orifice and decrease ureteral trauma. These beveled tip endoscopes also allow the manufactures to claim a smaller tip diameter, which rapidly enlarges to the distal shaft size, whereas the scopes with flush tips maintain the small distal diameter for several millimeters (Fig. 6).

Working/Irrigation Channels

Most of the modern flexible ureteroscopes have a single 3.6-Fr working channel with the exception of the Wolf 9-Fr ureteroscope that has a 4.5-Fr working channel. The larger caliber allows for a higher flow rate and insertion of larger instruments. Because the single channel is used for both passage of instruments and irrigation, an instrument in the channel will reduce the irrigant flow rate. The loss of flow may be compensated by pressurizing the irrigant fluid and the use of smaller, less than 1.9-Fr caliber instruments. It appears that the 200-µ laser fiber has the least deleterious effects on the flow rate, whereas the 3.0-Fr basket causes the greatest reduction in the flow rate (Table 4).

Scope Deflection

The active deflection of the tip of the flexible ureteroscope is manually controlled via a lever mechanism on the handle. Depending on the model, the tip may deflect from 130 to 270 degrees in either direction in the same plane. The scope may be designed with intuitive or counterintuitive deflection directions. In the more common intuitive deflection

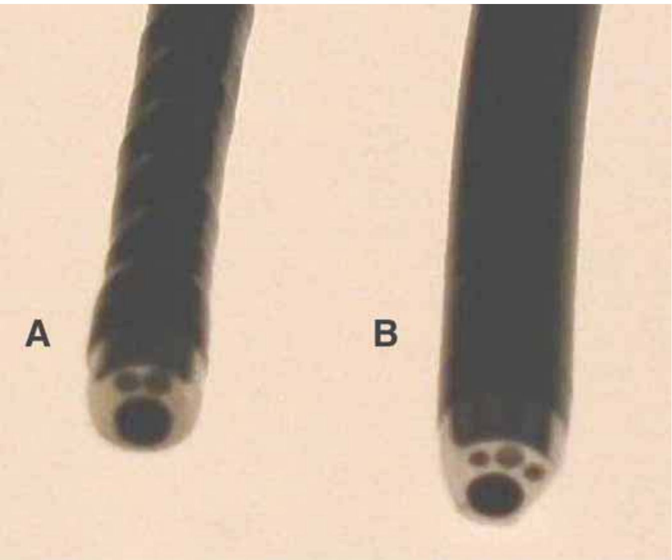

Fig. 6. Comparison of flexible ureteroscope tip design. **(A)** Flush tip of Flex-X ureteroscope (Karl Storz Inc, Culver City, CA). **(B)** Beveled tip of Dur-8 Elite (ACMI, Southborough, MA).

Table 4
Irrigation Flow Rate (cc/min) at 100 mmHg and Percent Reduction With Various Instruments

	ACMI Dur 8 Elite	*Stortz Flex-X*	*Olympus URF-P3*	*Wolf 7325.172*	*Wolf 7330.072*
Empty	60	56	65.5	70.5	153
200-µ laser	33.3 (44.5%)	28.5 (49%)	36 (45%)	37 (47.5%)	110 (28%)
400-µ laser	12 (80%)	8.5 (84%)	11 (83%)	11 (84%)	63 (58%)
1.9-Fr EHL (ACMI)	17.5 (71%)	13.7 (75%)	18.5 (71.8%)	19 (73%)	81 (47%)
2.2-Fr basket	15.1 (75%)	11.5 (79.5%)	11 (83%)	14 (80.1%)	79 (48.4%)
3.0-Fr basket	3.7 (94%)	2.7 (95.1%)	5 (92.3%)	4 (94.3%)	45 (70.5%)
2.6-Fr grasping forceps (microvasive)	4.5 (92.5%)	3.1 (94.5%)	5.5 (85.7%)	5 (93%)	53 (65.4%)

ACMI, Advanced Cytoscope Makers, Inc.; EHL, electrohydraulic lithotripsy.

scopes, the tip deflects in the same direction as the movement of the thumb lever, as opposed to counterintuitive deflection where the tip deflects in the opposite direction to the movement of the thumb lever. Whereas most of the scopes can be deflected 120 to 180° in either direction, the recently introduced “Flex-X” flexible ureteroscope (Karl Storz America Inc, Culver City, CA) can be deflected 270° in either direction (Fig. 7A). Another new ureteroscope, the “DUR-8 Elite” (ACMI Corp, Southborough, MA) incorporates a more proximal secondary 130° one way deflection in addition to the primary 170/180° up and down deflection (Fig. 7B). Besides the active deflection, flexible ureteroscopes also contain a passive deflecting segment; it is a more flexible segment of the scope that is placed several centimeters proximal to the active deflectable segment. This

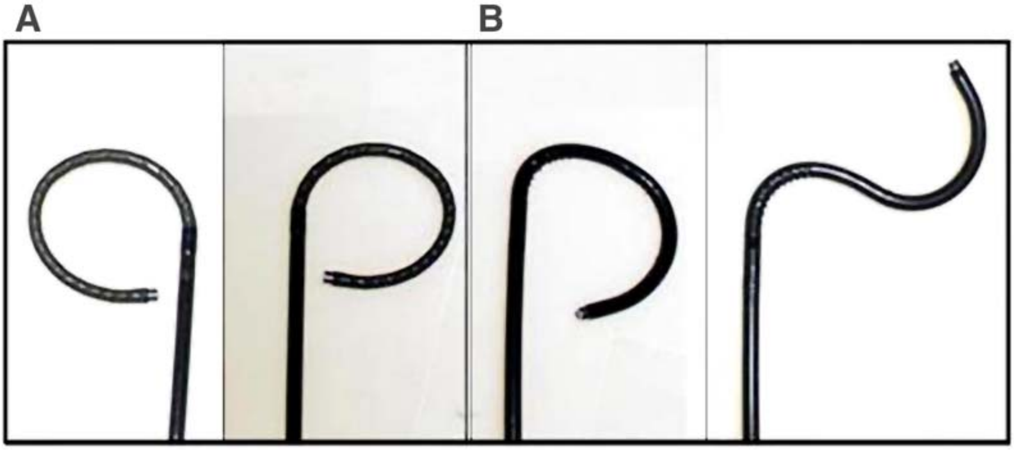

Fig. 7. Comparison between the Flex-X and DUR-8 Elite tip deflection mechanism. **(A)** Flex-X (Karl Storz Inc). **(B)** Dur-8 Elite, (ACMI).

passive deflecting segment, when used in consort with the active deflection, allows the scope to curl upon itself when the tip of the scope is reflected off the medial aspect of the renal pelvis for maneuvers into the lower pole infundibulum. Just as the flow rate is negatively impacted, the angle of active and passive deflection can also become severely restricted by the presence of instruments in the working channel. This effect on the angle of deflection can also be lessened with newer, smaller, and more malleable instruments. Various techniques have been described to limit the impact of instruments in the working channel, including the use of an unsheathed (bare naked) nitinol basket to reduce its diameter *(13,14)*. The degree of loss of deflection caused by the presence of various instruments were studied at University of California-Irvine Medical Center; measurements of deflection were made by photocopying the ureteroscopes when completely deflected. In general, the angle of deflection was most impaired by the 365-μ laser fiber, and the least impaired by the 2.2-Fr nitinol basket. The results are shown on Table 5.

Care and Sterilization

Although these modern flexible ureteroscopes are capable of accessing the most difficult areas in the upper urinary tract, they are fragile and require major repair after an average of 6 to 15 uses (*15*). Common reasons for repair are broken fiberopitc fibers, damaged working channel, and poor, or loss of, deflection. Currently, the durability and cost of maintenance is the main limiting factor against incorporation of these delicate instruments in most general urology practices *(16,17)*.

Rigid and semirigid ureteroscopes are considerably more durable than their flexible counterparts because of their outer metal casing. However, proper handling by holding these scopes near their eyepieces at the base while supporting the shaft should be emphasized. Cleansing with warm water and a nonabrasive detergent, as well as irrigation of the working channels, following each use is important. The rigid and semirigid ureteroscopes can be sterilized by gas (ethylene oxide) or by soaking; some may be autoclaved. Similarly, the more fragile flexible ureteroscopes should also be cleaned initially by rinsing and irrigating with warm water and a nonabrasive detergent, and then sterilized by gas or soaking. These delicate scopes are prone to damages from bending or

Table 5
Percent Loss of Deflection With Various Instruments

	ACMI DUR 8 Elite				*Storz FLEX-X*		*Olympus URF-P3*		*Wolf 7325.172*		*Wolf 7330.027*	
Instrument	*Down*	*Up*	*Active secondary*	*Active 1+2*	*Down*	*Up*	*Down*	*Up*	*Down*	*Up*	*Down*	*Up*
200-µ laser fiber	18.3%	21.1%	22.7%	7.1%	9.3%	12.4%	9%	11%	5.4%	11.5%	5.1%	3.1%
365-µ laser fiber	46.3%	39.5%	28%	25.9%	26.8%	31.8%	34.1%	43.9%	38.8%	35.9%	33.3%	28.1%
1.9-Fr EHL	9.1%	11.2%	18.9%	6.8%	8.5%	12.4%	14.1%	14.2%	12%	10.7%	19.2%	10.9%
2.2-Fr basket	4.9%	14.5%	16.7%	6%	2.4%	9.9%	12%	9.7%	0.7%	5.3%	13.5%	4.3%
3-Fr basket	12.2%	17.1%	18.2%	7.9%	10.6%	12.9%	13.2%	14.8%	17.4%	6.9%	14.7%	3.1%
2.6-Fr grasper	22%	20.4%	25.8%	14.3%	15.9%	21.9%	17.4%	14.8%	19.9%	12.2%	16.7%	14.1%

EHL, electrohydraulic lithotripsy.

trauma to the distal tip or the eyepiece. Therefore, every effort should be made to maintain them in a straight orientation during cleansing and use. In addition, the flexible ureteroscopes require venting during gas sterilization, either by manually opening a vent near the irrigation port near the light post, or some may have an automatic, patented, *Autoseal* system. Liquid steriliztion may be accomplished by soaking in 2.4% glutaraldehyde (i.e., Cidex, Advanced Sterilization Products, Irvine, CA) or 35% peroxyacetic acid (i.e., Steris, Mentor, OH). Peroxyacetic acid is harsh on flexible endoscopes and has been demonstrated to be associated with higher flexible cystoscope repair costs *(18)*. However, the durability of the flexible ureteroscopes may also be effected by the technique and number of personnel involved in the cleaning and maintenance rather than the technical demands of the procedure and the endoscopists' technique *(19)*. The routine use of newer ureteroscopic accessories such as ureteral access sheaths, nitinol devices, and 200-µ holmium laser fibers can decrease the strain on the flexible ureteroscopes and significantly increase the longevity *(17)*.

Rigid and Flexible Nephroscopes

The rigid nephroscopes have undergone little change since the advent of percutaneous nephrostolithotomy. In general, they provide excellent visualization with a rod–lens system and an offset eyepiece to allow passage of large, straight instruments for stone fragmentation, such as the ultrasonic lithotriptor or the lithoclast. Various lengths are available, ranging from 17.5 to 30 cm, to accommodate a variety of patient body habitus. Sheaths range from 15 to 27 Fr in size; "mini-nephroscopes" with a smaller, 11-Fr diameter which can be used as a compact cystoscope are also available. A flexible cystoscope may be used as a nephroscope when needed. A new digital cystonephroscope by ACMI has been developed and offers additional flexion to the traditional up/down plane to meet the demands of percutaneous nephrostolithotomy (Fig. 5).

CONCLUSION

Since the initial concept of inspecting a body cavity using a light and image transmitting system, significant development and advancements have been made in the field of urologic endoscopy. With the availability of a wide range of rigid, semirigid, flexible endoscopes, and specifically designed working instruments, most upper urinary tract lesions can be effectively diagnosed and treated in a minimally invasive approach. Continued refinements to these instruments may potentially improve the optics, durability and efficacy of the treatment as technological advances are incorporated into the design of the endoscopes and accessory instruments.

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2

Access, Stents, and Urinary Drainage

Ben H. Chew, MSc, MD, FRCSC
and John D. Denstedt, MD, FRCSC

Contents

SUMMARY

Ureteral access is necessary in many endourological procedures including ureteroscopy and ureteral stenting. Technologies such as ureteral access sheaths, balloon dilators, and coaxial dilators may be helpful in facilitating ureteral access in difficult cases. This chapter describes a stenting technique that relies on fluoroscopic guidance once the initial guidewire is placed and the cystoscope is removed.

Key Words: Ureter; stent; calculi; ureteroscopy; nephrostomy tube; shockwave lithotripsy.

INTRODUCTION

Ureteral stents are a mainstay in the urological armamentarium and are utilized in the treatment of urolithiasis including postureteroscopy, preshockwave lithotripsy, and to relieve symptomatic renal colic. Routine stenting postureteroscopy and intracorporeal lithotripsy, once the standard of care, have been shown to be unnecessary following uncomplicated ureteroscopy and stone manipulation. Advances such as laser lithotripsy and smaller ureteroscopes have minimized the potential morbidity of ureteroscopy to the point that the indwelling stent has become the most morbid part of the procedure. Ureteral stents may cause considerable side effects ranging from dysuria, urgency and frequency to hematuria

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and suprapubic pain. There is an emerging body of literature that routine stenting postureteroscopy is not necessary and that the need for stenting should be determined on a case by case basis.

Stents are also used to provide urinary drainage in nongenitourinary causes of ureteral obstruction, such as pregnancy and malignant ureteral obstruction. An alternative and effective method of urinary drainage is the percutaneous nephrostomy tube which is easily placed in patients with significant hydronephrosis and may be even more successful than retrograde ureteral stenting when urinary drainage is required as a result of obstruction of the distal ureter. Incompressible stents incorporating metal into the stent material have been used to provide urinary drainage to patients with malignant ureteral obstruction. Conversely, biodegradable stents have been developed to provide ureteral drainage temporarily following an endourological procedure before degrading and being excreted in the urine, thus obviating the need for cystoscopic stent removal. Other stent advancements will see coatings, new materials, and drugs loaded directly into the stent material or coated on the stent surface to improve comfort and reduce biofilm formation, infection, and encrustation.

Access to the ureter is required any time closed endoscopic ureteral procedures are to be carried out including during ureteral stenting and in association with diagnostic and therapeutic ureteroscopy for urolithiasis. More detail will be provided in other chapters regarding procedure specific aspects of ureteroscopy and percutaneous procedures; this chapter will focus on initially gaining retrograde access to the ureter, aspects related to ureteral stenting and a comparative analysis of alternative methods of urinary drainage. A brief summary of new stent technologies and biomaterials will also be presented.

Indications to Access the Ureter

Achievement of ureteral access is necessary for performing retrograde endoscopic procedures such as ureteroscopy, or for placing a ureteral stent. Table 1 lists common indications for ureteral stent placement.

Stones

Urolithiasis represents one of the more common reasons to insert a ureteral stent. Clinical indications for stenting include patients with intractable pain, those with infected pyonephrosis, or patients with impaired renal function from obstruction. In addition, ureteral stenting is often employed as an adjunct to shockwave lithotripsy or endoscopic procedures in patients requiring surgical stone management.

Ureteral Stones: Retrograde Ureteral Stenting vs Nephrostomy Tube Drainage

Pyonephrosis with an obstructing stone requires urgent decompression using either retrograde ureteral stent placement or antegrade percutaneous nephrostomy tube drainage *(1)*. Whether urinary drainage to bypass the obstruction is best accomplished via a ureteral stent or a nephrostomy tube is a subject of debate. The first randomized clinical trial to compare these two methods in obstructed, infected patients was performed by Pearle et al. *(2)* in 42 patients with obstructing urolithiasis and pyonephrosis. The time to defervescence, length of stay in hospital, pain symptoms, and normalization of leukocytosis did not differ between these two groups suggesting that urinary decompression by either retrograde ureteral stenting or antegrade percutaneous nephrostomy tube insertion are both equally effective in treating obstructed pyonephrosis. However, patients had significantly less fluoroscopy exposure (2.6 minutes less) when they were stented in a retrograde fashion.

Table 1
Indications for Ureteric Stent Insertion

- Stones—intractable pain, infection, hydronephrosis, acute renal failure, solitary kidney
- Postureteroscopy
- Pretreatment (pre-SWL)
  - Solitary kidney, stone >15 mm in diameter,
- Steinstrasse post-SWL
- Pyonephrosis (infection)
- Stricture (endoureterotomy)
- Trauma
- Fistula
- Ureteropelvic junction obstruction
  - To relieve symptoms
  - Post endopyelotomy/pyeloplasty
- Hydronephrosis/calculi of pregnancy
- Post reconstruction
  - Renal transplant
  - Ureteroneocystotomy
  - Ureteroureterostomy
  - Cystectomy and urinary diversion
- Extrinsic ureteral obstruction

SWL, shockwave lithotripsy.

A similar study was performed by Mokhmalji and colleagues *(3),* who also found no difference in relief of the presenting symptoms between patients randomized to nephrostomy tube insertion and ureteral stent placement. Percutaneous nephrostomy tube placement was successful in all of the 20 patients randomized to that group, but only 80% of the 20 patients randomized to retrograde ureteral stent placement were successfully stented. Although not statistically significant, there was a trend towards an improved quality of life in the nephrostomy tube group when pain, dysuria, frequency, and hematuria were taken into consideration.

From the standpoint of infection and the requirement for urinary decompression, it appears that nephrostomy tube drainage and ureteral stents offer equal drainage of the upper urinary tract. Symptoms of pain and irritation are also similar. Placement of a nephrostomy tube or ureteral stent depends on availability of good interventional radiologists and the urologist's access to the cystoscopy suite or operating room. At some hospitals, the radiology suite may be more accessible than the operating room or cystoscopy suite or vice versa. Subsequent procedures should also be taken into account. For instance, in patients who will require a percutaneous nephrolithotomy, a percutaneous nephrostomy tube is the preferred intervention and in patients with stones amenable to shockwave lithotripsy (SWL), a ureteral stent is often preferable. Many variables must be taken into account to determine whether a percutaneous nephrostomy tube or ureteral stent should be placed in patients with obstructing stones.

Ureteral Stenting Effects on Ureteral Physiology and Stone Passage

Animal studies have demonstrated that ureteral stents decrease the frequency and amplitude of ureteral contraction in animals. In an animal model of ureteral stones causing obstruction, ureteral dilatation was observed proximal to the obstruction in the stented group whereas a nephrostomy tube group had no dilatation *(4)*. Stents also impeded spontaneous stone passage and reduced ureteral contractility when compared to the nephrostomy group *(4)*. This is controversial, however, as others have shown that ureteral stents facilitate spontaneous passage of distal ureteric stones less than 10 mm in diameter in 83% of patients studied *(5)*. The ureter and ureteral orifice are theorized to passively dilate from the stent, thus facilitating stone passage. Although stents may affect ureteral peristalsis, the dilation of the ureter and orifice do facilitate spontaneous passage of smaller stones.

Stent Comfort and Quality of Life

There is an increasing awareness that stents impact patients' quality of life. Stents may cause morbidity in up to 80% of patients with symptoms ranging from irritative voiding symptoms, hematuria, flank pain, suprapubic pain, infection, and stent migration to the "forgotten" encrusted stent *(6–8)*. As a consequence of these concerns, the use of routine stent placement is being more thoroughly considered on a case-by-case basis when utilized as an adjunct to SWL or ureteroscopy.

In order to quantify patient morbidity from stents, Joshi et al. *(7,8)* have developed and validated the first questionnaire of stent symptoms, the Ureteral Stent Symptom Questionnaire, which consists of 48 items spanning five criteria: pain, voiding symptoms, work performance, sexual health, and overall general health. Results indicate that 76% of stented patients experienced negative symptoms, 70% required analgesic, and 42% had to reduce their activity by half *(8)*. This validated tool should become a standard evaluation technique of new stent technologies.

Stones: Stenting as an Adjunct to Shockwave Lithotripsy

Stenting prior to SWL is thought to preclude renal obstruction from stone fragments following SWL *(9)*. More recently, the prophylactic efficiency of pre-SWL stenting has been called into question and is now a debated topic where some believe that stents in SWL patients not only lack efficacy to prevent renal obstruction, but may, in fact, impede the passage of stones fragments following SWL *(10)*.

Steinstrasse, or the "street of stone" occurs with an overall rate of 3 to 6% of patients undergoing SWL *(11)* and in 13 to 26% of nonstented patients with stone burdens greater than 25 mm in diameter *(12,13)*. Placing stents prior to SWL in patients with stones greater than 20 to 30 mm in diameter significantly decreased the rate of steinstrasse to 3 to 7% *(11,14–16)*. In patients with stones smaller than 25 mm, the rates of steinstrasse and infection were unaffected by stenting *(9,17–20)*. The reason for this latter finding is likely the result of a significant risk decrease of steinstrasse in patients with stones less than 20 mm *(21)*. A retrospective review by Madbouly et al. *(21)* has shown that there are four variables that are significantly correlated with an increased risk of steinstrasse: stone size greater than 20 mm, stones located in the renal pelvis, a dilated renal pelvis, and shock wave energy greater than 22 kV. The risk of steinstrasse was 3.7 times less in stones smaller than 20 mm compared with stones greater than that 20 mm. Stone location was also a factor because dilation of the collecting system would lead to decreased amplitude of each contraction and lower intrapelvic pressures and propulsive power. Stone fragments in the ureter and a nondilated renal pelvis are subjected to a higher force and rate of peristalsis which would lead to propulsion through the system. The risk of steinstrasse was reduced by two times for energies delivered at 18 to 22 kV and reduced by three times at energies of 14 to 18 kV *(21)*. High-energy shock waves have been shown to produce larger stone fragments compared with more frequent lower powered shocks which result in finer stone fragments *(22)*.

These studies suggest that ureteral stents should be placed prior to SWL for large stones (>20-mm diameter). Some studies, particularly those treating large stones with SWL, must be considered with caution as percutaneous nephrolithotomy is usually the treatment of choice in stones greater than 20 or 25 mm. For patients with stones less than 20 mm who are to be treated with SWL, there is little evidence that stenting prior to SWL reduces the rate of steinstrasse or infection.

Stones: Stenting Postureteroscopy

The principle of avoiding ureteral obstruction secondary to ureteral edema and stone fragments is the main driving force for routinely leaving a stent post ureteroscopy and has traditionally been regarded as the standard of care. Technical advances including miniaturization of ureteroscopes, utilization of the holmium:YAG laser, and softer stone baskets have made ureteroscopy relatively atraumatic and the main morbidity following ureteroscopy originates from the use of ureteric stents. Furthermore, stents add to the cost of patient care and require an additional cystoscopy for removal unless a pull string is used. Reducing stent use following ureteroscopy should improve patient care and satisfaction (*see* Table 2).

Hosking *(23)* was the first to report a large series of nonstented ureteroscopy patients who had minimal complications. Approximately half of the patients had no discomfort and the majority of those with discomfort described it as mild and easily resolved by oral analgesics. Although this report was a case series and did not have a stented control group, it was the first series to suggest that ureteroscopy did not routinely require stenting. Denstedt et al. *(24)* randomized 58 patients to receive either a stent or no stent after ureteroscopy. The results demonstrate that there were no differences in rehospitalization rate, analgesic use or stone free rates. At 1 week, the stented group had significantly more pain and irritative voiding symptoms than the nonstented group. None of these patients underwent ureteral dilation, the holmium:YAG laser was used for intracorporeal lithotripsy, and all stones were less than 2 cm. The holmium:YAG laser is safe and has minimal effects on surrounding tissue which makes it an ideal modality to preclude the need for a stent postoperatively *(25)*. In addition, a randomized study using intracorporeal electrohydraulic lithotripsy also demonstrated that these patients can be safely left unstented *(26)*. Other randomized studies have found similar results suggesting that following uncomplicated ureteroscopy without ureteric dilation, stenting is not routinely required *(24,26–28)*. Even in patients who underwent ureteral dilation at the time of ureteroscopy, nonstented patients had results and complication rates similar to stented patients *(23,29)*. In the series by Hosking and associates *(23)*, ureteral dilation was performed in 88% of patients who suffered minimal complications postoperatively. Borboroglu et al. *(29)* performed a study in 107 patients, which also included 83 patients who underwent ureteral balloon dilatation, and found that stented patients had more pain and analgesic requirements, but no difference in stone free or rehospitalization rates. These studies provide evidence that stenting after uncomplicated ureteroscopy is not routinely necessary, but rather should be determined on a case-by-case basis.

Hydronephrosis/Calculi in Pregnancy

Upwards of 90% of women have hydronephrosis by the third trimester of pregnancy *(30)*, but only 0.2–25% will become symptomatic and require medical attention

Table 2
Summary of Stent vs No-Stent Trials Following Ureteroscopy

Authors (ref)	*Year*	*Number of patients stented/not stented*	*Balloon dilation of ureter?*	*Difference in stone-free rates?*	*Method of intracorporeal lithotripsy*	*Significant difference in major complications? (fever, rehospitalization, obstruction)*	*Significant difference in minor complications? in minor complications? (pain, irritative voiding symptoms)*
Hosking et al. *(23)*	1999	0/93	Yes 82/93 (15-Fr balloon)	No	Electrohydraulic (3 pts.) Pneumatic lithotripsy (17 pts.) Basket extraction (73 pts.)	N/A	85% had no pain or pain controlled by oral analgesics
Denstedt et al. *(24)*	2001	29/29	No	No	HO:YAG Laser	No	More irritative symptoms in stented patients
Chen et al. *(26)*	2002	30/30	No	No	Electrohydraulic	No	No
Hollenbeck et al. *(27)*	2001	51/51	Yes (15-Fr balloon)	No	HO:YAG Laser	No	More pain in stented patients
Byrne et al. *(28)*	2002	38/22	No	No	HO:YAG Laser Pneumatic Lithotripter	No	Suprapubic discomfort on POD no. 1 was worse in non-stented patients, but by POD no. 6, was worse in stented patients.
Borboroglu et al. *(29)*	2001	53/54	Yes 83/107 (15- or 18-Fr balloon)	No	HO:YAG Laser Electrohydraulic	No	Stented patients has significantly more flank and bladder pain, urinary symptoms and required more narcotic analgesia.
Netto et al. *(29a)*	2001	133/162	No	No	Basket extraction Ultrasonic lithotripsy	No	No

HO:YAG, holmium: YAG.

(30–32). The vast majority of patients respond to conservative treatment (70–93%) and few will require ureteral stenting or nephrostomy tube insertion. Indications for stenting include: rising creatinine, pyelonephritis (febrile infection), and intractable pain *(30–32)*. Although ultrasonography may be used to confirm the position of the stent during the procedure *(33–36)*, limited fluoroscopy, which most urologists are more familiar with, can be used safely and effectively, especially in the later stages of pregnancy *(37,38)*. Shielding of the uterus and brief pulses of fluoroscopy should minimize the risks of radiation, but fluoroscopy should be avoided during the early stages of pregnancy *(37,39)*.

The incidence of urolithiasis ranges from 1 in 200 to 1 in 2500 pregnancies *(40)*. The majority of calculi presenting during pregnancy will pass spontaneously with conservative management *(41–44)*. If an obstructing calculus fails spontaneous passage, the options are to decompress the kidney and treat the stone after delivery, or to definitively treat the stone during pregnancy. Prolonged indwelling stents or nephrostomy tubes may lead to encrustation, biofilm formation, and infection as pregnant women have physiologic hyperuricosuria and hypercalciuria *(45,46)*; therefore, some studies suggest that ureteral stents should only be placed after 22 weeks gestational age to avoid the need for multiple stent changes *(44)*. In pregnant women less than 22 weeks gestational age, a percutaneous nephrostomy tube can be inserted and changed multiple times with relative ease *(44,47)*. If conservative management fails, ureteroscopy and intracorporeal lithotripsy is a reasonable treatment option and have proven to be safe in the treatment of urinary calculi in pregnant patients *(41,46,48–50)*. Utilization of intracorporeal methods of lithotripsy, such as the pulsed-dye laser, pneumatic lithotripsy, and the holmium: YAG laser, have been shown to be safe with success rates greater than 90% *(38,41,44,46,49)*. Advances in anesthesia and ureteroscopic equipment have made intracorporeal lithotripsy safe and effective in pregnancy when conservative management fails.

Stenting Postureteropelvic Junction Obstruction Reconstruction

Endopyelotomy for ureteropelvic junction obstruction was initially described by Wickham and Kellett in 1983 *(51)*. A standard procedure following endopyelotomy is to leave a tapered 14/7-Fr endopyelotomy stent to traverse and splint the incised ureteropelvic junction. The size of endopyelotomy stent remains controversial with one study suggesting that a larger diameter stent (27 Fr) improves results at 2 years *(52)*, whereas other studies in animal models find no difference between 7 and 12–14-Fr stents *(53,54)*. Stent indwelling time is also controversial: in two studies comparing 2 vs 4 weeks of stenting postendopyelotomy, 2 weeks were shown to have similar results to 4 weeks *(55,56)*. Patency rates were similar between 2 and 4 weeks of stenting (92 vs 90%, respectively) and patients stented for the longer period of time had significantly higher rates of infection *(56)*. There is also further evidence in an animal model that a longer duration of stenting results in more ureteral fibrosis and thus, a higher rate of failure *(57)*.

These studies demonstrate that 2 and 4 weeks of stenting with a 14/7-Fr endopyelotomy stent result in the same success rates following endopyelotomy. Likewise, the ideal stent diameter is still a matter of debate as sizes from 7- to 27-Fr have been shown to produce equal results.

Malignant Ureteric Obstruction

Malignant extramural compression of the ureter causing hydronephrosis and renal compromise may be a consequence of many nongenitourinary cancers. When faced with this situation, the urologist must decide if the patient needs decompression and if so, whether it is urgent and if a stent or antegrade nephrostomy tube should be placed *(58)*. If a stent is to be placed, what type of stent should it be and how often should it be changed? In the decision algorithm, the patient's entire clinical picture must be taken into account including the overall prognosis, symptoms such as flank pain, presence of infection, renal function, and intention for further treatment, such as chemotherapy *(59)*. For instance, a terminally ill patient with bilateral hydronephrosis who is asymptomatic and free of infection may only suffer from the addition of urinary drainage tubes *(60)*. The symptomatic patient (infection, flank pain, fluid overload from renal failure) should be diverted. Patients with renal compromise from obstruction and who are about to undergo chemotherapy (palliative or curative) should have their renal function optimized by urinary drainage.

Park et al. *(58)* reported on patients who initially had bilateral ureteral stents that failed to lower serum creatinine or relieve ureteral obstruction and subsequently required percutaneous nephrostomy tube insertion. They suggested that percutaneous nephrostomy tubes are advantageous over ureteral stents in relieving malignant ureteral obstruction and lowering serum creatinine *(58)*. Pappas et al. *(61)* evaluated 206 patients with malignant ureteral obstruction treated with percutaneous nephrostomy tubes and found that it was a safe and effective procedure that returned normal renal function to 66% of obstructed patients. One theory of why nephrostomy tubes are more efficient at relieving obstruction is that because urine drains around a stent rather than through the lumen, extraluminal compression from cancer prevents ureteral peristalsis and precludes peristent urinary drainage *(58,62)*. Lastly, because stents often cause significant bladder and flank symptoms, nephrostomy tubes may offer a better quality of life than stents in cancer patients *(60)*.

The percentage of successful retrograde stent placements is lower than nephrostomy tube insertion which is nearly always successful in a dilated system *(3,63)*. With very distal ureteral obstruction owing to advanced pelvic malignancies, retrograde stenting may be difficult because of the lack of "purchase" required to advance a guidewire or stent up the ureter *(3,63)*.

Recently, a third method of diversion involving a silicone polytetrafluorethylene coated tube that connects the renal pelvis to the bladder via a tunneled subcutaneous route has been described *(64–66)*. Metal, noncollapsible stents have also been attempted in malignant ureteric obstruction, but the main limiting factors have been blockage of the stent with hyperplastic tissue and infection *(67–70)*.

Percutaneous nephrostomy tubes offer easy placement, exchange, and good drainage of the upper urinary tract in this difficult group of patients *(71)*. Improvements in stent materials and technology will increase the use of indwelling ureteral stents in managing malignant ureteral obstruction *(72)*.

ACCESS TECHNIQUES

Ureteral Access: Step 1—The Urethra

Retrograde approaches to the urinary tract begin at the urethra and face the potential challenges that are encountered in the lower urinary tract such as meatal stenosis, urethral stricture, false passage, prostatic hyperplasia, and priapism. Good urological principles guide the management of each situation: meatotomy for stenosis, visual internal urethrotomy or dilation for strictures, insertion of a safety guidewire to circumvent false passages, use of flexible cystoscopy as an adjunct when an enlarged prostate is encountered, and intracorporal α-agonist injection for priapism.

Table 3
List of Instruments Required to Obtain Access to the Ureter

1. Flexible cystoscope (or rigid cystoscope)
2. Guidewires
   a) 0.038-in. floppy-tipped wire,
   b) hydrophilic coated wire straight or angled
3. Open-ended retrograde catheters, angled catheters
4. 8/10-Fr coaxial dilators
5. Radiocontrast and syringe
6. Ureteral access sheath
7. Balloon dilator
8. Amplatz dilators

Ureteral Access: Step 2—Advancing a Guidewire Into the Ureter

Table 3 lists the equipment necessary for ureteral access. Cystoscopy is initially carried out to identify the ureteral orifices. Either a flexible or rigid cystoscope may be used, but flexible cystoscopes are less traumatic, offer more patient comfort, and provide the surgeon with greater range of motion, particularly in patients with an enlarged prostate gland. A floppy-tipped guidewire 0.038 in. in diameter is inserted into the ureter, advanced, and coiled into the renal pelvis under fluoroscopy. Once the guidewire is secure in the ureter, the scope is removed leaving the guidewire in place. If there is doubt about the position of the wire or the anatomy of the collecting system, an open-ended ureteral catheter can be placed over the guidewire to perform a retrograde pyelogram using dilute contrast.

After the guidewire is placed, the next step is dependent on the procedure at hand: rigid ureteroscopy can be carried out by inserting the semirigid ureteroscope alongside the guidewire, whereas flexible ureteroscopy requires placement of a second guidewire which will be removed after enabling advancement of the flexible ureteroscope over the wire *(73)*. Placement of a secondary wire can be achieved by placing a double lumen wire introducer or an 8/10-Fr ureteral dilator sheath set. The flexible ureteroscope is back-loaded over one guidewire and advanced into the renal pelvis. Some advocate using a "double-floppy" guidewire, which reduces the potential for damage to the working channel of the ureteroscope *(74)*. The second wire must remain as a "safety" for access and identification of the ureteral lumen. Ureteral perforation, false passage, or any other difficulties can be salvaged by simply placing a stent over the safety wire and deferring the definitive procedure to a later date.

Ureteral Access: Step 3—Difficulties With the Ureteral Orifice

Once two guidewires are advanced into the renal pelvis, difficulty may be encountered at the ureteral orifice when introducing a flexible ureteroscope. This can be counteracted by gently rotating the scope over the guidewire while advancing it into the ureter. Ureteral dilation is not routinely necessary for ureteroscopy *(75)*, but if a truly stenotic orifice is encountered, balloon or coaxial dilatation may be necessary *(76)*. An alternative technique is to place an indwelling stent for 7 to 10 days to passively dilate the ureter and resume ureteroscopy at that time. Balloon dilators come in 5- to 7-Fr diameter catheters with balloons ranging from 4 to 7 mm in diameter that can exert up to 220 psi (15 atm). Experimental animal studies suggest that overzealous dilation to 15 Fr at 10 atm can cause

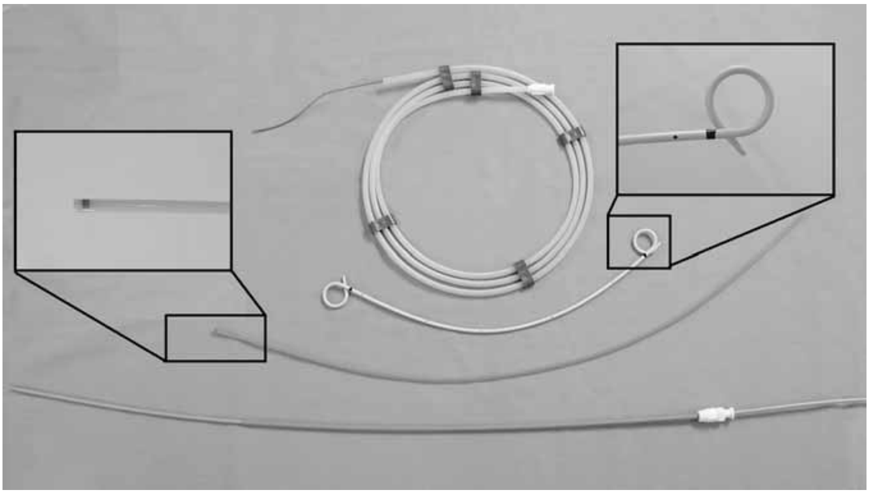

Fig. 1. Materials required for ureteral stenting. (From top to bottom) Floppy tipped guide wire, Double-J stent (curl magnified), metal-tipped stent pusher (radiopaque metal tip magnified), 8/10 coaxial sheath dilator set.

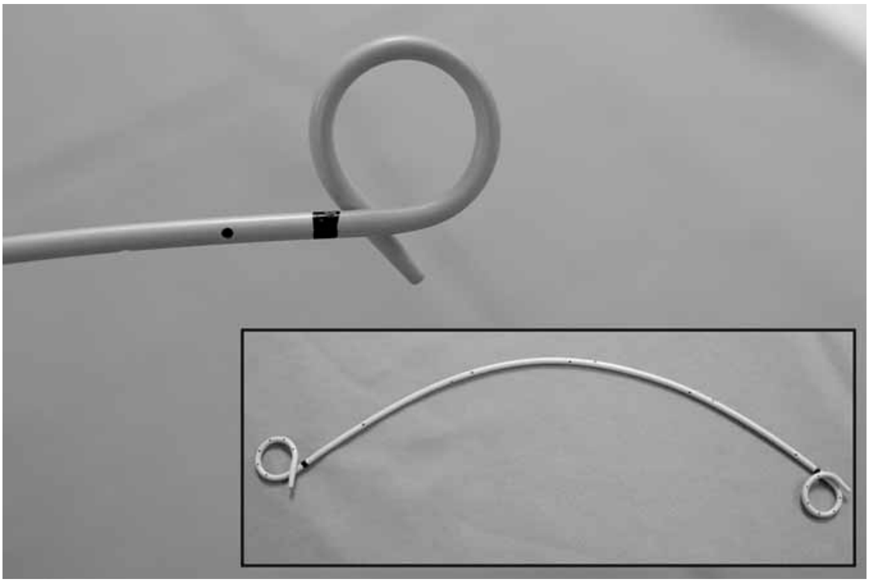

Fig. 2. Double-J stent. (Curl magnified) Sideholes aid in drainage and the black mark on either end of the stent facilitate visualization of the curl when placing a stent visually through the cystoscope.

ureteral aperistalsis, vesicoureteric reflux, increased pressure and hydronephrosis proximal to the area of dilation, and diminished ureteral contractility *(77,78)*. Only after 6 to 7 weeks of dilatation did the ureteral physiology and histology return to normal in these animals *(77–79)*. The safety and efficacy of balloon dilators in ureteroscopy have been confirmed in humans and are in routine use *(80,81)*. Sequential polyethylene coaxial dilators range from 6 Fr and up and are more cost effective than balloon dilators *(82)*. Care must be taken not to damage the urethra, ureteral orifice, or ureteral lumen. Applying the correct amount of tension to the guidewire while advancing the dilators will reduce the

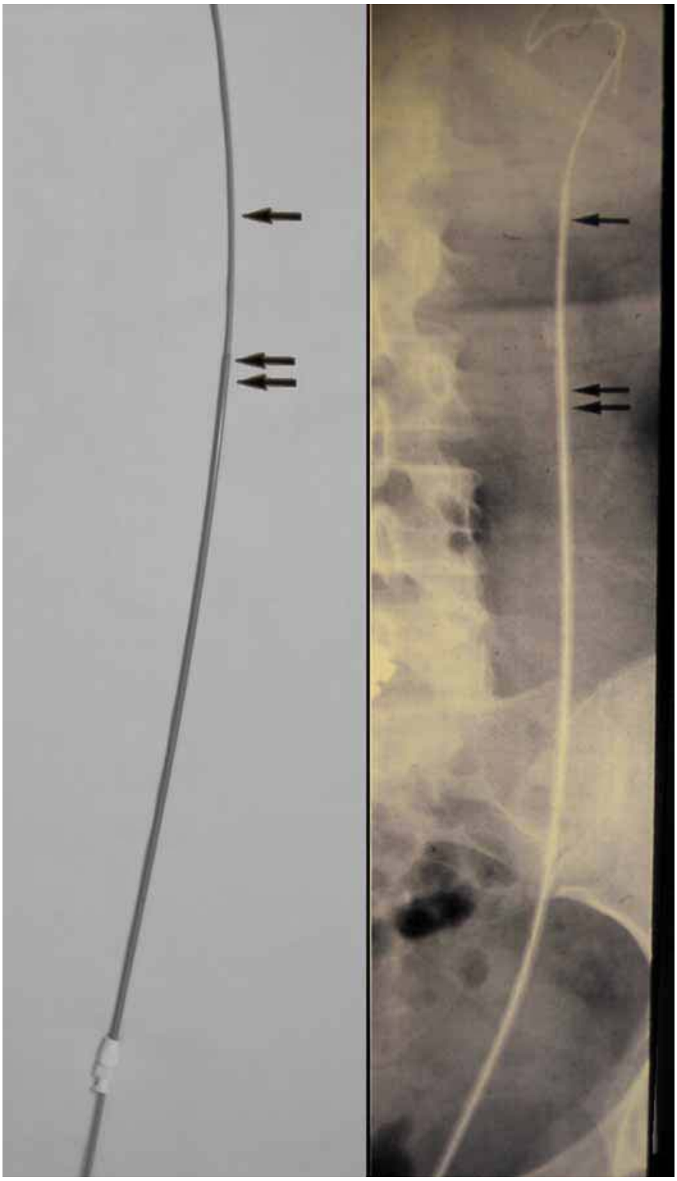

Fig. 3. Table-top and corresponding radiograph of the 8/10 coaxial dilator set. After advancement of the guidewire into the renal pelvis, the cystoscope is removed and the remainder of the procedure is performed under fluoroscopy. The 8/10 dilator set is advanced over the guidewire. The double arrows correspond to the end of the 10-Fr sheath. The single arrow delineates the end of the 8-Fr dilator which is almost in the renal pelvis. The 10-Fr sheath is advanced up to the hub of the patient's urethral meatus and the proximal end reaches the midureter in this case since the patient is female. In males, the 10-Fr sheath reaches just above the iliac vessels.

likelihood of ureteral or guidewire damage. Shearing forces can damage the ureter or guidewire, which will either prevent advancement of the ureteroscope or damage the working channel during advancement of a flexible ureteroscope. If resistance is met during scope advancement over the guidewire, the scope should be removed and the

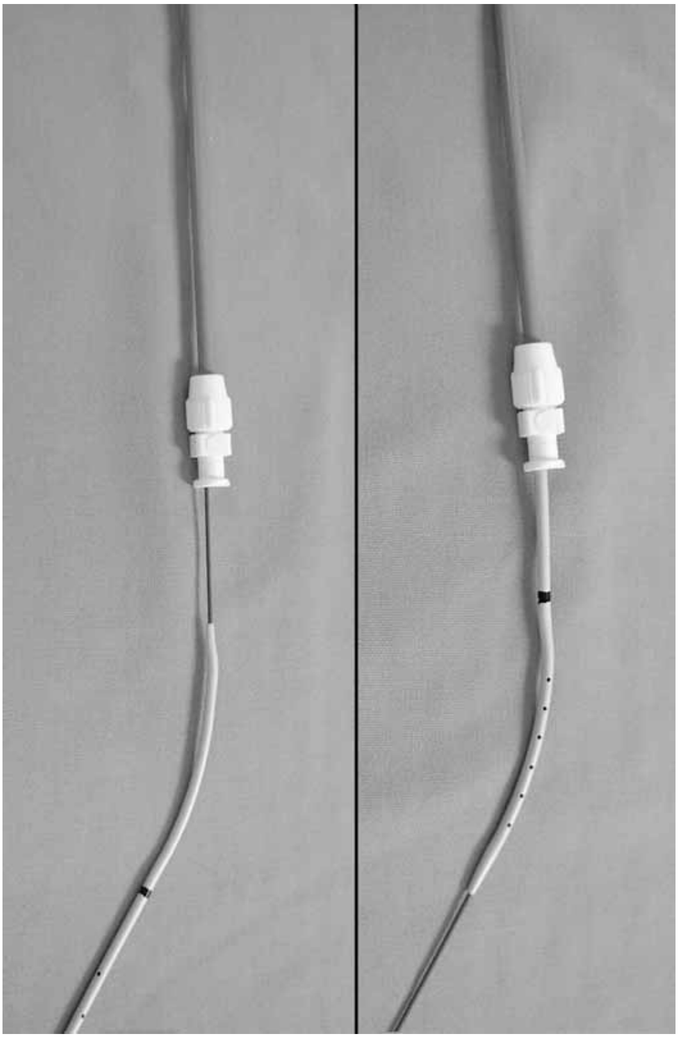

Fig. 4. The 8-Fr dilator has been removed and the stent is being advanced over the guidewire into the 10-Fr sheath. The 10-Fr sheath acts as a conduit to prevent buckling of the stent in the urethra, bladder, or ureter. Tension must be placed on the guidewire while the stent is advanced.

guidewire should be replaced through a ureteral catheter. Although balloon dilators are more expensive, they are less traumatic to the ureter than coaxial dilators.

Ureteral Access Sheath

Ureteral access sheaths were first developed in the 1970s to aid in difficult access to ureters for ureteroscopy *(83)*. The peel-away sheath became used in the 1980s which required sequential rigid dilators and several steps before the ureteroscope could be inserted, but was associated with a high rate of ureteral perforation (15–30%) *(84)*. Today's access sheaths consist of a two-piece hydrophilic, lubricious outer sheath and inner introducer which is removed after advancement over the guidewire. Sheaths come in various lengths (20–55 cm) and diameters (10–16 Fr) depending on patient size and gender. The access sheath acts as a dilator and a conduit that prevents buckling of the

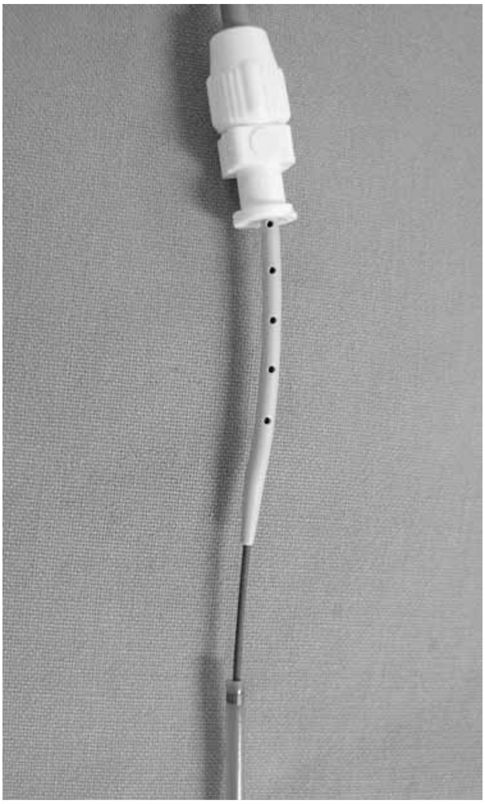

Fig. 5. The stent is advanced into the 10-Fr sheath as far as possible and the metal-tipped stent pusher is then advanced over the guidewire to push the stent.

flexible ureteroscope within the bladder. Operating room times and costs are also decreased by use of the access sheath *(85)*.

With these devices, the flexible ureteroscope is not inserted over a guidewire, but is advanced directly up the lumen of the access sheath. Ureteral access sheaths offer the advantages of better flow of irrigation, and thus visualization, concomitant intra-operative drainage of the bladder, and ease of access for repeated removal and reinsertion of the flexible ureteroscope *(74)*. This last benefit is particularly useful if basketing of multiple stones is desired. At the end of the procedure, the access sheath can facilitate the insertion of a ureteral stent if necessary *(86)*.

Pressure on the tip of ureteroscopes may be partially responsible for damage to the fibreoptics resulting in costly scope repair. The use of access sheaths has been shown to prevent and delay scope damage by reducing the stress on the tip of the scope during advancement, as well as preventing damage to the working channel by obviating the need for advancement over a guidewire *(87)*. One theoretical complication of access sheaths is prolonged pressure on the ureteral wall and ischemia resulting in a ureteral stricture. However, this has not been substantiated and the stricture rate is low as demonstrated in a retrospective review by Delvecchio et al. *(87a)* where only 1 of 71 patients developed a stricture.

Ureteral access sheaths have been shown to be a safe method for obtaining ureteral access for ureteroscopy with a low rate of stricture or ureteral perforation. Furthermore, operating room times and such postoperative symptoms as frequency, urgency, dysuria,

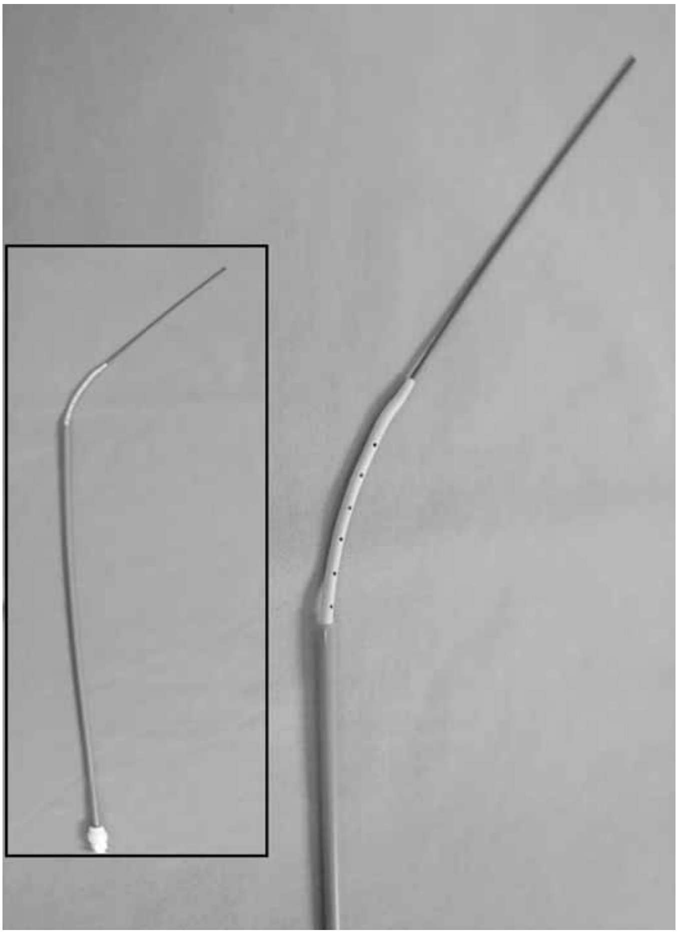

Fig. 6. As the stent is advanced, it will exit the 10-Fr sheath and enter into the renal pelvis. Pulling the guidewire slightly back will result in the curling of the proximal part of the stent.

and hematuria were significantly less in patients who were randomized to undergo ureteroscopy with a ureteral access sheath. Surgeon frustration is also diminished as multiple withdrawals and introduction of the scope can be performed easily and operative visualization is improved with the higher flow of irrigation through the sheath.

STENTING TECHNIQUE

The technique of stenting is outlined in Figs. 1 to 11. After a guidewire is placed into the renal pelvis, the cystoscope is removed and the procedure is visualized using only fluoroscopy, a technique used by radiologists. Instead of a single view of the inside of the bladder using cystoscopy, fluoroscopy allows the urologist to monitor both the distal and proximal ends of the guidewire and stent during the procedure. This technique is also more comfortable for the patient if they are only under light sedation because the cystoscope has been removed. An 8/10-Fr dilator is placed over the guidewire into the ureter by first advancing the 8-Fr portion. Once inside the ureter, the 10-Fr sheath is advanced over the 8-Fr portion into the ureter and confirmed by fluoroscopy. The 10-Fr sheath is advanced so that the hub is at the level of the urethral meatus. The 8-Fr dilator is removed

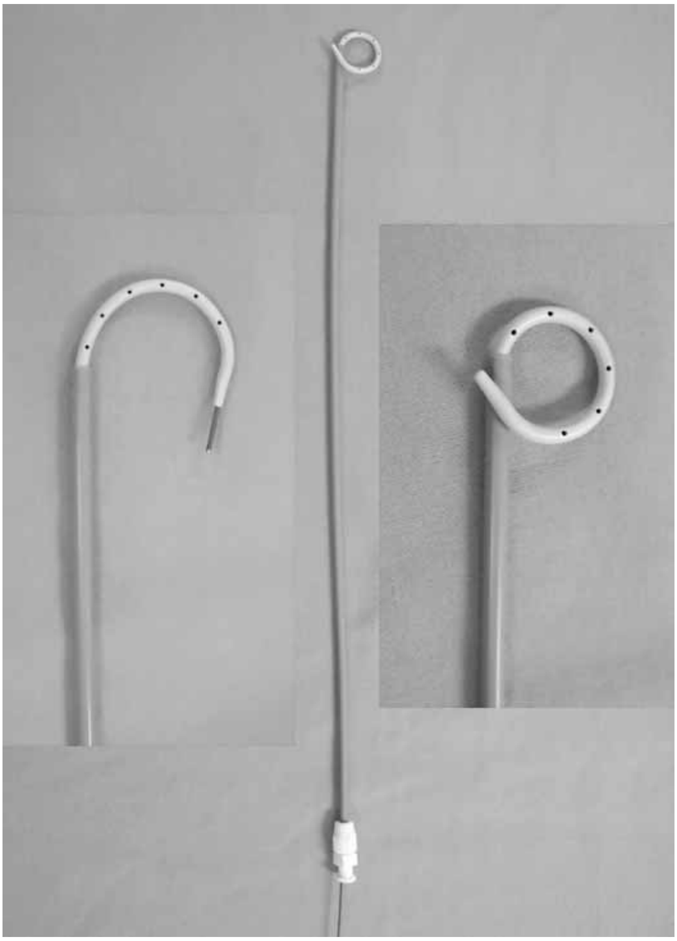

Fig. 7. Fluoroscopy is used to follow the stent into the renal pelvis. Once within the renal pelvis, the guidewire is withdrawn slightly so that the upper stent curls in the renal pelvis.

leaving the 10-Fr sheath which acts as a conduit for the stent and prevents buckling or coiling of the stent within the urethra, bladder, or ureter. The stent is advanced through the 10-Fr sheath and the pusher is advanced until its radiopaque marker is at the lower level of the pubic symphysis in females, and midway between the upper and lower level of the symphysis in males. The kidney is viewed on fluoroscopy and the guidewire is slightly retracted until the upper loop is seen to curl in the renal pelvis. With fluoroscopy on the pubic symphysis, the pusher is held with the radiopaque marker at the correct level and the 10-Fr sheath is withdrawn from the urethra. As the guidewire is removed the lower loop of the stent will curl in the bladder; however, if it remains in the urethra, it can be advanced by inserting a foley catheter or applying manual suprapubic pressure to the bladder which will displace the bladder cephalad and pull the stent into the bladder. This technique of stenting is demonstrated in the companion DVD, that accompanies this volume and a similar technique utilizing a ureteral access sheath has also been described *(86)*.

A potential complication of this technique of ureteral stenting is inadvertent advancement of the distal end of the stent into the ureter. The best way to avoid this

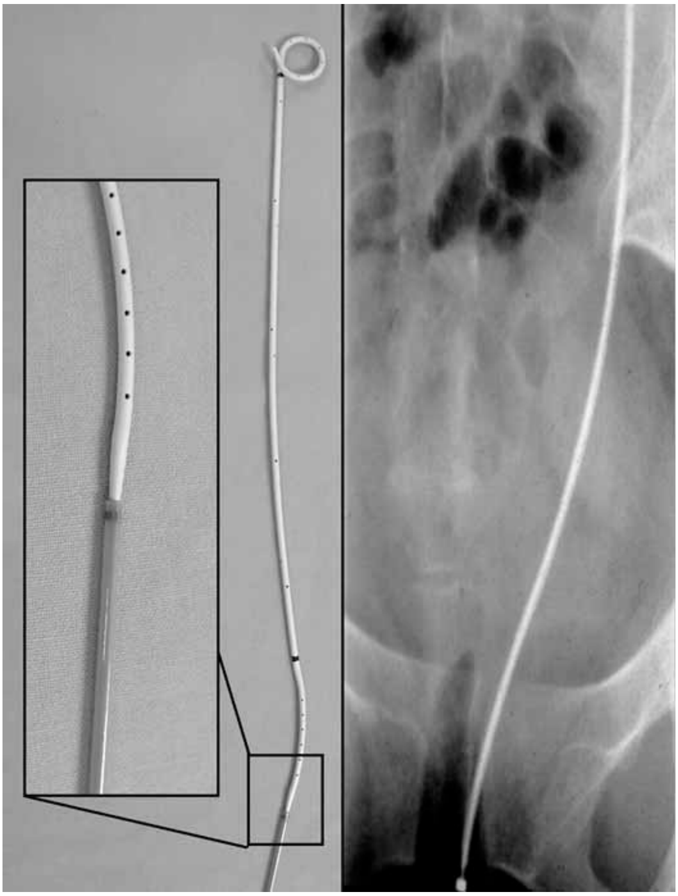

Fig. 8. Radiographically, the metal-tipped pusher is at the correct level of the symphysis for a female patient and the 10-Fr sheath has been withdrawn. The metal-tipped pusher is positioned at the lower border of the pubic symphysis in women and at the level of the mid pubic symphysis in men. Once the metal-tipped pusher is in the correct position, the 10-Fr sheath is backed-up over the guidewire.

complication is to prevent it by ensuring that the radiopaque marker on the stent pusher during the procedure does not go above the bottom of the pubic symphysis in females or above the middle of the symphysis in males. If a stent is advanced too proximal into the ureter, cystoscopy should be carried out and a grasper should be used to pull the stent into the bladder if the end of the stent is visible in the bladder. If the tether is still attached to the stent, this can be used to pull the stent back into the bladder. If the stent is well within the ureter, a guidewire should be advanced into the ureter, and a semirigid ureteroscope inserted to attempt removal of the stent using a stone basket or graspers. An alternative method is to place a ureteral dilating balloon alongside the stent, partially inflate it and deflate it causing the stent to adhere to the deflated balloon. The stent is removed as the deflated balloon is slowly withdrawn under close fluoroscopic observation taking special care to avoid ureteral avulsion or damage to the ureteral orifice *(88,89)*. These maneuvers are best performed with the patient under neuroleptic or general anesthesia. There are also reports that stents may migrate distally or even retrogradely into the kidney *(88,90,91)*.

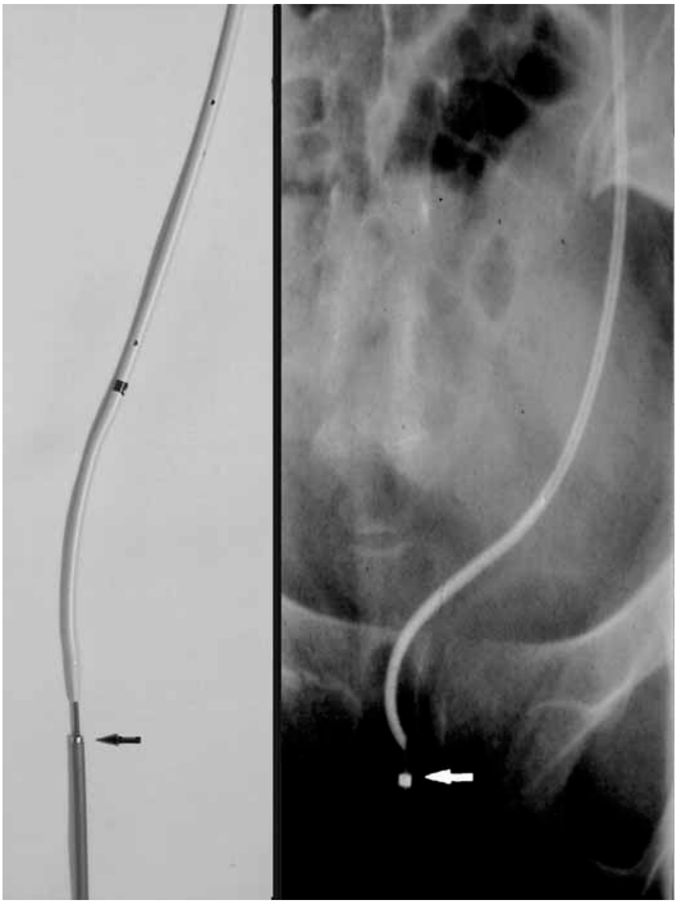

Fig. 9. The pusher is held in place at the correct level with the radiopaque marker (arrow) at the pubic symphysis.

STENT COMFORT, INFECTION, AND ENCRUSTATION: THE ROLE OF NEW BIOMATERIALS AND COATINGS

Ureteral stents may cause considerable morbidity, thus limiting their clinical tolerability and effectiveness *(6)*. It is only recently that a validated questionnaire to examine the morbidity of stents has been developed and showed that stented patients suffer substantial morbidity *(7,8)*. Without question, the major obstacles that limit stent use are the fact that they are uncomfortable, may cause infection, and provide a surface for crystals to bind and aggregate. The use of new biomaterials and stent technology are reviewed in detail elsewhere and highlight the recent advances in stent technology to improve stent comfort and decrease encrustation and infection rates *(92–96)*.

Risk factors for stent-associated infection include female sex, diabetes, chronic renal failure, and indwelling stent time greater than 90 days *(97)*. Oral antibiotics are often administered after stent insertion and have been found to prevent or delay both biofilm formation and infection *(98)*. Oral ciprofloxacin has been found to adhere to a ureteral stent at high enough concentrations to inhibit bacterial growth *(98)*. Even 2 to 3 days of oral antibiotics following stent insertion has been shown to delay biofilm formation and urine infection for up to 2 weeks *(99)*.

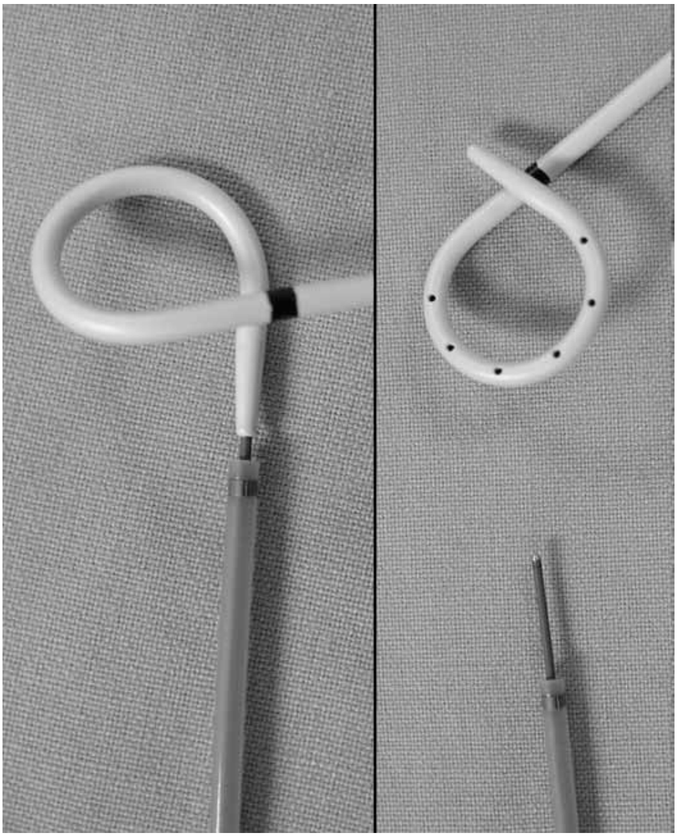

Fig. 10. The guidewire is withdrawn and the distal end of the stent is seen to curl in the bladder.

In an effort to improve comfort, prevent short-term postoperative ureteral edema and preclude cystoscopic stent removal, temporary ureteral drainage stents have been developed and shown to have little or no inflammation on porcine ureters *(100)*. Novel stent coatings, such as the enzyme oxalate decarboxylase, which breaks down oxalate, have been shown to decrease encrustation in an animal model *(101)*, whereas silver coatings have been shown to decrease bacterial adherence *(102)*. Other agents, such as intravesical anti-inflammatories, have also been employed to decrease stent symptoms and may prove to be a useful stent coating *(103)*.

A potential advance in stent technology utilizes metal in the stent material resulting in a crush resistant stent *(67–70)*. It has been used almost exclusively in malignant ureteral obstruction because of its rigidity and crush resistance. The clinical and animal trials utilizing the metal stent all point to stent failure secondary to lumen narrowing from tissue hyperplasia *(68)*. In addition, the surface of the stent is vulnerable to biofilm formation, as well as encrustation leading to infection and possible difficulty removing the stent *(68)*. Metal stents should be used sparingly and perhaps only in patients who have not tolerated regular double-J stents. Further development of more rigid, uncompressible stents may make this modality more effective in the future.

TIPS AND TRICKS

During stenting or ureteroscopy, a large or impacted stone can often impede passage of the guidewire into the renal pelvis. Table 4 outlines a treatment algorithm for advancing

Fig. 11. Radiographic appearance as the guidewire is withdrawn and the stent curls in the bladder.

Table 4
Algorithm for Passing a Guidewire Past an Obstructing Stone

1. Attempt passage with a hydrophilic guidewire.
2. Attempt passage using a retrograde ureteral catheter, or use to push stone into renal pelvis.
3. Pull ureteral catheter back, re-insert guidewire using the catheter to buttress the guidewire and give it support (***Note***: careful of ureteral perforation, only soft-tipped guidewires should be used in this situation).
4. Remove guidewire, and perform retrograde pyelogram to push stone back into renal pelvis (ureteral perforation will also be detected at this point, if present).
5. If the stone is very distal, leave the wire at the level of the stone, insert semirigid ureteroscope and treat the stone with intracorporeal lithotripsy (ensure the safety wire is visible at all times). A second guidewire should be placed into the renal pelvis as soon as it is possible.
6. If above fails, ensure there is no extravasation (perforation) by retrograde pyelogram, remove all instruments, and end the procedure. Patient may require a percutaneous nephrostomy tube if indicated (infection, symptomatic, compromised renal function, solitary kidney). Alternative therapies should be considered (antegrade ureteroscopy, open ureterolithotomy, or a second attempt ureteroscopy in 7 to 10 days).
    a. There is evidence that percutaneous nephrostomy tubes actually facilitate stone passage *(4)*. Furthermore, there is also evidence that ureteral stents impede the passage of stones *(4)* and may even be ‘jacked’ up to the kidney by a stent during shockwave lithotripsy *(90)*.

a guidewire past an obstructing stone. If a regular floppy tipped guidewire cannot be inserted, a ureteral catheter can be used to exchange it for a hydrophilic guidewire. The hydrophilic property of these wires reduces friction and allows them to slide between the stone and the ureteral lumen. Hydrophilic guidewires come in both angled and straight tips; the angled tips are often easier to manipulate around the stone. If this is unsuccessful, the next step is to reinsert the ureteral catheter over the wire and attempt to advance this past the stone. Owing to its blunt tip and greater rigidity, the ureteral catheter will slide past the stone or push it up into the renal pelvis where it can be easily treated. The ureteral catheter can also be used to perform a retrograde pyelogram which may propel the stone backwards into the renal pelvis. The retrograde pyelogram will also detect any extravasation of contrast which indicates a ureteral perforation, a potential risk in inflamed ureters with impacted stones.

When faced with difficulty advancing the guidewire past a distal ureteral stone, an alternative is to leave the guidewire at the level of the stone, insert the semirigid ureteroscope and treat the stone. The guidewire should remain visible at all times and as soon as it is possible, the guidewire should be advanced into the renal pelvis beyond the obstructing lesion. The last resort is to remove all instruments and abandon the surgical procedure, particularly if ureteral perforation has occurred. Patients will usually require urinary drainage via a percutaneous nephrostomy if there is infection, symptomatic pain, compromised renal function, solitary kidney, or ureteral perforation. Rarely, patients may be treated conservatively and alternative methods, such as SWL, open ureterolithotomy, or a second attempt at ureteroscopy in 7 to 14 days may be considered.

CONCLUSION

Retrograde access to the urinary system is the first step in many endourologic procedures and all urologists should be adept at dealing with the nuances of achieving access. Ureteral stents are a vital part of the urological armamentarium and play a role in the treatment of stones, reconstructive urology, ureteropelvic junction obstruction, hydronephrosis of pregnancy, and ureteral obstruction. Development of novel ureteral stent coatings, new stent materials, and compounds loaded directly into the stent should improve patient comfort and reduce the risks of infection and stent encrustation.

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3 Percutaneous Access to the Urinary Tract

Samuel C. Kim, MD
and James E. Lingeman, MD, FACS

CONTENTS

SUMMARY

Percutaneous access to the kidney is the most important step in percutaneous nephrolithotomy because the site of puncture determines how easily the targeted stone can be treated. Strategies to maximize the use of rigid instruments and allow for the performance of concurrent procedures, such as endopyelotomy, while minimizing patient discomfort and pleural morbidity should be considered when planning the site of access. The ability of the urologist to perform percutaneous access allows for flexibility in the procedure, particularly if multiple accesses are necessary and obviates the need for dependence on a radiologist's schedule. This chapter reviews the indications for percutaneous nephrolithotomy and the technique of percutaneous access.

Key Words: Percutaneous access; nephrolithotomy; lithotripsy; nephrolithiasis; kidney; nephroscopy.

INTRODUCTION

Percutaneous access for the sole purpose of removing a renal stone was first performed by Fernstrom and Johannson in 1976 *(1)*. Since that time, advances in endoscopy, fluoroscopy, and the development of intracorporeal lithotrites have helped refine the technique of percutaneous nephrolithotomy (PCNL) and percutaneous approaches have

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obviated the need for open stone surgery. With current endoscopic technology, PCNL can be used to treat upper tract urinary calculi of any size.

Access to the kidney is the most critical step in PCNL as the site of access determines how readily the calculus can be treated and which instruments can be utilized. When planning the site for renal puncture, strategies are utilized that maximize the use of rigid instruments, minimize pleural morbidity, and allow for the performance of adjunctive procedures such as endopyelotomy. This chapter reviews the indications and technique of percutaneous access.

INDICATIONS

The goal of all surgical stone procedures is to maximize stone removal while minimizing morbidity to the patient. Although shockwave lithotripsy (SWL) and ureteroscopy (URS) are less invasive options for stone treatment, these approaches are not capable of treating all stones. PCNL is generally performed for larger stone burdens unable to be managed efficiently by URS or by SWL or if anatomical situations are not amenable to other approaches. Application of PCNL to these clinical scenarios takes advantage of the high stone-free rates of percutaneous techniques compared with less invasive therapies.

A strategy for selecting treatment is Lingeman's law for the management of nephrolithiasis (Table 1). Simple stones can be successfully treated with SWL, URS, or PCNL; complex stones encompass various conditions best managed with a percutaneous approach (Table 2). The first complex stone situation is a stone burden greater than 2 cm. Both a National Institutes of Health (NIH) Consensus Conference and an American Urological Association (AUA) Nephrolithiasis Committee have reviewed the indications for PCNL in patients with nephrolithiasis *(2,3)*. The NIH recommendation in 1988 for any renal stone greater than 2 cm was PCNL. This conclusion was made in light of the high retreatment rates and the need for auxiliary procedures with SWL. The AUA Staghorn Guidelines panel in 1994 recommended PCNL as the optimal treatment for staghorn calculi with adjunctive SWL as needed. With the availability of improved intracorporeal lithotriptors and the addition of flexible nephroscopy, combination (or "sandwich") therapy is not currently necessary as residual calculi following initial PCNL can be removed at the time of secondary PCNL *(4–6)*. Although URS has been advocated for noninfectious stones larger than 2 cm, Grasso et al. reported that the 6-months stone-free rate was only 60% and 24% had remaining lower pole debris *(7)*. As URS and SWL are unable to clear large stone burdens, the most efficient method of treatment for large and/or complex stone disease is PCNL.

One of the major advantages of PCNL is the independence of stone-free rates from both stone burden and composition. Cystine, brushite, and calcium oxalate monohydrate stones are noted to be resistant to fragmentation with SWL *(8)*. As both cystine and brushite patients are both at a high likelihood of needing multiple interventions, less invasive modalities would be best. Stone-free rates for cystine calculi treated with SWL and URS, however, are poor (14.8 and 11.5% respectively), whereas PCNL achieves a 67.2% stone-free rate *(9)*. The superiority of PCNL for brushite was also demonstrated by Klee and colleagues *(10)* who noted that PCNL achieved an excellent stone-free rate (100%), whereas URS and SWL were only 66 and 11% stone-free respectively. Although more invasive, the application of PCNL is often necessary to clear a patient's stone burden and is justified by better stone-free results.

Although the majority of ureteral calculi are best treated by SWL or URS, large, especially impacted, proximal ureteral stones are best treated percutaneously. SWL is

Table 1
Lingeman's Law for Management of Nephrolithiasis

If the stone problem is simple, any intervention will be successful.
If the stone problem is complex, perform percutaneous nephrolithotomy.

Table 2
Complex Stone Problems Appropriate for Percutaneous Nephrolithotomy

1. Stone factors
   a. Nonstaghorn calculi >2 cm
   b. Staghorn calculi
   c. Composition (brushite, cystine, calcium oxalate monohydrate)
   d. Impacted proximal ureteral calculi
   e. Failure of URS and/or SWL
2. Renal anatomy
   a. Lower pole calculi >1 cm
   b. Caliceal diverticular calculi
   c. Surgical correction of ureteropelvic junction obstruction and concurrent large stone burden
   d. Ectopic renal calculi (horseshoe, pelvic)

URS, ureteroscopy; SWL, shockwave lithotripsy.

successful in treating 84% of proximal ureteral stones less than 1 cm and 72% of stones greater than 1 cm *(11)*. Impacted stones, however, are more resistant to SWL *(11,12)* and URS with holmium laser lithotripsy is an effective method for dealing with all ureteral stones regardless of location or impaction *(12,13)*. Larger ureteral stones (>2 cm), however, have a favorable median stone-free rate of 86% when treated with PCNL *(11)*. If a dilated proximal ureter is present, stones may be addressed with a rigid nephroscope making stone removal more efficient *(14)*. As PCNL is more invasive, the percutaneous approach is reserved for complex proximal ureteral calculi-impacted stones that have failed other modalities, dilated renal collecting systems, large stone burdens, urinary diversions, and distal ureteral strictures *(15)*.

PCNL can be used as salvage therapy for any failures of URS and/or SWL in the kidney or proximal ureter. Often patients will opt for less invasive treatments, such as SWL, knowing the risk of multiple treatments and the need for adjunctive procedures. If a patient is not stone-free after multiple SWL sessions or after both SWL and URS, stones in the proximal ureter and/or kidney may be addressed with PCNL.

Lower pole calculi (LPC) represent a unique clinical challenge to the urologist. Although SWL, URS, and PCNL are all options for treatment, PCNL again demonstrates better results. LPC treated with PCNL achieves a 73 to 95% stone-free rate, whereas SWL only reaches 37 to 59% *(16–18)*. PCNL maintains a high stone-free rate (73 to 91%) when LPC greater than 1 cm are treated; SWL success, however, drops to 21 to 44% *(18)*. A recent prospective, randomized trial by the Lower Pole II Study group studied URS and PCNL for LPC 11–25 mm and stone-free rates using follow-up noncontrast computed tomography (NCCT) were 29.6 and 70.6%, respectively *(19)*. The poor results of both SWL and URS suggest that PCNL should be the initial treatment for LPC larger than 1 cm.

Calyceal diverticula are uncommon, congenital entities that can cause flank pain, recurrent urinary tract infections, hematuria, or even damage to surrounding parenchyma *(20,21)*. Traditionally, these diverticular cavities were treated with open surgical deroofing or marsupialization procedures, diverticulectomy, or partial nephrectomy with suture closure of the communicating infundibulum *(21–24)*. SWL can provide symptomatic relief of pain in 36 to 70% of patients; stone-free rates, however, are low, ranging from 4 to 20% *(25,26)*. Current minimally invasive treatments include ureteroscopy *(27–30)*, laparoscopy *(31,32)*, and percutaneous procedures *(25,27,33,34)*. Of these techniques, the percutaneous approach is the most widely used with excellent stone-free rates (93–100%) and successful obliteration of the diverticular cavity (76–100%) *(25,34,35)*.

Urinary calculi are often associated with ureteropelvic junction obstruction (UPJO). Traditionally, patients with UPJO and concurrent renal calculi have been treated with open pyeloplasty and pyelolithotomy. Laparoscopic pyeloplasty has recently replaced open surgical repair as primary therapy as success rates up to 96% have been reported for laparoscopy with concurrent pyelolithotomy achieving a stone-free rate of 90% *(36)*. Although laparoscopic stone removal via a pyelotomy is feasible, we find this approach to be cumbersome, time-consuming, and appealing only when a few stones are present. With a larger stone burden, PCNL with antegrade endopyelotomy is a more efficient approach with an 85% success rate for antegrade endopyelotomy *(37)*. As lodging of residual calculi in a pyelotomy incision is a worrisome issue, we believe that PCNL is preferred over URS for UPJO in the setting of a larger stone burden as it allows for secondary access if any fragments remain on postoperative NCCT.

Horseshoe kidney is the most common congenital renal anomaly *(38)*. Although SWL monotherapy can achieve up to 55% clearance rates, adjunctive procedures, such as stent placement, URS, or PCNL, are necessary in up to 69% of patients *(39,40)*. PCNL is a very effective option (75 to 87.5% stone free) for stones in a horseshoe kidney *(41,42)*.

Pelvic kidneys are difficult to treat as the kidney is surrounded by many normal anatomical structures. The sacrum is posterior to the pelvic kidney and bowel loops located anteriorly and laterally prevent a direct approach to the kidney. The standard percutaneous flank approach is not possible without injuring adjacent structures. URS and SWL are feasible but not efficient for treating large stone burdens. To circumvent the anatomical issues, a laparoscopically assisted PCNL technique can be used *(43–47)*. Although other institutions place a nephrostomy tube at the conclusion of the case, we perform laparoscopically assisted PCNL tubeless, by placing a ureteral stent and suturing the nephrotomy closed *(46,48)*.

PATIENT CLINICAL FACTORS

In the setting of urinary tract infections and stones, complete removal of the stone burden is essential. As SWL depends on the passage of fragments, PCNL or URS may be more appropriate for the eradication of the stone. This is particularly true of staghorn stones as the incidence of sepsis is almost threefold higher in this population as compared to the overall sepsis rate for SWL *(49)*. Staghorn calculi are best managed with PCNL as any and all stone burdens can be cleared with the percutaneous approach.

An important contraindication to PCNL is uncorrected coagulopathy. As both SWL and PCNL can cause life-threatening bleeding in this setting, URS with holmium laser lithotripsy is an excellent alternative. Grasso and Chalik *(50)* demonstrated that URS

Table 3
Instruments Used for Percutaneous Nephrolithotomy at Methodist Hospital of Indiana

1. Intra-operative C-arm
2. 5-Fr ureteral catheter (consider occlusion balloon catheter if the proximal ureter is dilated)
3. 18-gage access needle
4. Wires:
    a. 0.035-in. Glidewire
    b. 0.035-in. Straight removable core wire
    c. 0.035-in. Amplatz Superstiff wire
    d. 0.035-in. Removable core J-wire
5. 5-Fr angiographic catheter
6. 8-Fr fascial dilator
7. 24-Fr rigid offset nephroscope (longer nephroscope if needed)
8. 8/10 coaxial dilator
9. Balloon dilator with 30-Fr sheath
10. Ultrasonic lithotrite (pneumatic used if necessary)
11. Holmium laser with 365 or 200 μ fiber
12. 16-Fr flexible nephroscope
13. Nitinol basket (if necessary)
14. 8.5- or 10.2-Fr Cope loop

can successfully treat urinary calculi without an increase in bleeding complications. Once the coagulopathy is corrected, both SWL and PCNL can be performed safely *(51)*.

INSTRUMENT STRATEGY

The instruments that are used for percutaneous procedures at Methodist Hospital of Indianapolis, Indiana are listed in Table 3. The instruments we use for PCNL are consistent for both adult and pediatric procedures. The equipment listed can be used for any stone burden whether simple or complex because multiple accesses can easily be performed. If multiple punctures are necessary, additional wires and 30-Fr sheaths may be needed; all other equipment can be reused throughout the procedure. Mini-PCNL, as advocated by some *(52,53)*, requires specialized smaller diameter equipment with reduced working channels that are unable to accommodate current intracorporeal lithotrites. These equipment changes are costly and, in our view, unnecessary.

Intraoperatively, we attempt to minimize radiation exposure to both the patient and surgeon. The radiation dose absorbed by the patient, surgeon, and operating room personnel depends on both direct beam and scatter radiation. Direct radiation exposure occurs when tissue is placed in the primary X-ray beam. As direct radiation exposure to the patient correlates with the square of the diameter of the X-ray beam, a 50% reduction in the diameter of the X-ray beam results in a fourfold reduction in radiation exposure *(54)*. Currently, our preferred C-arm is the Ziehm Exposcop 7000 (Ziehm Imaging, Nuremberg, Germany) owing to its smaller 6-in. image intensifier and good resolution. The diameter of the radiation beam can be further reduced by coning down on the X-ray tube and using only the fluoroscopic field of view necessary. During our fluoroscopic triangulation access technique, the C-arm is also tilted away from the axis of puncture in order to keep the operator's hands out of the X-ray beam (Fig. 1).

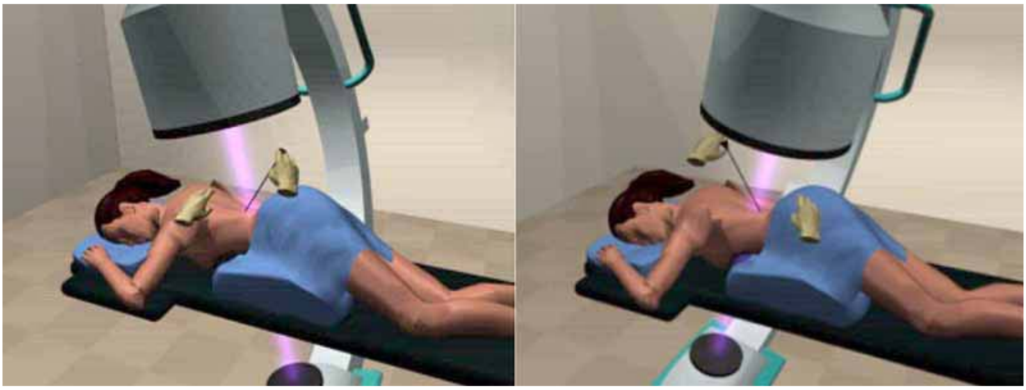

Fig. 1. Positioning of the C-arm in relation to the surgeon's hand during percutaneous access. When performing a lower pole puncture (left panel), the C-arm is tilted towards the patient's head (cephalad). When performing an upper pole access (right panel), the C-arm is tilted toward the patient's feet (caudad).

The correct selection of wires during PCNL is essential. We prefer using a glidewire with a prefashioned Coude tip on the floppy end as most calyces and even large stones can be negotiated during initial access. The glidewire has a good combination of a floppy, lubricious tip and a stiffer core that safely allows coiling of the wire in the collecting system and eventual passage into the ureter. Once placed into the ureter, we exchange out the glidewire for an Amplatz superstiff wire, a more secure working wire. The 0.035-in. straight removal core wire is used as the safety wire and the removal core J-tipped wire is used for brushing off stones and/or clot.

A complimentary set of rigid nephroscopes aids in PCNL of difficult kidneys. We prefer to maximize the use of rigid nephroscopy as this expedites the overall procedure. For all PCNL, we begin rigid nephroscopy with a 24.5-Fr offset Wolf nephroscope (Wolf, IL) without the outer sheath and often use this scope for the entire case. This rigid nephroscope is excellent for use in most patients, but may not reach the most distant portions of the collecting system when performing PCNL in obese patients, horseshoe kidneys, or via an upper pole puncture. A longer offset rigid Storz nephroscope (Karl Storz, Tuttingen, Germany) is used in cases where the Wolf nephroscope is unable to negotiate the entire collecting system. Of note, a longer 11-Fr alligator forceps (Storz, Tuttingen, Germany) must be used in the longer Storz instrument.

The use of both rigid and flexible nephroscopy allows for the examination of all calyces and optimizes the chances of achieving a stone free kidney. All attempts are made to maximize use of the rigid nephroscope and flexible endoscopy is performed when the collecting system is thought to be clear of stones. We use flexible nephroscopy during *all* PCNL cases; calyces that are not accessible with rigid nephroscopy can be entered. In our practice, we use a 15-Fr flexible Storz nephroscope in tandem with a 15-Fr Pentax instrument (Pentax Imaging Company, Golden, CO). We find that the flexible Storz nephroscope will allow access to all calyces in most kidneys. When we are unable to enter a calyx with the flexible Storz scope, it is our experience that the flexible Pentax instrument will allow entry into the calyx. The Storz and the Pentax scopes are complimentary as the working channels are 180° apart. If the working channel of one nephroscope does not allow us to basket a stone in a difficult to access calyx, for instance, we find that the other endoscope is able to accomplish the task. The Storz endoscope maintains more axial rigidity for entrance especially during secondary PCNL when not using an Amplatz sheath, whereas the flexibility of the Pentax allows for entrance into calyces with difficult anatomy.

TECHNIQUE

Preoperative Preparation

Preoperative imaging of the kidney, ureters, and bladder with plain abdominal films, intravenous pyelogram (IVP) and NCCT can be used to identify the number and location of stones and detail the anatomy of the collecting system. A NCCT is able to visualize renal anatomy in any clinical scenario especially in ectopic kidneys, malrotated or fused kidneys, morbid obesity, or patients with deformities secondary to spinal cord injury. Retrorenal colons can also be identified on computed tomography scans, as well. As a retrograde pyelogram is performed at the time of surgery, a preoperative IVP is not perfunctory. An IVP is essential, however, when the diagnosis of a calyceal diverticulum or medullary sponge kidney is in question.

As urinary calculi can contain bacteria, preoperative antibiotic treatment is imperative. A urine culture is obtained and, if positive, the antibiotic choice is tailored to the organism's sensitivity profile. Even if the culture is negative, the stone may harbor bacteria, so we empirically treat patients with a 2-week course of fluoroquinolones. In our opinion, a 2-week antibiotic regimen minimizes the risk of perioperative fever/sepsis.

Anatomical Considerations

The preferred access site should traverse the kidney at a site least likely to injure the renal vasculature. Because the posterior calyces are usually oriented so that the long axis points to the avascular Brodel's area, a posterolateral puncture into a posterior calyx would be expected to cross through the avascular plane of the kidney. A posterior calyx is also the shortest path to access the renal collecting system. The determination of calyceal orientation and the selection of the optimal calyx of entry are best determined intraoperatively with fluoroscopic guidance.

An infracostal approach should be performed whenever possible. Supracostal access is associated with a greater risk of pleural injury than an infracostal approach and should be used only when necessary *(55,56)*. The location of the puncture site also must be carefully chosen to avoid injury to neighboring structures. Care should be taken not to place a puncture too laterally as colon injury can occur. The position of the colon is usually anterior or anterolateral to the lateral most part of the kidney, therefore access to the kidney should not be performed lateral to the posterior axillary line *(57)*.

Puncture Site Selection

Consideration of stone location and stone burden are the main factors when choosing the optimal site for access. The lower pole approach is generally preferred as it is associated with fewer complications than an upper pole puncture and all punctures should be performed to maximize the use of the rigid nephroscope. The angle of the puncture should be aligned with the infundibular axis of the appropriate calyx to minimize the renal trauma that torquing with rigid instruments will cause.

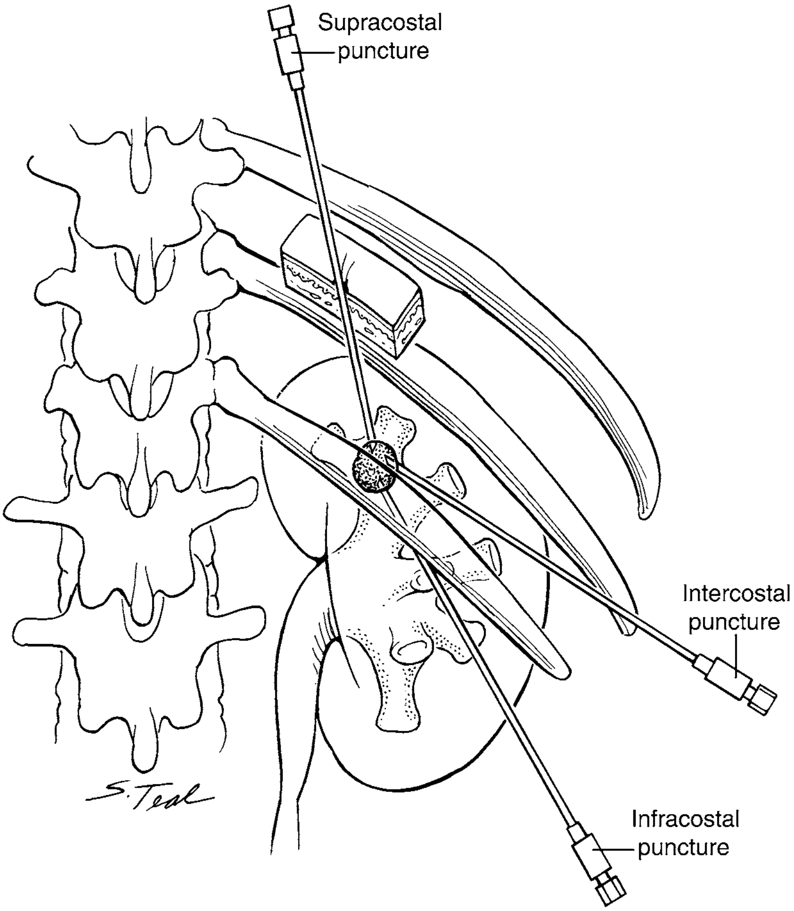

Fig. 2. Upper pole access can be can be performed by a supracostal, intercostal or infracostal approach. A supracostal approach most closely aligns the puncture with the renal axis and allows access to the proximal ureter and ureteropelvic junction. (Adapted from ref. 58, with permission from Elsevier.)

A supracostal puncture may be indicated when the majority of the stone burden is in the upper pole calyces, when multiple lower pole calyces contain stone material, in horseshoe kidneys, or in cases where access to the ureter is vital (i.e., antegrade endopyelotomy or proximal ureteral stone) *(4)*. A supracostal access may also be used for stones unable to be fully treated by a lower pole puncture. The main advantage of the supracostal approach is that the line of puncture is aligned with the renal axis and thus allows excellent access to the ureteropelvic junction and proximal ureter (Fig. 2).

Upper pole access can be performed by an infracostal or intercostal approach in addition to a supracostal one *(58)*. For a single stone in an upper pole calyx or an upper pole calyceal diverticulum, an infracostal puncture can be used. If an infracostal approach is not feasible, an intercostal access between the 11th and 12th ribs can be placed to reach the upper pole. The risk of pleural injury for this intercostal access is less than that for a supracostal puncture *(59)*.

Access Technique

Renal access at our institution always begins with cystoscopic placement of a ureteral catheter in dorsal lithotomy. We prefer the lithotomy position as catheter placement is rapid and all anatomical conditions, such as urethral or ureteral strictures, can be easily addressed in this position as compared to the prone position. A 5- or 6-Fr open-ended ureteral catheter is routinely used for retrograde opacification of the collecting system. An occlusion balloon catheter is considered when the proximal ureter is dilated in order to block the ureteropelvic junction and distend the collecting system for easier puncture. Additionally, the occlusion balloon can prevent antegrade migration of fragments into the ureter when treating large stone burdens, which can often be troublesome and time-consuming to remove.

In cases where patients have had a urinary diversion, the introduction of contrast into the collecting system must be achieved using alternate methods. If a small or large bowel conduit is present, a Foley catheter is passed through the stoma and seated with the balloon inflated. Once the catheter is placed, the patient is positioned prone and contrast is introduced by gravity and allowed to reflux into the kidneys. If gravity contrast instillation is not successful, a 22-gage Chiba needle can be introduced directly onto the stone if fluoroscopically visible or into the renal pelvis if the stone is not visualized. Confirmation by urine flow through the needle precedes injection of contrast. Once the Chiba needle is in the collecting system, intravenous extension tubing attached to a contrast filled syringe is placed on the proximal end of the needle to prevent any possibility of dislodgement during contrast injection. The puncture is then carried out in a routine fashion with opacification of the collecting system via the Chiba needle.

For the puncture, the patient is placed prone with the side to be approached elevated approx 30° on a foam wedge. This position brings the posterior calyces into a more vertical orientation. The patient is secured with tape and the ureteral catheter is connected to intravenous extension tubing to facilitate access to the catheter during the percutaneous procedure. A rolled towel is placed prior to draping in order to direct irrigation into the drainage bag. For bilateral PCNL, the patient is placed in the straight prone position and the more symptomatic side or the side with the larger stone burden is addressed first.

A portable C-arm is used for imaging during percutaneous access. During access, the C-arm is angled away from the line of puncture which helps to keep the surgeon's hands well away from the X-ray beam. For *lower* pole access, the image intensifier is angled towards the patient's *head* (Fig. 1, left panel) and for an *upper* pole puncture, the image intensifier is angled towards the patient's *feet* (Fig. 1, right panel). For upper pole access, the puncture is performed between the 11th and 12th ribs just lateral to the paraspinal muscles. The puncture is begun at the inferior border of the 11th rib (Fig. 3) as the angle of the puncture will allow the needle to enter the center of the interspace between the two ribs (Fig. 3 inset). For lower pole access, the skin puncture is performed approx 1 cm inferior and 1 cm medial to the tip of the 12th rib (Fig. 4).

Orientation of the line of puncture is simply a triangulation procedure. The C-arm is moved back and forth between two positions: one parallel to and one oblique to the line of puncture. With the C-arm oriented parallel to the line of puncture, adjustments are made in the mediolateral (or left/right) direction. The C-arm is rotated to the oblique position and adjustments are made in the cephalad/caudad (or up/down) orientation of the line of puncture taking care not to alter the mediolateral orientation of the needle. Once the proper orientation of the line of puncture has been obtained, respirations are suspended in full expiration and an 18-gage needle is advanced into the desired calyx. The needle is advanced in the *oblique* position in order to gage the depth of puncture.

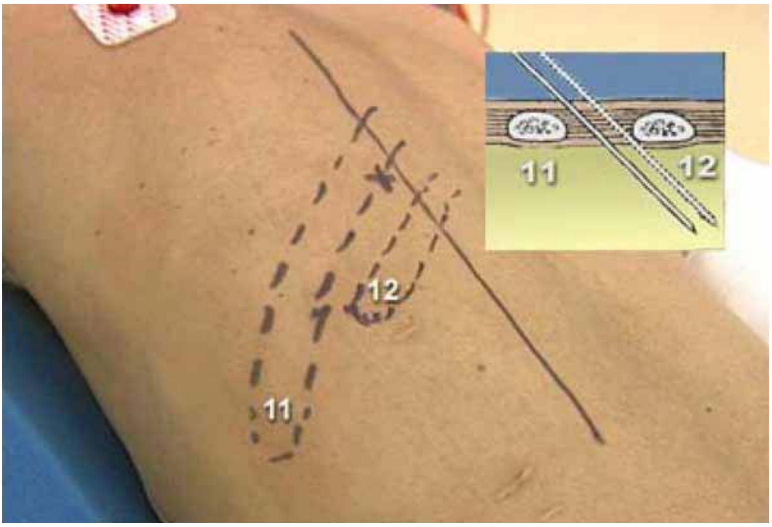

Fig. 3. For a supracostal upper pole puncture, the point of entry at the skin is at the inferior border of the 11th rib and just lateral to the paraspinal muscles. This point of entry will allow the needle to enter the middle of interspace (solid needle of inset). If the entry point at the skin is at the midpoint between the 11th and 12th rib, the needle will come too close to the 12th rib (dashed needle of inset), and the rigid sheath will be difficult to place.

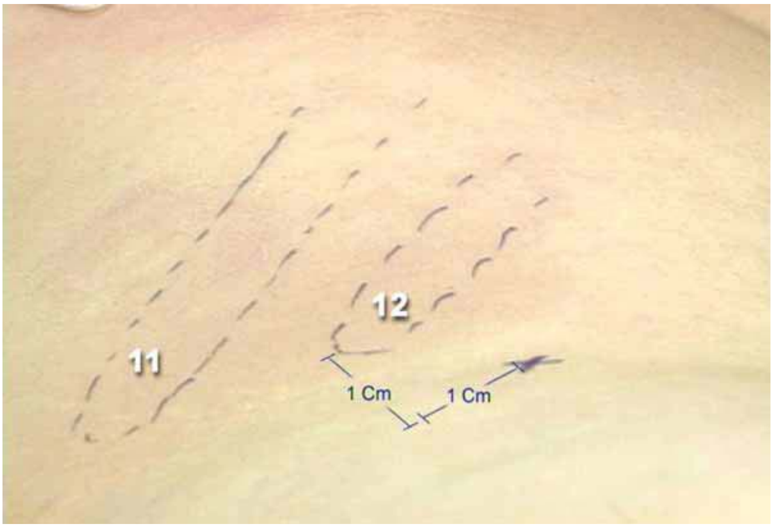

Fig. 4. For a lower pole puncture, a good starting point is 1 cm inferior and 1 cm medial to the tip of the 12th rib. The starting point is marked with an X.

As the desired calyx is punctured, contrast is instilled through the retrograde catheter to opacify and to distend the collecting system. Gentle aspiration helps to confirm that the appropriate calyx has been entered. A glidewire with a previously fashioned Coude tip is placed into the pelvis. If a supracostal puncture is performed, the wire will often flip down into the upper ureter with minimal manipulation. If the wire does not pass easily into the ureter or a lower pole puncture is used, the wire is left coiled in the renal pelvis.

An 8-Fr fascial dilator is passed into the calyx followed by a 5-Fr Cobra-tipped angiographic catheter to help direct the glidewire into the ureter.

Once the glidewire is positioned into the distal ureter, the 5-Fr angiographic catheter is used to exchange out the glidewire for our working wire of choice, an Amplatz superstiff wire. The glidewire should never be used as a working or safety wire because its very low coefficient of friction could allow it to become easily dislodged. An 8/10-Fr coaxial sheath system is then passed sequentially in order to place our safety wire, usually a 0.035-in. straight removal core wire.

Dilation of the tract is performed with a balloon dilator. In our view, bleeding during percutaneous procedures is minimized if tract dilation is accomplished with balloon dilators. Balloon dilators have been reported to cause significantly less bleeding than sequential dilators *(60)*. The radial force to spread renal parenchyma produced by balloons is less traumatic than the shearing or cutting action of sequential Amplatz dilators or metal telescoping dilators. The balloon will dilate virtually any nephrostomy tract, but in the setting of fibrosis from previous renal surgery, the use of sequential dilators (Amplatz or metal dilators) may be helpful. Care should be taken to avoid over advancement of the balloon and sheath combination particularly if the renal collecting system is nondilated or if it is filled with stone material as when treating staghorn stones. Trauma to the collecting system from over advancement of dilators or sheaths is one of the most common causes of undue bleeding during percutaneous procedures. The sheath is advanced only into the calyx of puncture and rarely is it necessary to pass the sheath all the way into the pelvis.

Stone Removal

Once the tract has been dilated and the Amplatz sheath properly positioned, the stone burden can be addressed. We prefer to use an ultrasonic lithotrite to both fragment and suction out stone fragments. A pneumatic or combined pneumatic/ultrasonic lithotriptor is used for particularly hard stones and once fragmented, the stone pieces can then be manually removed with graspers or ultrasonic lithotripsy.

Flexible nephroscopy is always performed to visualize calyces inaccessible by rigid nephroscopy. Pressurized irrigation fluid is necessary to distend the collecting system during flexible nephroscopy. The entire collecting system should be examined and instillation of contrast can help with systematic visualization of all calyces. If necessary, a holmium laser can be used for fragmenting and releasing embedded calculi and a removable core J-wire can be used for atraumatically clearing calyces of clots and fragments. Small fragments can also be removed with stone baskets through the flexible endoscope.

At the end of the procedure it is our preference to use an 8.5- or 10-Fr Cope loop catheter. This catheter is preferred because its small diameter maximizes patient comfort without compromising drainage or access for secondary procedures *(61)*. The Cope loop is placed directly through the 30-Fr sheath. In cases where the Cope loop does not coil well in the renal pelvis, a wire can be placed in a calyx and the Cope loop passed over the wire. Contrast is instilled through the Cope loop to confirm satisfactory positioning of the Cope loop. Although a Cope loop is almost always placed, certain clinical situations necessitate larger nephrostomy tubes (Fig. 5). We place 20-Fr Malecot nephrostomy catheters when there is gross infection, residual stone burden requiring a secondary procedure, or complex renal anatomy that requires secure access. For complex collecting systems that required multiple accesses at primary PCNL and will be needed for secondary procedures, a 20-Fr circle loop catheter is most appropriate for drainage.

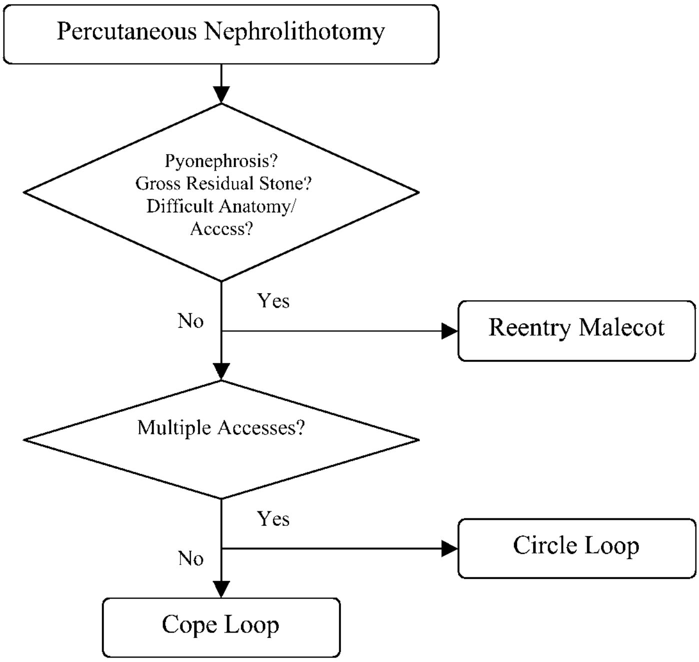

Fig. 5. Algorithm for nephrostomy tube selection after percutaneous nephrolithotomy.

Table 4
Postoperative Pain Management

1. Local anesthetic: 0.25% bupivicaine injected at 11th and 12th rib and at puncture site
2. Intravenous ketorolac: (if renal function is normal)
   a. Bolus: 15 or 30 mg as appropriate at the conclusion of the procedure
   b. Drip: mix 90 mg of ketorolac in 1 L of normal saline and infuse at 40 cc/h
3. Oral/Parenteral narcotics: use only as needed

Fluoroscopy can be used to check lung markings if an intercostal or supracostal puncture was performed. Ogan and associates demonstrated that all clinically significant pneumothoraxes were imaged using intraoperative fluoroscopy obviating the need for routine postoperative chest X-rays *(62)*. Intraoperative imaging is optimal as aspiration of pleural fluid can be easily performed while the patient is under anesthesia.

Twenty milligrams of furosemide are given intravenously at the conclusion of the procedure to promote diuresis and maintain nephrostomy tube patency. In order to minimize post-PCNL pain, we perform a rib block using 0.25% bupivicaine. The intercostal neurovascular bundles of the 11th and 12th ribs, as well as the puncture site, are injected with local anesthetic. In addition, patients with normal renal function receive an appropriate bolus and a continuous infusion of ketorolac (Table 4) at the conclusion of the procedure while still under an anesthetic in the operating room. We feel this maximizes pain relief and find that few patients require narcotic analgesia with this regimen.

RESULTS

It is our practice to place patients on 2 weeks of preoperative oral antibiotics in preparation for PCNL. The selection of the appropriate antibiotic is tailored to the results of a preoperative urine culture. Our antibiotic of choice is a fluoroquinolone when the pre-operative urine culture is sterile. Septic events that were relatively common at the onset of PCNL are now rare at the Methodist Hospital. We believe that 2 weeks of antibiotic coverage limits the number of bacteria prior to puncture into the collecting system and has minimized the risk of septic events.

Approximately two-thirds of the percutaneous procedures performed at our institution are done via an infracostal, lower pole puncture. Lower pole access avoids the morbidity of pleural injury and the placement of drainage tubes intercostally. With the use of the flexible nephroscope, we find that all calyces unable to be accessed with rigid nephroscopy can be clearly visualized.

Our treatment technique for calyceal diverticular calculi has evolved over time. Initially, the percutaneous approach included the placement of a ureteral catheter, location and dilation of the infundibular connection and occasionally supracostal access to upper pole diverticulae. Although stone removal and fulguration methods remain the same, our current percutaneous technique eliminates the placement of a ureteral catheter and localization of the infundibular communication. All accesses to calyceal diverticulae are performed infracostally and our last 21 patients have been treated successfully with this approach with a mean operative time of 58.5 minutes *(63)*.

Examination of PCNL at the Methodist Hospital of Indiana demonstrates the safety and efficacy of current percutaneous techniques and the ability to place small diameter nephrostomy tubes *(61)*. We reviewed 106 consecutive renal units undergoing PCNL for calculi greater than 2 cm with placement of an 8.5- or 10-Fr Cope loop, a 20-Fr reentry Malecot catheter, or a 20-Fr circle loop. In our cohort, 134 accesses were created in 106 renal units: 35 upper, 7 mid, and 92 lower pole. Sixteen accesses (14 upper, 1 mid, 1 lower) were left tubeless with a concomitant nephrostomy tube placed in the lower pole. Of the 111 nephrostomy tubes placed, the majority (85) were Cope loops (76.6%), 19 were Malecot catheters (17.1%), and 7 were circle loops (6.3%). 31.1% of the renal units were stone free with a single procedure and increased to 95.6% with two procedures. There were no difficulties with drainage or access for secondary PCNL. Complications included two hydrothoraxes, one arteriovenous fistula, and one ureteral perforation. Three of four renal units requiring transfusions underwent bilateral PCNL and at least one kidney in each of the four patients required multiple accesses. Of note, 57.1% of infection stones required a reentry Malecot or circle catheter; only 12% of nonstruvite stones necessitated one of the larger nephrostomy tubes.

TIPS AND TRICKS

For nephrostomy tract dilation, we routinely use the NephroMax™ high pressure nephrostomy balloon dilator (Boston Scientific, Natick, MA). It is a rapid dilating technique as both dilation and sheath placement is a one-step procedure. We also believe it causes less bleeding owing to the radial force generated rather than the shearing or cutting action of sequential Amplatz or metal telescoping dilators.

Occasionally the standard length (16-cm) 30-Fr rigid sheath that is placed with the balloon dilator is not long enough to reach the collecting system. In these instances, we use a 20-cm, 30-Fr rigid sheath that will bridge the access tract from the skin to the calyx of interest.

Another strategy to lessen patient discomfort is the avoidance of an intercostal nephrostomy tube. In cases where an intercostal puncture is necessary and intraoperatively the kidney is deemed to be stone free, a separate infracostal lower pole puncture may be used to place a nephrostomy tube. This minimizes a patient's discomfort while maintaining access to the collecting system for possible secondary procedures.

In obese patients, special consideration must be made when choosing a nephrostomy tube. Although a rare occurrence, nephrostomy tubes can become dislodged in obese and spinal cord injury patients. If the choice of a Cope loop was made, consideration should be made to placing a 5-Fr ureteral catheter to maintain access to the ureteral for possible secondary access. Alternatively, a larger reentry Malecot catheter can be securely positioned.

Patients that have had multiple renal procedures can form a perinephric layer of scar tissue. This fibrosis can be difficult to dilate during access. If initial dilation of the tract is difficult with an 8-Fr fascial dilator, a smaller dilator can be used. A dilator as small as 5-Fr can begin the dilation in 1-Fr increments until the 8-Fr dilator can be placed into the calyx of puncture. A 4.5-mm fascial incising needle (Cook Urological, Spencer, IN) can also be placed over the working wire to cut through the fibrosis, especially at the fascial level, and facilitate dilation.

The placement of a Superstiff wire into the ureter is the goal of access during percutaneous procedures. The wire that we use for original access to the ureter is the 0.035-in. glidewire. Once the glidewire is in the ureter, we exchange out the glidewire for a superstiff wire over a 5-Fr angiographic catheter. If the angiographic catheter does not pass easily over the glidewire, making a "herky-jerky" maneuver in which the angiographic catheter is abruptly advanced a small amount at a time over the glidewire often allows the catheter to pass. The angiographic catheter will eventually slide easily once negotiated past the point of difficulty.

In patients with history of urinary tract infections and/or infection stones, a stone culture is beneficial. Although a positive preoperative urine culture can tailor perioperative antibiotic choice, we find by sending a fragment crushed in sterile saline and obtaining a stone culture is helpful for guiding longer term postoperative antibiotic treatment. As our goal is to eradicate the stone burden and all associated bacteria, we are compulsive about removing any fragments visualized on postoperative day-1 NCCT. If the stone culture is positive, we place the patient on therapeutic doses of an appropriate antibiotic for 2 weeks then complete a 3-months course of suppressive antibiotics. A urine culture is obtained at the end of the 3-months course and monthly thereafter for several months to confirm that the patient has been cleared of infection.

CONCLUSIONS

Percutaneous access is best performed by the urologist in the operating room at the time of stone removal. This is because urologists are most familiar with renal anatomy and with the instruments necessary for nephrolithotomy. The ability to obtain access avoids dependence on the skill of another person and their schedule. Additionally, flexibility in the procedure is allowed, particularly if multiple or additional accesses are necessary. Finally, it allows the performance of the operation as a single stage, which is preferable from both the patient's and surgeon's perspective.

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4

Lateralizing Essential Hematuria

Murali K. Ankem, MD
and Stephen Y. Nakada, MD

CONTENTS

SUMMARY

Lateralizing essential hematuria is a rare clinical syndrome which poses a diagnostic and therapeutic challenge for the treating urologist. Despite its benign nature in the majority of patients, recurrent macroscopic hematuria can be very frustrating and stressful to the patient. Historically, these patients were treated by irrigating the renal collecting system with various cauterizing solutions, surgical evaluation of exposed collecting system, partial nephrectomy, or even nephrectomy. Recent advances in the endourological techniques and the development of more sophisticated instruments have enhanced our abilities to diagnose and treat many upper urinary tract lesions. This chapter focuses on the latest developments in the evaluation, technique, and results of fiberoptic ureteropyeloscopy in the management of lateralizing essential hematuria.

Key Words: Hematuria; essential hematuria; unilateral hematuria; lateralizing hematuria; diagnosis; flexible ureteropyeloscopy; laser coagulation.

INTRODUCTION

Lateralizing essential hematuria is a rare clinical syndrome, which poses a diagnostic and therapeutic challenge to the treating urologist. Despite its benign nature in the majority of patients *(1,2)*, recurrent macroscopic hematuria can be very frustrating and

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stressful to the patient. This condition is also known as chronic unilateral hematuria, unilateral essential hematuria, or benign lateralizing hematuria. The complex is defined as gross hematuria localized to one side of urinary tract by cystoscopy. The diagnosis is made by excluding all common causes of hematuria in the face of normal radiological (computed tomography [CT], ultrasound, intravenous urogram [IVU]) and hematological studies. Historically, these patients were managed by irrigating the renal collecting system with various cauterizing solutions *(3,4)*, surgical evaluation of exposed collecting system, partial nephrectomy or even nephrectomy in some patients *(5)*. Recent advances in endourological techniques and the development of more sophisticated instruments have enhanced our abilities to diagnose and treat many upper urinary tract lesions *(6,7)*. This chapter describes the preoperative evaluation, indications, technique, and results of fiberoptic ureteropyeloscopy in the management of lateralizing essential hematuria.

DIAGNOSIS

Lateralizing essential hematuria often presents as asymptomatic chronic recurrent gross hematuria. Some patients may present with clot colic, clot retention, and even significant anemia *(1,7,8)*. Lateralizing essential hematuria is common in younger patients and has no predilection for either sex or side. The work-up should include a thorough history, physical examination, and a cystoscopy at the time of bleeding to lateralize the hematuria to one side of the urinary system and to exclude other common sources of urinary bleeding. Next, serum studies including complete hemogram, basic renal function studies, coagulation studies, and sickle cell preparation should be performed. Urine for microscopy, routine culture, and voided cytology (to rule out inflammatory, malignant, and nephrological sources of bleeding) should be part of the initial evaluation. Consideration for special urine cultures to rule out atypical fungal and tuberculosis *(9)* infections should be given. Three early morning voided urine samples should be sent for Ziehl-Nielsen staining and culture for mycobacterial organisms. In the presence of positive Mantoux test and negative mycobacterial cultures from the voided specimens, ureteroscopy and urine from the renal pelvis should be sent for mycobacterial cultures *(9)*. Where appropriate, 24-hour urine collection for albumin and phase-contrast microscopy for identification of ghost cells could be useful in differentiating glomerular from the epithelial bleeding.

The IVU typically demonstrates the urinary system in entirety and any areas that are not clearly seen should be further characterized by retrograde urography. Oblique views are very important to avoid superimposition of calices and will aid in methodical examination of calices by ureteropyeloscopy later. If the IVU is equivocal the next logical step should be a CT or an ultrasound to rule out renal masses. Patients with intravenous contrast allergy should be evaluated by ultrasound and bilateral retrograde pyelograms after adequate steroid preparation of the patient. CT urography and magnetic resonance (MR) urography are evolving techniques and may eventually replace IVU *(10)*. In certain centers MR urography currently serves as an alternative imaging technique to intravenous urography and CT urography for children and pregnant women and for patients with contraindications to iodinated contrast media *(10)*.

There is no uniform consensus regarding the timing and role of arteriography in the evaluation of lateralizing essential hematuria. As spontaneous arteriovenous malformations (AVMs) are rare, and most of the AVMs are secondary to prior renal biopsy, surgery, renal trauma, or renal tumors *(11)*, this step could be bypassed in the absence of above history. However, patients can be evaluated by noninvasive radiographic imaging either by color duplex doppler ultrasound, CT or MR angiography. In patients with histories highly suspicious for AVM, selective arteriography may be best so that the patient can undergo selective embolization in the same setting.

INDICATIONS

The differential diagnosis of lateralizing essential hematuria includes undetected renal stones, renal and urothelial tumors including carcinoma *in situ* (CIS), benign fibroepithelial polyps, renal papillary necrosis, strictures, hemangiomas, venous ruptures, fungal infections, tuberculosis, AVM, arteriopelvic/ureteral fistulas, and renal vein hypertensive states.

The diagnostic algorithm for lateralizing essential hematuria is depicted in detail in Fig. 1. Once a patient has undergone a history, physical, detailed laboratory, and radiology survey as previously mentioned, the urologist should perform cystoscopy during a gross hematuria episode if possible to lateralize the hematuria. In the absence of hematuria, brief physical exercise in the form of climbing stairs may on occasion trigger the hematuria episode. The next step is to evaluate for renal AVM if the history is suspicious; otherwise, we advocate unilateral diagnostic ureterorenoscopy with selective cytology.

Currently, the role of percutaneous nephroscopy in these patients is limited; flexible nephroscopy could be considered in patients when a mature percutaneous nephrostomy (PCN) tube/track is already present and a complete flexible ureterorenoscopy is technically challenging or not feasible. In the rare circumstances where a lesion can be visualized but cannot be treated, percutaneous access with fulguration of the suspicious lesion may be considered.

TECHNIQUE

Diagnostic ureteropyeloscopy is performed in the ambulatory setting, either under conscious sedation, deep intravenous sedation, or regional or general anesthesia. Although diagnostic ureteropyeloscopy can be performed under local anesthesia alone, any subsequent intervention requires additional anesthesia. We prefer general anesthesia with controlled ventilation for therapeutic intervention to minimize the respiratory excursions. We use a standard urology imaging table with C-arm fluoroscopy for all ureteroscopic procedures. The typical setup we use is listed in the Table 1. In the dorsal lithotomy position, after padding all pressure points, cystoscopy is performed initially. We do not perform retrograde pyelograms in the beginning to avoid any pressure related artifacts in the pelvicalyceal system and to minimize the misinterpretation of upper tract cytology.

We usually do not dilate the ureteral orifice or pass a guide wire into the collecting system so as to avoid inadvertent injury to the urothelium. The procedure is initiated by passing a 6.9 semirigid ureteroscope into the distal ureter. Occasionally passage of a guidewire 1 to 2 cm proximal to the tip of the ureteroscope to open the ureteral orifice may be necessary. The entire distal ureter should be visualized (Fig. 2A). Care should be taken to keep the irrigating fluid pressure less than or equal to 40 cm of water to minimize barotrauma to the upper urinary tract. The rigid ureteroscope is passed as far proximally as possible as long as it passes easily. The goal is to visualize the ureter in its entirety. Through the ureteroscope a dual floppy 0.035-in. guidewire is passed just out the endo of the ureteroscope and the instrument is withdrawn taking utmost care not to further advance the guidewire by using constant fluoroscopic monitoring by the sur-

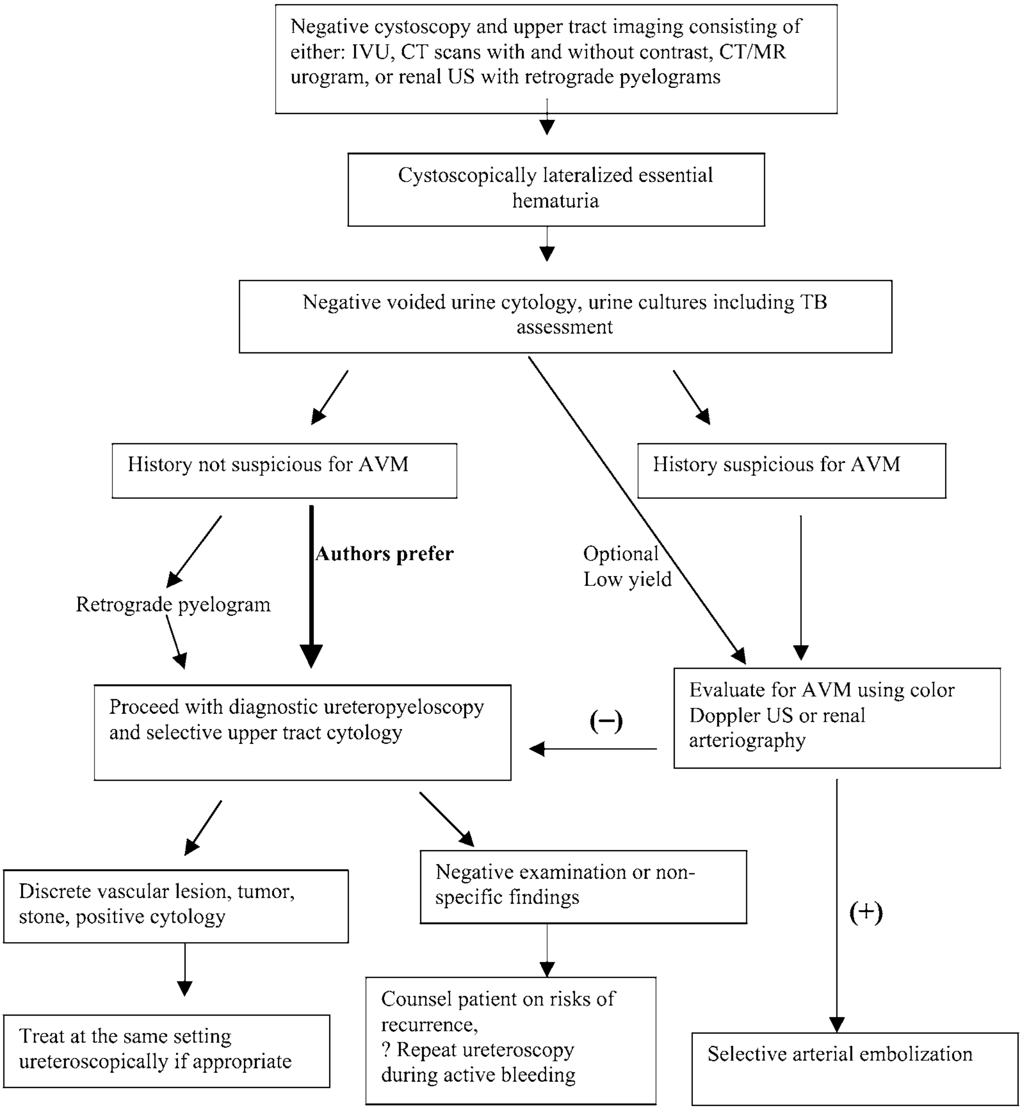

Fig. 1. Diagnostic algorithm for lateralizing essential hematuria. (Reproduced from ref. *11a*. with permission from AUA Office of Education.)

geon (Fig. 2B). Next, a small caliber, actively deflecting flexible ureteroscope is passed over the wire under fluoroscopic guidance taking care not to advance the wire beyond the point of prior visual inspection (Fig. 2C). Then the guide wire is removed and the remaining ureter is examined up to ureteropelvic junction followed by renal pelvic evaluation. If the visibility is poor, the urine from the pelvis can be emptied via the side port and gentle irrigation can be performed using the 20-mL syringe filled with normal saline. Selective urinary cytology is obtained at this time.

Systematic evaluation of the superior, middle, and inferior calices is performed (Fig. 2D). Dilute contrast medium is injected to verify inspection of all calices of the renal collecting system. Alternatively dilute contrast (30%) can be added to the irrigant to visualize the collecting system *(8)*. In the event of bleeding, the collecting system is emptied and

Table 1
Instrument List

Equipment list, diagnostic, and therapeutic ureterorenoscopy (University of Wisconsin)
15-Fr flexible cystoscope
21-Fr cystoscope with 0°, 30°, and 70° telescopes
Semirigid 6.9-Fr ureteroscope
Actively deflectable 7.5-and 6.9-Fr flexible ureteroscope
Sureseal adaptor
0.035-in. dual floppy guide wire
10-mL and 20-mL syringes
Contrast medium 50:50 with saline in graduated cylinder
3 Chip video camera and endoscopic tower
Stirrups, drapes
C-arm fluoroscope with still image capability
Available in the room but not open
Bulb tip pressure irrigator
0.035-in. Amplatz super stiff guide wire
0.035-in. angled glide wire
Torque control device
Holmium laser and goggles
200-µ holmium laser fiber
2-Fr bugbee electrode
3-Fr ureteroscopic biopsy forceps
3-Fr ureteroscopic biopsy brush
2.4-Fr N-circle stone basket
5-Fr ureteral access catheters
8/10-Fr Coaxial dilator
6-Fr double pigtail ureteral stent, assorted lengths
Dual deflecting flexible ureteroscopes

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re-inspection with gentle irrigation will aid in identifying the source of bleeding. This systematic examination will prevent confusion owing to bruising of the upper-pole infundibulum caused by passive deflection of scope against this area when viewing the lower-pole calices (Fig. 2E). Kumon et al. *(13)* made a point that each calyx should be examined with and without irrigation, as the irrigation pressure might stop low-pressure bleeding from venous ruptures and hemangiomas. In special circumstances where a patient with an ileal loop has lateralizing essential hematuria, the above protocol should be followed; but entry into the selected ureteral orfice may need guidewire assistance.

Any clear-cut lesion, i.e., small stone, transitional cell carcinoma (TCC) (Fig. 3) or hemangioma, is appropriately treated using the holmium laser or bugbee electrode depending on the provisional diagnosis after biopsy using biopsy forceps, flat wire basket, or brush (Table 1). If no treatment is rendered and balloon dilation of ureteral orifice is not performed, no ureteral stent is left *in situ*. If treatment is rendered, balloon dilation performed, or bleeding encountered, a 6-Fr double-pigtail stent is left for a limited period

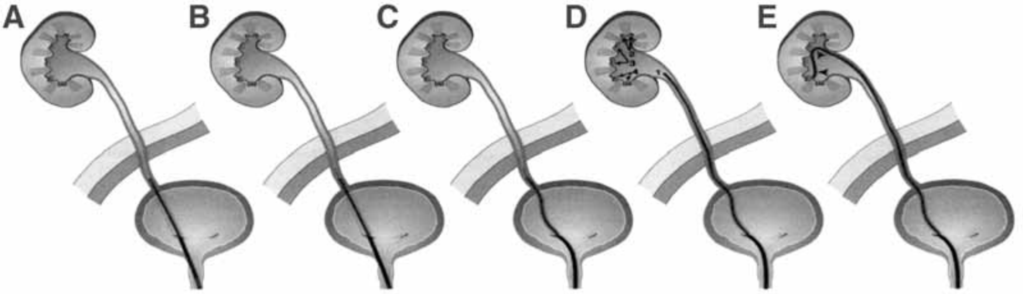

Fig. 2. Diagnostic ureteropyeloscopy is initiated by passing a small caliber (6.9 Fr), semirigid ureteroscope to rule out any distal ureteral pathology **(A)**. Through the ureteroscope, a dual floppy 0.035-in. guidewire is advanced to the uppermost point to which the 6.9-Fr semirigid ureteroscope is advanced under fluoroscopic control **(B)** and the short rigid ureteroscope is removed. Next, a small caliber, actively deflectable flexible ureteroscope is passed over the guidewire and into the ureter under fluoroscopic guidance **(C)** being cautious not to advance the guidewire beyond the point of prior visual inspection. With the availability of the newer, smaller caliber ureteroscopes, the guidewire can be removed and visual inspection of the remaining ureter can be performed. Proximal ureteroscopy is performed followed by examination of the renal pelvis. Selective upper tract urinary cytology is obtained through the ureteroscope at this time. Systematic evaluation of the upper, middle, and lower pole calices is performed in that order **(D)**. This approach prevents confusion owing to endoscopic bruising of the upper pole infundibulum caused by passive deflection of the shaft of the scope against this area when viewing the lower pole calices **(E)**. (Reproduced from ref. *11a*, with permission from AUA Office of Education.)

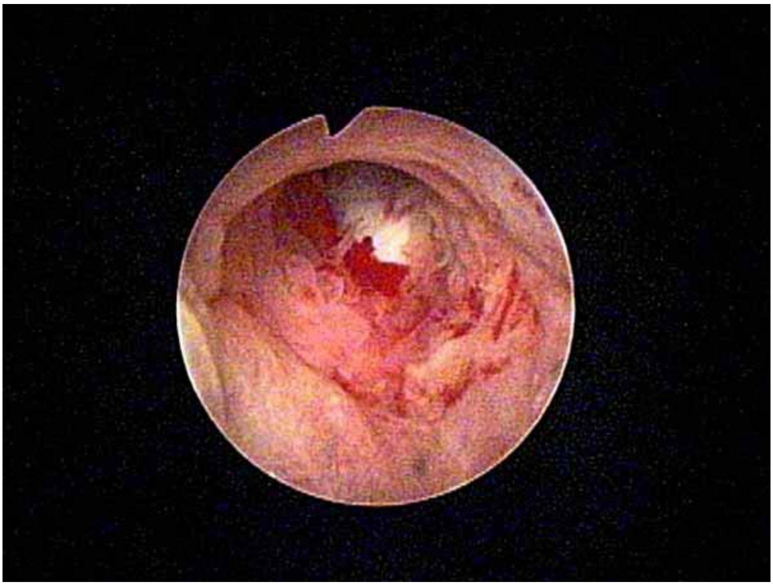

Fig. 3. Transitional cell carcinoma of superior calyx.

of time at the surgeon's discretion. The patient can be discharged on the same day and usually can be given a short course of oral antibiotics.

The recent introduction of dual actively deflecting ureteroscopes can make visualization of lower-pole calices much easier and will increase the sensitivity of upper tract inspection. However, these new ureteroscopes are slightly larger than the standard actively deflecting flexible ureteroscopes. Currently, we use the DUR-8 Elite ureteroscope as a second line instrument for upper tract ureteroscopy (Ankem et al., unpublished data).

In patients where diffuse nonspecific changes are seen, Bahnson et al. *(4)* reported instilling 10 mL of 1% silver nitrate into the renal pelvis using ureteral catheters ($n = 3$). Hematuria stopped after one to two instillations and urine remained clear in 13 months of follow-up. Stefanini and colleagues *(14)* reported usage of oral Epsilon aminocaproic acid at a daily dose of 150 mg/kg in four divided doses given for up to 3 weeks. A total of nine patients with gross hematuria were given the above dose and the hematuria was controlled effectively without any significant complications.

RESULTS

Today, successful examination of entire upper urinary tract using the above-described approach is straightforward. In 1998, Tawfiek et al. *(6)* reported 100% visualization of ipsilateral urothelium in all 23 patients in his series. In 156 published cases of lateralizing essential hematuria, only 8% (13 cases) have been found to have tumors ($n = 7$) or stones ($n = 6$) not diagnosed by preoperative imaging (Table 2). Among the patients presenting with lateralizing essential hematuria, approx 50% will have a discrete vascular lesion *(15)* that can be fulgurated. The most common treatable vascular abnormality is hemangioma, found in 11 cases in Bagley's series, seven in Tawfiek's series, nine in Kumon's series, and five in Nakada's series for a total of 32 cases out of 156 (20%) reported in the literature. Hemangiomas are typically seen on the renal papillae and are usually submucosal. They may appear as small, red, or bluish spots, usually on the tip or base of the papilla or they may be large, bulbous erythematous lesions on the papillary tips *(6)*. Minute venous ruptures are considered discrete vascular lesions, which are often located on the bridge of tissue between compound papillae. These vascular lesions appear to be seen equally distributed throughout the kidney *(7,8)*. The etiology and pathogenesis of these venous ruptures is not clear and they could be related to venous hypertensive states secondary to left renal vein obstruction (nut cracker phenomenon) *(13,16,17)*.

Coagulation of discrete lesions when present is effective; Nakada and associates *(7)* reported resolution of hematuria in the range of 82%. On the other hand, patients with diffuse lesions or negative examination usually have persistent hematuria following ureterorenoscopy (17% long term resolution) *(7)*. Tawfiek and his associates *(6,8)* made similar observations as well.

Upon reviewing the literature, there is strong evidence that ureteroscopic management of these lesions has yielded durable results and this pattern suggests a causal relationship between endoscopic fulguration and resolution of bleeding. In only 12% of patients, despite successful fulguration of hemangiomas, recurrence of bleeding occurred. Multifocality may explain these failures in patients who underwent fulguration. Tawfiek *(6)* reported that 4/5 patients, despite negative examination. maintained clear urine and they theorize that some minute venous-caliceal communications that were not detected by endoscopy might have sealed off secondary to the pressure of irrigation and inflammatory response incited by ureteropyeloscopy alone.

Negative ureteroscopic examinations are disappointing and frustrating both for the patient and the urologist. In modern series the negative examination rate is in the order of 23%. Nakada and colleagues *(7)* found that 67% of patients with negative examinations had persistent bleeding. Tawfiek *(6)* reported 4/8 patients with nonspecific findings continued to have hematuria; however, 4/5 patients with negative examination

Table 2
Published Series, Lateralizing Essential Hematuria

			Vascular abnormalities						
Author	*No.*	*Approach No.*	*Discrete*	*Diffuse*	*Stone*	*Tumor*	*Negative evaluations*	*Recurrence (%)*	*Follow-up (month)*
Gittes et al. *(5)*	12	Nephroscopy 12	5	7	0	0	0	0	N/A
Patterson et al. *(2)*	4	Nephroscopy 3							
		Ureteroscopy 4	1	3	0	0	0	0	5 (2–10)
McMurtry et al. *(18)*	8	Nephroscopy 7							
		Ureteroscopy 3	4	3	1	0	0	25 at 4 month	6 (2–41)
Kavoussi et al. *(19)*	8	Ureteroscopy 8	Not specified		0	0	0	12 at 7 month	11 (7–18)
Bagley et al. *(8)*	32	Ureteroscopy 32	14	9	1	1	5	16	N/A
Kumon et al. *(13)*	12	Ureteroscopy 12	9	1	0	0	2	0	10 (6–21)
Kumon et al. *(13a)*	30	Ureteroscopy 30	22	1	1	1	5	N/A	N/A
Nakada et al. *(7)*	17	Nephroscopy 2							
		Ureteroscopy 15	10	2	1	1	3	41	58 (24–103)
Tawfiek et al. *(6)*	23	Ureteroscopy 23	10	3	2	3	5	0	8 (4–18)
Yazaki et al. *(20)*	6	Ureteroscopy 6	1	1	0	0	5	N/A	N/A
Hara et al. *(21)*	4	Ureteroscopy 4	Not specified		0	1	3	N/A	N/A
Totals	156		76	30	6	7	28		

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maintained clear urine in his series. In the event of negative examination we recommend ureteropyeloscopy be repeated at the time of active bleeding.

Nakada et al. *(7)* reported one major complication in the form of distal ureteral stricture in their series of 15 patients. With the introduction of actively deflecting smaller size ureteroscopes, strictures should occur rarely today.

TIPS AND TRICKS

1. Flexible ureteropyeloscopy should be considered early in the evaluation and management of lateralizing essential hematuria.
2. Retrograde pyelogram should be avoided at the beginning of the procedure to avoid pressure related artifacts in the pelvicalyceal system and minimize the misinterpretation of upper tract cytology.
3. Initial passage of guidewire in to the collecting system should not be done to avoid inadvertent injury to the urothelium.
4. Accidental advancement of guidewire into the collecting system while switching the ureteroscopes should be prevented to avoid bruising of urothelium.
5. Preoperative and perioperative marking and checking of individual calices should be performed on the intravenous urograms.
6. Maintaining the irrigation fluid pressure less than 40 cm of H_20 is essential and gentle manual irrigation is the rule.
7. Each calyx should be examined with and without irrigation to see if bleeding occurs from calyceal venous ruptures/hemangiomas.
8. Systematic and methodical examination of calices, preferably the same way every time will minimize bruise artifacts in the collecting system.
9. Dual actively deflectable ureteroscopes may be used if the standard flexible ureteroscopes fail to visualize the lower calices.

CONCLUSION

Although a rare clinical entity, lateralizing essential hematuria can be a source of frustration for the patient and the urologist. However, we are encouraged by the significant improvements in the instrumentation and ablative energies that are now available to urologists. Additionally, improvements in radiographic imaging should decrease the "undetected" stones and tumors. Today, we expect the majority of lateralizing hematuria cases can be treated with symptom resolution.

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5 Diagnosis and Surveillance of Upper Tract Tumors

Douglas W. Soderdahl, MD
and Michael D. Fabrizio, MD, FACS

CONTENTS

SUMMARY

Upper tract transitional cell carcinoma is rare and historically has resulted in nephroureterectomy. Diagnosis and treatment historically relied upon finding radiographic filling defects in the collecting system. With the advent of small caliber ureteroscopes, small working instruments, and lasers, nephron-sparing procedures are available to these patients. Additionally, these technological advances can be used to rapidly diagnose patients.

The results of endoscopic treatment in transitional cell carcinoma are based on the fact that survival is directly related to the grade and stage of the tumor. Low grade lesions recur less frequently and have less invasive potential than high grade lesions. After endoscopic treatment of upper tract transitional cell carcinoma, low grade lesions rarely progress and recurrences usually respond to retreatment. This chapter describes the background surrounding upper tract transitional cell carcinoma. It also outlines the diagnosis and surveillance regimens and report treatment results.

Key Words: Transitional cell carcinoma; ureteroscopy; upper tract tumor.

INDICATIONS

Introduction

Transitional cell carcinoma (TCC) arising in the upper tract urothelium (ureters, renal pelves, and calyces) often presents diagnostic and therapeutic challenges to the urologist.

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Fortunately as technology and surgical skills have advanced into the 21st century, the ability to accurately diagnose, stage, and even primarily treat this disease has become possible. With the advent of smaller, flexible, high-resolution ureteroscopes, access to the entire urothelium is possible. Not only can suspicious areas be directly visualized, but also urothelial barbotage and biopsy can be performed as well. This valuable staging information can further clarify results obtained from radiological studies and urine screening tests in patients presenting with signs, symptoms, and risk factors for upper tract TCC and lead to a correct diagnosis.

Once a diagnosis of upper tract TCC is made, the traditional gold standard for treatment is nephroureterectomy with a cuff of bladder *(1–3)*. Because of the high recurrence rates, multifocality of the disease and the low incidence of bilateral disease, total extirpation of the involved urothelium made sense and provided excellent cancer control. However, patients with an anatomically or functionally solitary kidney, renal insufficiency, or bilateral upper tract disease presented a difficult challenge as the goals of maintaining adequate renal function and of cancer control conflicted. Fortunately, experience with open nephron sparing approaches, such as distal ureterectomy with ureteral reimplantation, demonstrated that nephroureterectomy may not be necessary in all cases of upper tract TCC *(4,5,5a)*. This experience was then later used to rationalize a minimally invasive endoscopic approach for nephron sparing treatment of upper tract TCC in selected patients. Subsequently, several investigators have shown that endoscopic management of upper tract TCC is not only feasible in patients in whom a renal sparing approach is clearly indicated, but also in those with a normal contralateral kidney *(6–8)*. Inherent to this strategy, however, is that patients treated with nephron-sparing endoscopy will continue to be at high risk for tumor recurrence. This strategy, as in bladder cancer, will require a long-term surveillance program in which upper tract ureteroscopy plays a vital role.

Epidemiology

The majority of upper urinary tract tumors originate from transitional epithelium (90%); however, primary squamous cell carcinoma, adenocarcinoma, and rare sarcomatous tumors must also remain in the differential diagnosis. Primary TCC of the upper urinary tract occurs in approx 2–4% of patients with a previous history of bladder cancer *(9)*. The American Cancer Society estimates 31,000 and 2400 new cases of renal and ureteral cancers were diagnosed in 2003 *(10)*. Renal pelvic tumors generally account for 5% of all urothelial tumors and less than 10% of all renal cancers *(11)*. Ureteral tumors present at approximately one-quarter of the rate of renal pelvis TCC *(12)*. Bilateral disease is rare, and occurs in 2–4% of patients with a history of bladder cancer *(3)*. However, 23 to 75% of patients with upper tract TCC will eventually develop a bladder lesion, which mandates close surveillance *(6,7,9,13)*.

Risk Factors

As with bladder cancer, several factors have been shown to be associated with the development of upper tract TCC. The strongest association has been shown with cigarette smoking which is found in a majority of patients presenting with TCC *(14)*. Other risk factors include occupational exposures (chemical, petrochemical, plastics, coal, asphalt, aniline, and tar), chemotherapy (cyclophosphamide), analgesic abuse, and hereditary familiar cancer syndromes *(15)*. Additionally, patients with Balkan nephropathy have a high incidence of upper tract TCC which more often is bilateral and tends to run a more indolent course *(16)*.

Diagnosis

Most patients with upper tract TCC will initially present with gross or microscopic hematuria *(2)*. The presence of vermiform clots suggest an upper tract source. Occasionally, patients will also complain of flank pain which may mimic ureteral colic. This is presumably the result of transient obstruction from either the mass or from clots. Finally, a small percentage of patients may experience no signs or symptoms and the tumor is picked up serendipitously on a diagnostic study done for another reason.

The American Urological Association best practice policy defines microhematuria as the presence of three or more red blood cells per high power field on two of three urinalyses gathered at separate settings *(17)*. The panel also provided a consensus work-up for patients presenting with hematuria which should include a detailed history and physical examination, imaging of the upper urinary tract, urine studies (microscopic urinalysis, culture, cytology), and cystoscopy *(18)*.

The traditional imaging studies for a hematuria work-up are an intravenous pyelogram (IVP) with tomograms or retrograde pyelography with renal ultrasonography in patients with contrast allergy or those with poor upper tract visualization on other studies *(19–21)*. Most commonly upper tract TCC will be identified as a radiolucent filling defect or obstructing lesion on an IVP. Occasionally, the involved kidney will be poorly or nonvisualized owing to obstruction. Computed tomography (CT) scanning, due to improvements in resolution, capacity for three-dimensional reconstruction and ability to diagnose unrelated, nonurological conditions has recently become an acceptable initial imaging selection *(18)*. It is vital to obtain pre- and postcontrast scans in order to adequately characterize masses and to identify radiodense renal calculi *(22–24)*. Magnetic resonance urography has been recently described and may have the ability to differentiate ureteral tumors from other filling defects and may prove to be superior to IVP in upper tract TCC diagnosis *(25,26)*.

Urinary cytology also plays a role in the work up of hematuria in high-risk individuals. The sensitivity of urine cytology is dependent on several variables including number of specimens obtained, the stage and grade of the tumor and the experience of the cytopathologist *(27–28)*. Saline barbotage has been shown to improve the diagnostic accuracy of cytology; however, this requires catheterization or endoscopy *(29)*. Patients with positive cytology results and no demonstrable pathology in the bladder should undergo selective ureteral catheterization for upper tract urinary cytology and saline washings. This can be performed prior to retrograde pyelography. Several other urine tests (bladder tumor associated antigen, nuclear matrix protein 22, telomerase, etc.) to detect TCC in the bladder have been studied, but their role in upper tract TCC detection is not clear *(18)*.

Cystoscopy is vital to the work-up of hematuria or in those presenting with radiological evidence of upper tract TCC owing to the high incidence of concomitant bladder pathology. Bladder lesions can be visually characterized and biopsied, and if performed at the time of bleeding, cystoscopy may also be helpful in localizing the side of upper tract hematuria *(30)*. Additionally, at the time of cystoscopy, specimens can be obtained from the bladder and each ureter for cytological examination.

Once the bladder and urethra have been cleared endoscopically and the suspicion of upper tract TCC remains owing to abnormal imaging studies or cytological results, ureteroscopy is the next step for diagnosis, staging and possibly treatment. The entire urothelium at risk is carefully inspected, ureteral and renal pelvis washings are collected, and suspicious areas biopsied/resected and the base fulgurated.

INSTRUMENT LIST

1. Room equipment:
    a. Fluoroscopy table with stirrups.
    b. Padding for pressure points.
    c. Fluoroscopy (C-arm, image intensifier) with monitor.
    d. Lead personal protection aprons/thyroid shields.
    e. Video camera (3 chip).
    f. High-resolution monitor.
    g. High-power light source (300 W Xenon).
    h. Anesthesia machine and cart.
    i. Ho:YAG/Nd:Yag laser machine.
    j. High-power electrocautery generator.
    k. Pressure bag for irrigation system.
    l. Irrigation fluids (normal saline, sorbitol, water).
2. Back table stock:
    Equipment:
    a. 21-Fr Cystoscope with working channel.
    b. 30 and 70° rigid lens.
    c. Light cords.
    d. Cystoscopy tray and pan filled with sterile water.
    e. Cups for contrast and normal saline.
    f. Minor instruments: Kelly clamps (3).
    g. Semirigid ureteroscope.
    h. Flexible ureteroscope.

    Disposable Items:
    a. Cystoscopy drapes.
    b. Sterile towels.
    c. Irrigation tubing.
    d. Guidewire (0.038 in. straight, Teflon-coated, floppy-tip).
    e. Syringes, 60 cc (1), 20 cc (2).
    f. Surgical lubricant.
    g. Diluted contrast (50:50 mix with saline).
    h. Working port seal.
    i. 5-Fr Open-ended ureteral catheter.
3. Readily available; not open
    a. Guidewires (hydrophilic, super-stiff, angled).
    b. Resectoscope set.
    c. 5-Fr Open-ended ureteral catheter.
    d. 10-Fr Dual-lumen catheter.
    e. Ureteral dilation kit.
    f. Pump irrigation set.
    g. Torque control device.
    h Laser fibers (200, 365 μ).
    i. 3-Fr Biopsy forceps.
    j. 3-Fr Flat wire basket.
    k. 2-Fr Fulgurating electrode.

TECHNIQUE

Procedure Preparation

Ideally, ureteroscopy should be performed by an experienced operative team that is familiar with the steps and usual progression of the case, as well as the required instrumentation. Communication between anesthesiologist and the urologist is also vital to ensure the patient is properly sedated throughout the case (especially while operating endoscopes in the ureter and renal pelvis). The patient's radiographs should be prominently displayed in the operating room. These not only remind the team of the affected side, but also they provide a road map of the upper urinary tract during the case. Prior to starting any endoscopic case, the scopes should be inspected for any damage or nofunction which could compromise patient outcome. Back-up scopes should be available for unexpected contingencies. Also, preventive maintenance should be performed on the fluoroscopy unit to ensure high quality images which can be stored and saved are consistently generated.

Patient Preparation

After obtaining informed consent, the patient is brought to the operating room where anesthesia is induced using a general, regional, or monitored sedation technique. We prefer general anesthesia in cases in which tumor biopsy and laser fulguration is anticipated and a general technique is not contraindicated owing to patient comorbidities. A preoperative urine culture is obtained, and prior to the procedure, prophylactic antibiotics (first generation cephalosporin) are given. The patient is placed in the dorsal lithotomy position and care is taken to provide adequate padding for pressure points. Sequential compression stockings are applied and the patient is then prepped and draped.

Cystoscopy

Rigid cystoscopy is performed in standard fashion using the 21-Fr cystoscope with the 30 and 70° telescopes. Barbotage cytology is obtained using a 60 cc syringe and normal saline after thorough examination of the bladder. If the patient presented with gross hematuria, careful attention should be paid to each of the ureteral orifices in order to potentially lateralize the hematuria. We choose not to perform a retrograde pyelogram at the onset of the procedure; instead, contrast is withheld until after cytological specimens are retrieved from the ureter and renal pelvis. If any suspicious bladder lesions are noted at the time of cystoscopy, they are biopsied/resected and fulgurated. The cystoscope/resectoscope is then removed from the bladder.

Ureteroscopy

The semirigid ureteroscope is advanced through the urethra and into the bladder. The ureteral orifice on the affected side is identified and the scope is placed into the intramural ureter under direct vision. We have found in the majority of cases, using the 6.9-Fr scope, that ureteral dilation is unnecessary. Additionally, in order to prevent any possible ureteral trauma prior to initial visualization, we routinely do not pass a guidewire prior to scope placement as we would for nephrolithiasis indications. Many times, simply rotating the semirigid scope 90–180° to control the position of the beveled tip, will result in successful scope passage. In the uncommon case where access cannot be directly obtained in this manner, we will occasionally use a 0.025-in. hydrophilic glidewire through the working port of the ureteroscope to aid in manipulating the lip of the ureteral orifice to gain scope access. Finally, in rare cases, we will employ a 12-Fr (4 mm) ureteral dilating balloon, which is preferable to continuing multiple attempts at ureteroscope passage and potentially raising a submucosal flap or creating traumatic edema precluding any access.

The semirigid ureteroscope is used to visually inspect the distal third of the ureter. Irrigation pressure should be regulated such that a clear look at the urothelium is provided while limiting potential barotrauma to the upper tract. Any blood or debris that hinders the examination should be aspirated via the working port of the instrument. In cases where pressure irrigation is required, we prefer using a pressure bag that provides a constant pressure which can be controlled at the level of the bag as well at the level of the scope. Alternatively, bulb or pump action systems can be used to improve visualization. After ureteral inspection, ureteral barbotage is performed via the working port of the scope using 5–7 cc of normal saline. The most proximal position of the ureteroscope in the ureter is noted on fluoroscopy and then the scope is withdrawn towards the ureterovesical junction with care taken not to completely remove the scope from the ureter. Through the working channel of the ureteroscope, a 0.038-in. floppy tip guidewire is placed under fluoroscopic guidance to a point that had been previously visually inspected and not any farther. The semirigid ureteroscope is then removed, leaving the wire in place.

A small-caliber, dual actively deflecting ureteroscope is then advanced under fluoroscopic guidance to the ureteral level that had previously been inspected by the semirigid scope. The scope is then slowly advanced under visual guidance with care taken to maintain the tip of the instrument in the center of the ureteral lumen. Once the ureteroscope is advanced past the ureteropelvic junction into the renal pelvis, each of the calyces is systematically inspected beginning with the upper pole and then to the interpolar and lower pole calyces. It is very helpful to have a contrast study such as an IVP or retrograde available to anticipate the intrarenal calyceal anatomy. It is also very important to visually inspect all of the urothelium prior to the possibility of introducing inadvertent scope trauma from the ureteroscope tip or the shaft of the scope during flexion maneuvers to gain lower pole access. With the use of the dual deflecting ureteroscope, lower pole visualization with minimal trauma is facilitated. Once the intrarenal collecting system is inspected, collect saline barbotage for cytology and then inject dilute contrast via the working port under fluoroscopic guidance to insure that all of the calyces have been inspected. If no pathology is discovered and ureteral dilation is not required, the ureteroscope is then removed and a stent is generally not required. In cases where a biopsy is indicated, a floppy tipped wire is placed through the ureteroscope to maintain access. The scope is then removed and a safety wire is passed using a dual lumen catheter prior to reinserting either the flexible or semirigid scope for biopsy and possible treatment. In cases where treatment is provided, excessive bleeding encountered, or ureteral orifice dilation required, we will generally place a 6- or 7-Fr indwelling double-J ureteral stent for 4–10 days.

Ureteroscopic Biopsy

Biopsies of any suspicious lesions are performed with a 2.4-Fr flatwire basket or 3-Fr biopsy forceps which is followed by another saline wash and aspirate. The biopsy tissue is not transmitted through the ureteroscopic port, but it removed in the same manner as a basketed stone. All samples are then sent to the cytopathologist for interpretation. Cell blocks are made of the larger tissue samples, and the washes are processed with use of the Cytospin technique *(9,31)*. Pathological staging of the primary tumor is performed using the AJCC 1997 staging guidelines *(32)*. (Table 1).

Table 1
Staging of Primary Tumor for Renal Pelvis and Ureter

Stage	
TX	Primary tumor cannot be assessed.
T0	No evidence of primary tumor.
Ta	Papillary noninvasive carcinoma.
Tis	Carcinoma *in situ.*
T1	Tumor invades subepithelial connective tissue.
T2	Tumor invades the muscularis.
T3 Renal pelvis	Tumor invades beyond muscularis into peripelvic fat or the renal parenchyma.
T3 Ureter	Tumor invades beyond muscularis into periureteric fat.
T4	Tumor invades adjacent organs, or through the kidney into the perinephric fat.

Some authors have advocated the use of high-resolution endoluminal ultrasound to further evaluate the character and depth of involvement of the ureteral wall and periureteral tissues *(33)*. Guarnizo et al. *(34)*, recently reported a technique using the 11.5-Fr ureteroresectoscope and/or 3-Fr biopsy forceps to obtain samples. This enabled the pathologist to grade the sample based on the histopathological appearance and actually evaluate the lamina propria in 67.5% of patients *(32)*. One important consideration, however, is that not all patients are amenable to complete resection via endoscopic techniques. Suh et al. *(35)* reviewed 61 patients presenting with upper tract TCC and found that 43% could not be managed by endoscopy alone owing primarily to large tumor size.

Recently, the Neodymium:Yttrium-Aluminum-Garnet (Nd:YAG) and the Holmium: YAG (Ho:YAG) lasers have been used to fulgurate and ablate tumors in the ureter and renal pelvis following ureteroscopic biopsy *(36)*. Keeley et al. *(6)*, prefer to use the Nd:YAG laser to coagulate the tumor prior to ablation with the Ho:YAG. The shallow depth of penetration with the Ho:YAG (<0.5 mm) allows focused tissue ablation under direct visualization. In contrast to the Nd:YAG, the Ho:YAG must directly contact the tissue or be in close contact in order to treat the lesion. Optimally, the Nd:YAG, with its greater depth of penetration (4–6 mm) can be used to coagulate the tumor which is then ablated with the Ho:YAG. The authors prefer this technique with setting of 1 J and 8 Hz for the holmium laser and 30 W for the Nd:YAG.

Surveillance Following Endoscopic Treatment

Unlike bladder cancer, where surveillance protocols have been well defined, there exist only anecdotal strategies for upper tract TCC surveillance. In cases where the upper tract TCC is treated with nephroureterectomy, bladder surveillance follows the same protocol as *de novo* bladder cancer with periodic cystoscopy and intermittent upper tract studies. However, with a trend towards nephron sparing techniques for upper tract TCC, urologists are now faced with the question of how to follow these patients clinically. The detection of recurrent upper tract TCC can pose a significant challenge and the optimal interval and choice of the available studies and interventions has not been defined in the literature *(37)*. Chen et al. compared ureteroscopy to urinalysis, bladder and upper tract cytology/washings, and retrograde pyelography and found these latter methods less valid and accurate in detecting upper tract TCC recurrence and concluded that ureteroscopic evaluation with biopsy when indicated is essential in surveillance *(29)*. Other authors rely more heavily on radiographic studies and cytologies to follow the ipsilateral ureter *(38,39)*. Our approach is similar to bladder cancer surveillance, which requires serial endoscopic inspection of at risk urothelium. Patients undergo physical examination, urinalysis, voided cytology, cystoscopy, retrograde pyelography, ureteroscopy, and upper tract barbotage cytology at 3 and 6 months. If tumor-free at 6 months, patients return at 9 months for office cystoscopy and cytology. Ureteroscopy is repeated at 12 months and then every 6 months for a total of 3 years. If the patient has no recurrences at 3 years, ureteroscopy is performed yearly. Positive findings during surveillance will prompt further study and biopsy and treatment of any suspicious lesions. Depending on the stage and grade of the recurrence, patients will be offered nephroureterectomy or will be placed back into a surveillance protocol starting again at time 0. We have recently added the use of a commercially available multitarget fluorescence *in situ* hybridization (FISH) assay in high-risk patients with multiple recurrences or equivocal cytology who remain on a surveillance protocol *(40,41)*. Patients with high-grade or advanced-staged disease, regardless of initial treatment, should undergo a periodic evaluation for metastatic disease with a CT scan, chest X-ray, and liver function tests.

The surveillance protocol for upper tract TCC is labor and resource intensive and requires a motivated patient for optimal outcomes. Although ureteroscopy often requires a trip to the operating room and general anesthesia, several authors have described novel techniques for office-based endoscopic upper tract evaluation *(42,43)*. However, many urologists are not comfortable with office-based ureteroscopy, and until a more reliable method to detect upper tract TCC recurrence is available, periodic ureteroscopy should continue to play a prominent role in surveillance protocols.

RESULTS

The ideal radiological work-up for a patient presenting with microhematuria is not standardized and may include one or more of the following: IVP, retrograde pyelography, ultrasonography (US), CT scan, and magnetic resonance imaging. Because upper tract TCC is a relatively uncommon etiology for microhematuria, some investigators have proposed that renal ultrasound may serve as an initial screening test in defining renal masses and detecting nephrolithiasis or their obstructive sequelae *(20,44)*. Renal ultrasonography has proven to be effective in defining renal masses and detecting hydronephrosis; however, it is not sensitive in detecting upper tract TCC *(21)*. IVP provides details of the urothelium, but is not as effective in evaluating renal masses *(23)*. In order to maximize diagnostic sensitivity, some authors recommend combining both of these modalities in the work-up of hematuria, whereas others contend that it is not cost-effective. Retrograde pyelography may add additional detail of the urothelium, but its diagnostic accuracy is dependent on the technical quality of the examination and has a higher yield when read by the urologist at the time of the study than when later interpreted by a radiologist *(6,29)*. CT scanning provides the best modality for elucidating the various different etiologies of hematuria and can also provide pertinent information regarding non-urological conditions. It is superior in evaluating stones than both US and IVP (sensitivity of 94–97% vs 52–59% for IVP and 19% for US) and can provide detailed information for even small renal lesions (sensitivity of 75 vs 40% in US) *(45)*. CT scan urography has been shown to provide adequate opacification of the upper tract collecting system and is useful in the diagnosis of upper tract TCC *(46)*, but is less reliable in providing accurate staging information *(47)*. As the optimal imaging modalities for the upper tract have not yet been studied in a controlled, randomized trial, recommendations are based on anecdotal and retrospective evidence.

Voided urinary cytology in the detection of upper and lower urinary tract TCC is generally inadequate with a sensitivity of 10 to 80% and 40 to 76%, respectively *(18,38,48)*. Xia et al. *(49)* demonstrated that the sensitivity is related to tumor grade with positive results in 33% of patients with grade 1 disease, 71% with grade 2, and 100% with grade 3 upper tract TCC. The combination of direct visual inspection with cytological analysis has improved diagnostic accuracy. A potential adjunct in evaluating patients with equivocal or negative cytologies is multitarget FISH studies from the ureter. A recent study evaluating bladder cancer showed an 89 and 60% sensitivity in patients with equivocal and negative cytological results and a 97% specificity at 12 months. Interestingly, 89% of patients with an initial "false-positive" result on the FISH study, developed biopsy proven TCC in the 12-months follow-up period *(40)*. The use of FISH for upper tract TCC has not been adequately studied to provide evidence based recommendations.

One of the potential problems with the endoscopic approach is the ability to adequately stage the tumor. Ureteroscopic biopsies of upper tract tumors often do not yield a deep enough sample to allow microscopic determination of invasion *(50)*. However, initial open series confirmed a good correlation with grade and final pathological stage. Three series comparing the grade and final stage noted a nearly 100% correlation between grade 1 tumors and superficial (Ta) disease *(10,27,36)*. Similarly, Nielsen and Ostri *(51)*, noted that 96% of grade 3–4 tumors had parenchymal invasion.

The ability of ureteroscopic grading to correlate with final pathological stage was examined by Keeley et al. *(34)* They noted a 91% correlation between ureteroscopic grade and surgical grade. Moreover, 86.6% of grade 1–2 tumors were Ta or T1 lesions. Eight of twelve patients with grade 3 disease were T2 or T3 lesions. Some recent concerns over the ability of ureteroscopy to adequately stage were noted by Guarnizo et al. *(33)* In their series, 10 patients diagnosed with Ta disease ureteroscopically were actually upstaged after nephroureterectomy to T1 lesions. However, the literature does support the conclusion that the ureteroscopic grade gives some prediction of final pathological stage *(51,51a)*. In an attempt to better predict pathological stage, Skolarikos et al. *(52)* described using exfoliated cell cytology in patients with grade 2 upper tract TCC as a adjunct to avoid the possibility of tumor upgrading after nephroureterectomy. This information may aid in the selection of candidates for nephron sparing endoscopic treatments.

As in bladder cancer, patients with upper tract TCC treated with either ureteroscopic or percutaneous organ-sparing endoscopic techniques have a high propensity for tumor recurrence *(38,53)*. Initial studies were limited to case reports. In 1993, Gerber and Lyon *(13)* reviewed the literature and noted that local recurrence rates were low (13.7%); however, disease progression and disease-specific mortality were difficult to ascertain owing to the limited number of patients. In a more recent review, Tawfiek and Bagley *(9)* reviewed the treatment results in 205 renal units. The local recurrence rate was 33% for renal pelvic tumors and 31.2% for ureteral tumors. Of note, bladder recurrences were found in 43% of patients treated ureteroscopically emphasizing the importance of both lower- and upper-tract surveillance. Outcomes from several large ureteroscopic and percutaneous series are listed in Tables 2 and 3 *(6–8,51,41–58)*. A recent review by Suh et al. *(35)* found that disease recurrence was significantly influenced by initial tumor location, size, grade, and multifocality, but ultimately did not correlate with the success of a surveillance regimen. This led the investigators to propose the consideration of endoscopic management even in cases of high-grade, high-volume, and multifocal upper tract TCC.

Two small studies highlighted the potential concern for tumor dissemination. Tomera et al. *(59)*, reported on two patients who had local recurrence in the renal fossa after

Table 2
Outcomes Following Ureteroscopic Management of Upper Tract TCC

Series	*No. of patients*	*Recurrence (%)*	*Disease specific mortality (%)*	*Duration of f/u (mo)*
Daneshmand et al. *(50)*	26	23 (88%)	0	4–106
Chen et al. *(8)*	23	15 (65%)	0	8–103
Keeley et al. *(6)*	38 (41 kidneys)	8 (28%)	0	3–116
Elliott et al. *(7)*	44	17 (38%)	13.5	3–132
Martinez-Pineiro et al. *(54)*	28	8 (29%)	7	2–119

TCC, transitional cell carcinoma.

Table 3
Outcomes Following Percutaneous Management of Upper Tract TCC

Series	*No. of patients (renal units)*	*Recurrence (%)*	*Disease-specific mortality (%)*	*Duration of f/u (months)*
Liatsikos et al. *(55)*	69	Grade 1 (20%) Grade 2 (26%) Grade 3 (56%)	Grade 1 (100%) Grade 2 (96%) Grade 3 (64%)	11–168
Clark et al. *(56)*	17 (18)	6 (33)	3 (17)	1.7–75
Patel et al. *(57)*	26	6 (23)	2 (7.7)	1–100
Jarrett et al. *(58)*	34 (36)	10 (33)	4 (13)	9–111

TCC, transitional cell carcinoma.

intraoperative pyeloscopy for indeterminate lesions prior to nephroureterectomy. Lim et al. *(60)* unexpectedly found tumor in the submucosal vascular and lymphatic spaces of one patient with a small grade-2 lesion. Two studies looked at this potential problem. Kulp and Bagley *(61)* noted no tumor in the vascular or lymphatic spaces of 13 patients who had ureteroscopy followed by nephroureterectomy. Hendin et al. *(62)* evaluated 96 patients undergoing nephroureterectomy, half of whom had diagnostic ureteroscopy prior nephroureterectomy, and found no statistically significant difference in the 5-years metastasis-free survival or overall survival between the two groups.

Finally, complication rates are low in most ureteroscopic series. One to four percent of patients experience ureteral perforation from technical errors with endoscopes, guidewires, baskets, and/or lasers. The stricture rates approach 9% and are becoming less common most likely as a result of the use of small caliber ureteroscopes as well as the introduction of Nd:YAG and Ho:YAG lasers *(63)*. Ureteral stricture is not always the result of technical factors and may represent recurrent disease. This was demonstrated by Daneshmand et al. *(46)* where 40% of patients with postureteroscopy stricture had recurrent ureteral TCC.

TIPS AND TRICKS

1. When passing the semirigid ureteroscope at the level of the ureteral orifice, remember to rotate the scope. The tip is beveled. If this fails, simply pass a wire through the channel to elevate the orifice and pass the ureteroscope under direct vision. Remember to only advance the wire to the level of the distal ureter in order to avoid “scuff” marks in the ureteral wall.

2. To ensure stability of the semirigid ureteroscope it is helpful to perform the procedure while seated. Also, in males, a hand should support the scope at the level of the penoscrotal junction.
3. Although the need for ureteral dilation is rare; if necessary, we prefer a 4 mm × 4 cm ureteral dilating balloon or graduated dilating catheter.
4. Once the limit of the semirigid scope is reached, leave a wire at that point. Do not advance the wire into proximal regions that have not yet been visually inspected.
5. Pass the flexible ureteroscope over the wire and begin inspection at the level last inspected by the semirigid ureteroscope. Care must be taken to fix the wire in place during passage which can be aided by an assistant who holds the end of the wire straight and then does not move. Passage of the scope should always be done under fluoroscopic guidance keeping the wire steady. Advancing the flexible ureteroscope should not be difficult since the ureter has previously accepted the semirigid ureteroscope.
6. If possible, avoid contrast irrigation initially. This adversely affects cytological interpretation.
7. When a tumor is encountered, aspirate at the level of the lesion. Place a safety wire prior to using any working instruments. Next, proceed with a biopsy using a 2.4-Fr flatwire basket or 3-Fr biopsy forceps. When using the basket, it is important to completely "engage" the tumor by rotating the scope or basket or both. It is not necessary to completely close the basket, but to close it just enough so that the tumor is secured. The scope and basket are then moved as a unit to remove the tumor from its base.
8. The tissue in the basket should not be pulled through the working channel of the ureteroscope, but removed in a manner similar to a stone in a basket. The tissue in the 3-Fr biopsy forceps may be removed through the working channel.
9. Send the specimens in formalin if sufficient tissue is present; otherwise, send the specimens in saline for cytological analysis/cell block. If the specimen is small, routine processing will often result in "insufficient tissue."
10. Aspirate after biopsy and send for cytology.
11. Fulgurate the tumor with the Nd:YAG or electrocautery and ablate with the Ho:YAG if possible. A holmium laser alone is acceptable if that is all that is available, but it should be used primarily to ablate the tumor base. Owing to shallow penetration, it cannot efficiently fulgurate a large lesion. To prevent ureteral stricture, do not use the laser circumferentially in the ureter.
12. The tumor base should be ablated with short bursts of energy from the Ho:YAG laser. We prefer a setting of 1 J and 10 Hz for this procedure. Sometimes it is helpful to turn off the laser aiming beam in order to precisely direct the tip of the laser to the tumor base.
13. Send postablation cytologies.
14. Use saline during the entire procedure to preserve cellular architecture.
15. Power irrigations systems are helpful during ureteroscopic inspection. Manual or pressure bag systems facilitate visualization.
16. Ensure that the entire collecting system has been inspected by opacifying the collecting system with a dilute contrast solution. Passive deflection may be necessary to reach the lower pole calyces with older flexible ureteroscopes. This should be done only after inspecting the upper pole and interpolar regions. It is helpful to have an IVP or retrograde pyelogram available in the operating room to serve as a road map to the collecting system.

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II

CALCULUS THERAPY

6

Ureteroscopy

David E. Rapp, MD
and Glenn S. Gerber, MD

CONTENTS

SUMMARY

As technological advances continue to arise throughout the field of endourology, the indications and endoscopic management of urinary calculi continue to evolve. An excellent working knowledge of the various ureteroscopes and associated endoscopic instruments currently available is crucial to successful treatment of urinary calculi. These include guidewires, dilation devices, rigid ureteroscopes, flexible ureteroscopes, stone extraction devices, and lithotripsy devices. Much of the success of ureteroscopy also depends on a solid technical foundation. These technical aspects of ureteroscopy are reviewed in detail throughout this chapter. Finally, urological surgeons may encounter technically difficult situations that make ureteroscopy challenging. Such situations and potential approaches to these situations are discussed.

Key Words: Ureteroscopy; ureter; calculus; stones; lithotripsy.

INDICATIONS

As technological advances continue to arise throughout the field of endourology, the indications for ureteroscopic management of urinary calculi continue to change *(1)*. Ureteroscopes and related instruments also are evolving, allowing for treatment of stones in all locations within the urinary tract while decreasing the morbidity associated with intervention. With this evolution comes the need to define when intervention is required and which modilities for intervention are best suited for each clinical scenario.

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In general, there is a consensus that small stones may be treated with conservative management. For calculi of 5 mm or less, spontaneous passage is seen in most patients. Spontaneous passage rates of 71 to 98% are observed for such stones in the distal ureter, whereas passage rates of proximal ureteral calculi of small size range from 29 to 98% *(2)*. Spontaneous passage is much less likely with stones greater than 5 mm in size, with rates for larger calculi in the proximal and distal ureter of only about 50% or less *(2)*.

For patients with stones 5 mm or less in size, a period of observation is appropriate in the absence of complicating factors such as infection, renal dysfunction, and poor pain control. However, observation for longer than 4–6 weeks is generally not advised owing to concerns regarding effects on renal function. The precise duration of observation in which the risk of irreversible parenchymal loss is minimal has not been well defined. In experimental cases of complete unilateral obstruction, microscopic changes in the kidney are seen almost immediately, as changes consistent with injury to the papilla and fornix are observed at 24 hours *(3)*. Papillary necrosis is demonstrated in experimental models by 7 days *(4)*. Return of renal function following unilateral obstruction is variable, dependent on factors such as duration and degree of obstruction. Animal models have shown limited return of renal function beyond 40 days, while human cases have been reported with some return of renal function following 150 days of obstruction *(5,6)*. Regardless, in cases where spontaneous passage is unlikely or clinical symptoms of renal colic persist after a period of observation, intervention is indicated.

When surgical intervention is required for the treatment of calculi, both ureteroscopic management and extracorporeal shockwave lithotripsy (SWL) are effective modalities for stone removal. Following SWL, Segura et al. *(2)* reported overall stone-free rates of 83 and 85% for calculi located in the proximal and distal ureter, respectively. In the same review, distal ureteral stones treated via ureteroscopic removal were associated with overall stone-free rates of 90%; however, proximal stones yielded stone-free rates of only 72%. Such studies suggest that ureteroscopy has very high success rates in treating distal ureteral stones, whereas stone-free rates for proximal ureteral calculi are generally higher with SWL. However, with continued advances in flexible ureteroscopy and the use of the Holmium laser, ureteroscopic treatment of proximal ureteral stones has become more successful *(7)*.

Finally, several clinical scenarios exist in which ureteroscopic management of calculi may be indicated due to technical difficulty associated with SWL. Obese patients may represent a particular challenge to SWL as stone visualization is often poor. In these cases, fluoroscopic imaging may be suboptimal. When stone visualization is achieved, high amounts of radiation exposure are often required. Likewise, distal stones may be difficult to treat utilizing SWL. The bony structures of the pelvis can impede both fluoroscopic visualization and decrease the shockwave energy transmitted to the calculus. Finally, SWL is contraindicated in pregnant patients and those with uncorrected bleeding diatheses. In these cases, ureteroscopic management of ureteral calculi is generally appropriate.

INSTRUMENTS

A thorough working knowledge of the various ureteroscopes and associated endoscopic instruments currently available is crucial to successful treatment of urinary calculi.The following ureteroscopic equipment will be discussed in detail in this section:

1. Guidewires.
2. Dilation devices.
3. Rigid ureteroscopes.

4. Flexible ureteroscopes.
5. Stone extraction devices.
6. Lithotripsy devices.

Guidewires

Guidewires are used to gain access to the ureter, which is the initial step in most ureteroscopic surgery. Guidewires differ with respect to size, flexibility, and coating material. Typically, wire diameter ranges from 0.018 to 0.038 in. Guidewire length ranges from 145 to 260 cm. Although individual preferences vary, we generally use a 145-cm, 0.038-in guidewire for standard ureteroscopic procedures. Calibrated guidewires are now available which are marked to help identify length during ureteroscopic cases. Guidewire surfaces are generally coated with polytetrafluoroethylene (PTFE) or a hydrophilic material, both of which are designed to create a frictionless surface. We have found that hydrophilic guidewires are best used to navigate past tight strictures or impacted stones. However, they may become displaced more easily, thus jeopardizing ureteral access. Therefore, we generally prefer to use PTFE-coated wires whenever possible.

Guidewires have various tip designs available to aid in navigation of the ureter while attempting to minimize ureteral injury. In addition to standard straight-tipped guidewires, various shapes, such as angled tips, are available. These various guidewire tip designs help to navigate tortuous or narrow ureteral segments, as well as bypass impacted stones. Tip designs also include flexible or fixed tips. Finally, the core guide wire may be flexible, stiff, or super-stiff. Stiff variants may help to prevent kinking during passage of ureteroscopic instruments and may help straighten tortuous ureters that have been chronically obstructed.

Ureteral Dilation Devices

With the introduction of small caliber rigid and flexible ureteroscopes, as well as the powerful and precise stone fragmentation associated with the Holmium laser, the need for active ureteral dilation during ureteroscopy has decreased. However, there are still selected cases in which active dilation is useful. For these situations, a variety of dilation systems are available to aid in passage of ureteroscopic equipment into the ureter. Mechanical dilation is the oldest mechanism of ureteral dilation. Mechanical dilation may be accomplished via simple ureteral stent insertion during a separate procedure prior to attempting ureteroscopy. Placement of a stent for 3 to 7 days leads to passive ureteral dilation. More commonly, active dilation is accomplished during a simultaneous procedure. Dilators with a tapered tip are available for the purpose of dilating the ureteral orifice and distal ureter only. Conversely, mechanical dilators of progressively increasing calibers are available to dilate larger ureteral lengths. Finally, dilation systems including multiple dilators of different calibers, such as graduated Teflon dilators, allow for progressive ureteral dilation.

Balloon dilating systems are now commonly used in ureteroscopy. These systems are introduced into the ureter over a guidewire. The balloon is located at the distal aspect of the ureteral catheter and is advanced into position using a radio-opaque marker at the distal end of the balloon. The balloon is then inflated with contrast media to aid in fluoroscopic visualization. A pressure gage is used to monitor intraballoon pressure, thereby preventing overinflation, rupture, and ureteral injury. In general, balloon dilation is preferred to mechanical dilation because it is more precise and less traumatic to the ureter.

Table 1
Comparison of Currently Available Rigid Ureteroscopes[a]

Model	*Channels*	*Channel size (Fr)*	*Type*	*Diameter (Fr)*	*Working length (cm)*	*Direction of view (degrees)*
Olympus						
A2940A/41A	1	4.2	45° ocular	6.4/7.8	43(40A)/33(41A)	7
2948A/49A			Straight ocular	43(48A)/33(49A)		
A2942A		6.6	45° ocular	8.6/9.8	43	7
A22940A/42A		4.2(40A)/6.6(42A)	45° movable	6.4/7.8(40A),8.6/9.8(42A)	43	7
WA02943A/	2	3.4 & 2.4	45° ocular	7.5	43	7
44A/46A			Straight ocular		43(44A)/33(46A)	
Wolf						
8702.517/.518	1	4.2 × 4.6	Straight ocular	6/7.5	33(.517)/43(.518)	5
8703.517/.518		5.2 × 6.2		8/9.8	33(.517)/43(.518)	12
8702.523/.524		4.2 × 4.6	Parallel offset	6/7.5	31.5(.523)/43(.524)	5
8707.523/.524		5.2 × 6.2		8/9.8	31.5(.523)/43(.524)	12
8704.523/.524		6.2 × 8.2		8.5/11.5	31.5(704)/42.5(714)	12
8702.533/.534		4.2 × 4.7	45° offset	6/7.5	31.5(.533)/43(.534)	5
8707.533/.534		5.2 × 6.2 8/9.8	31.5(.533)/43(.534)			12
8708.513/.514	2	4.2 & 2.5 × 3.8	Straight	6.5 /8.5	33(.513)/43(.514)	5
8708.533/.534		4.2 & 2.5 × 3.8	45° offset	6.5 /8.5	31.5(.533)/43(.534)	5
8709.401/421		4.2 × 5 & 3.2 × 3.4	45° offset	8.9/9.8	31(401)/42.5(421)	10
ACMI						
MRO-733/742	1	5.4	45° ocular	7/9.2	33(733)/42(742)	5
MR-6/6L	2	3.4 & 2.3	Straight ocular	6.9/8.3	33(6)/41(6L)	5
STORZ						
27430K/430L	3	5/2.4/2.4	45° ocular	8/9	34(K)/43(L)	0
27401K/401L		5.5/3.0/2.0	45° ocular	10/10.5	34(K)/43(L)	0
411K/411L			45° movable		34(K)/43(L)	
27400CK/400CL	2	3.5 & 2.3	45° ocular	7.5/9	34(CK)/43(CL)	0
27410CK/410CL			45° movable		34(CK)/43(CL)	

[a] Specifications provided by manufacturers.

Rigid Ureteroscopes

Rigid ureteroscopes are available in many designs to facilitate ureteroscopic surgery (Table 1). Current rigid ureteroscopes offer several different eyepiece designs. The eyepiece of rigid ureteroscopes may be straight or offset. Offset models can be fixed or movable. The sheath design and size also varies among currently available rigid ureteroscopes. Most rigid ureteroscopes offer a beveled tip, designed to reduce trauma to both the ureter and to the ureteral orifice while introducing the ureteroscope. Several models also offer a beaked tip design. The shaft design is most commonly triangular or oval.

The working channel of rigid ureteroscopes is an important feature and may be a single larger diameter channel, allowing for simultaneous instrument passage and irrigation. Most working channels of this design offer a working channel ranging between 4 and 6 Fr. While allowing for larger instrumentation, the single channel can result in restricted irrigation. Other models offer separate working and irrigation channels. Typically, the larger working channel in these models ranges between 3 and 4 Fr.

Advances in optical systems have led to the development of rigid ureteroscopes with both excellent visualization abilities and a size small enough to permit facile navigation of the ureter. The recent development of semirigid ureteroscopes utilizing fiberoptic imaging techniques has been an advancement leading to larger working channels without compromising the visual ability. The larger working channels of current models allow for a variety of ureteroscopic instruments to be used for stone lithotripsy and extraction. In most cases, the smallest diameter ureteroscope that will allow for adequate visualization and treatment should be selected.

Flexible Ureteroscopes

Flexible ureteroscopes offer the ability to better navigate the upper ureter and renal pelvis and their development has improved the ability to treat ureteral calculi *(8)*. The added ability to steer the flexible ureteroscope is particularly important in the tortuous ureter and within the intrarenal collecting system. While rigid ureteroscopes generally offer larger working channels for instrumentation, their rigid character makes passage of certain ureteral segments difficult and increases the risk of ureteral injury. In such scenarios, the flexible ureteroscope may be more effective in successfully reaching all areas of the urinary tract.

Flexible ureteroscopes are also available in various designs (Table 2). Current ureteroscopes generally have straight eyepieces. Like their rigid counterparts, the tip of the flexible ureteroscope is most commonly beveled to protect against ureteral injury. The distal tip size of currently available flexible ureteroscopes generally ranges from 6 to 10 Fr. Working channels typically range between 3 and 4 Fr.

The most recent advances in flexible ureteroscopy relate to active deflection characteristics. The first ureteroscopes offered only passive deflection and considerable expertise in maneuvering these instruments was necessary to gain access to the entire urinary tract. More recent devices can be actively deflected, such that the ureteroscopic tip may be directed by the surgeon. The tip deflection angle has improved with technological advances, with newer ureteroscopes able to offer 270° deflection capabilities in both the upward and downward directions. The smaller size and greater flexibility of the lithotripsy probes that may be used in conjunction with such ureteroscopes offer the ability to access and treat urinary calculi in virtually all locations. Currently, 200-μ laser

Table 2
Comparision of Currently Available Flexible Ureteroscopes[a]

Manufacturer	*Olympus*	*Richard Wolf*			*ACMI*		*Karl Storz*		
Model	URF-P3	7325.172	7330.072	7331.001	DUR-8	DUR-8 Elite	11274AA	11273BD	Flex-X
Distal tip size (Fr)	6.9	7.5	7.4	7.4	6.75	6.75	7.5	10.5	7.5
Working length	70	70	70	60	65	64	70	54	67.5
Channel size (Fr)	3.6	3.6	4.5	4	3.6	3.6	3.6	4.5	3.6
Active deflection in degrees (up/down)	180/180 (2°)	130/160	130/160	130/160	175/185	170/180 plus 130 (2°)	170/120	180/80	270/270
Passive deflection Location (cm from tip)	4.0–7.0	6	6	6	7.5	7.5	N/A	N/A	N/A
Direction of View (degrees)	0	0	0	0	12 (air) 9 (water)	12 (air) 9 (water)	0	0	0
Field of view (degrees)	90	60	60	60	80	80	90	90	90
Depth of field (mm)	1.5–50	3–50	3–50	3–50	2–40	2–40	2–50	2–50	2–50

[a] Specifications provided by manufacturers.

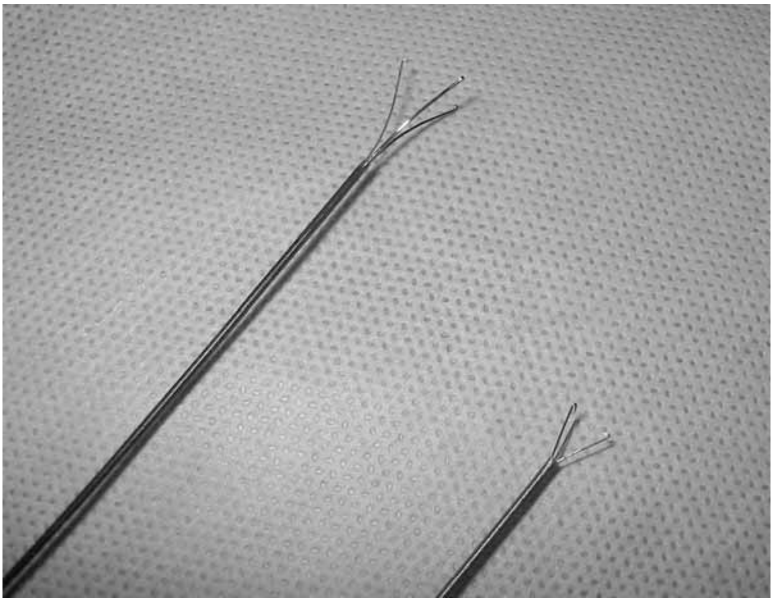

Fig. 1. Standard three-pronged grasping forceps.

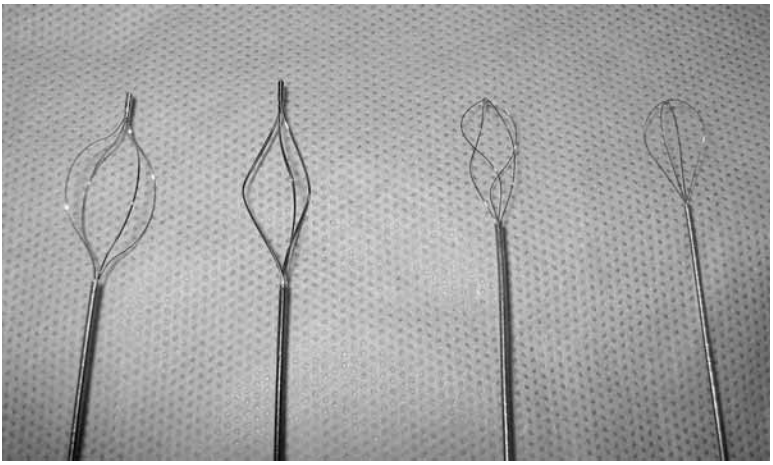

Fig. 2. Ureteroscopic baskets, left to right: four-wire Segura basket, three-wire helical basket, tipless helical basket, tipless non-helical basket.

fibers and nitinol based baskets are available which have been shown to cause minimal influence on the deflection capabilities of flexible ureteroscopes *(9)*.

Stone Extraction Devices

A variety of ureteroscopic instruments are available to extract calculi within the urinary tract. These include endoscopic graspers that are available in two- or three-pronged types and may be retracting or nonretracting (Fig. 1). Ureteroscopic baskets offer another accessory to aid in stone extraction. Basket varieties include helical, double-helical, tipless, and parachute designs (Fig. 2).

A notable technological advance is the development of nitinol instruments. The nitinol baskets allow for sheathless models, thereby decreasing the diameter of the baskets. The smaller diameter and flexibility of these instruments allow for greater flexion capabilities when used in conjuction with flexible ureteroscopes *(9)*. This ability becomes increasingly important when attempting to manage calculi within the proximal ureter and renal calyces. Further, the smaller diameter of these instruments aids in increasing irrigant capabilities and visualization when the baskets are in use.

Tipless baskets are a second recent development aiding in stone extraction. This design is novel from its predecessors in that the distal tip does not extend while deploying the basket. This feature becomes important when trying to entrap calculi lodged against the caliceal wall.

Ex vivo models have demonstrated a higher risk of mucosal and muscle damage when using parachute baskets and three-pronged graspers as compared to two-pronged graspers, helical, and Segura baskets *(10)*. Although small differences may be seen amongst ureteroscopic instruments, the choice of stone extraction device depends greatly on surgeon experience and level of comfort with each type of instrument.

Lithotripsy Devices

Several types of intracorporeal lithotripsy devices are available to the ureterosocopic surgeon. These modalities include pneumatic lithotriptors, electrohydraulic lithotriptors, ultrasonic lithotriptors, and laser lithotriptors. A detailed discussion of their use is found in the Lithotripsy Section.

TECHNIQUES

Ureteral Access

Ureteroscopic surgery begins with obtaining access to the ureter. A thorough knowledge of the underlying anatomy is important to achieving successful access to the ureters. Following entry past the bladder neck lies the trigone. Within the trigone lies the interureteric ridge. This crescent-shaped elevation lies at the proximal border of the trigone. In most patients the interureteric ridge can be easily identified and traced laterally to identify the ureteral orifices. The ureteral orifices often can be easily identified and may have a round, oval, or crescent shape. In some cases, however, identification of the orifices is difficult. In these cases, methylene blue or indigo carmine may be injected to aid in identification. If the obstruction is complete, however, passage of dye and visualization may be limited or delayed.

We prefer to insert a guidewire into the ureteral orifice as the initial step in any ureteroscopic case. A ureteral catheter may be used to direct the guide wire into the ureteral orifice. Prior to attempting to pass the guidewire, fluoroscopy should be used to image the pelvis and surrounding anatomy. Frequently, a radio-opaque stone may be visualized under fluoroscopy. In these cases, retrograde ureterography should be performed carefully to avoid obscuring the stone with contrast. When the calculus is not visualized using fluoroscopy, retrograde ureterography may be used to assess the location of the stone. Three areas exist where the ureteral diameter becomes narrowed and are prone to stone obstruction, including the ureteropelvic junction, at the pelvic brim where the ureter crosses the iliac vessels, and at the ureterovesical junction.

While advancing the guidewire, care should be taken to avoid ureteral injury, such as submucosal passage or ureteral perforation. If resistance is encountered during passage, the guidewire should be carefully manipulated based on the appearance of the retrograde ureterogram. Use of a hydrophilic-coated guidewire or an angled, flexible-tipped guidewire may facilitate passage in these cases. If resistance is encountered in the region of the calculus care must be taken to avoid retrograde propulsion of the stone during guidwire insertion. When passage of the guidewire past the calculus is difficult, a ureteral catheter may be advanced over the guidewire to a point just distal to the calculus. The catheter may then provide additional stability while attempting to direct the guidewire past the calculus. Further, the ureter is frequently inflamed and edematous at the level of stone impaction. This may increase the risk of ureteral perforation. In some cases, passage of the ureteroscope to the level of the stone may allow guidewire passage under direct vision.

Following successful passage of a guidewire to the level of the renal collecting system, we generally prefer to place a second guidewire to serve as a safety wire. This can be accomplished by advancing a double-lumen catheter over the initial guidewire under endoscopic control or by simply passing a second wire directly into the ureter. Owing to the larger caliber of the double-lumen catheter, care should be taken when introducing the catheter into the ureteral orifice so as not to injure the ureter. If significant resistance is met during this step, dilation of the orifice may be necessary not only for introduction of the catheter, but also for subsequent ureteroscopy. Once the double-lumen access catheter had been successfully advanced into the ureter, a second guidewire is introduced. We have found the double-lumen catheter to be helpful in gently dilating the distal ureter, as well as helping to assess the caliber and distensibility of the ureter. If a hydrophilic wire was used for initial access, it may be exchanged at this point for a PTFE-coated guidewire, which may serve more safely as a safety wire and be easier to work with during the remainder of the procedure.

Dilation

Technological advances have led to the development of small ureteroscopes that still provide good visualization. Therefore, there is no need for routine ureteral dilation in all ureteroscopic procedures. This trend can be seen in a recent comparison of ureteroscopic cases performed at the Mayo Clinic in 1992 as compared with those of 1998. Balloon dilation was performed in 74% of these cases in 1992 as compared with only 59% in 1998 *(11)*. Active dilation of the ureter may lead to ureteral edema and perforation. Although clinical studies showed that balloon dilation without subsequent stenting was associated with postoperative pain in only a small percentage of patients, it is generally advisable to place a ureteral stent in most cases in which significant ureteral dilation has been performed *(12)*.

In selected cases, ureteral dilation may be necessary to treat a ureteral stricture or to allow the ureteroscope to be advanced through the intramural ureter. In such cases, a ureteral balloon should be advanced such that it straddles the narrow area. The balloon should be inflated with contrast medium under fluoroscopic visualization. This allows the surgeon to assess the pliability and tightness of the ureter, as well as the length of the ureteral narrowing. A characterisitic ureteral "waisting" is seen as the balloon is inflated. The balloon should not be inflated to a pressure greater than recommended by the manufacturer.

Access Sheath

Although ureteral access sheaths were originally designed to help manage difficult procedures, recent investigators have recommended their routine use in ureteroscopic cases *(13,14)*. In addition to easy re-entry to the ureter, access sheaths have been shown to decrease intrarenal pressure while significantly increasing irrigant flow, and also to minimize ureteral trauma associated with repeated passage of the endoscope during withdrawal of stone fragments *(15)*. Owing to these characteristics, access sheaths may provide surgeons with better visualization during ureteroscopic stone extraction, as well as decreasing the risk of complications.

Access sheaths are sized based on both the inner and outer diameter of the sheath. The most common sheaths are generally sized 10/12, 12/14, and 14/16 Fr, with various sheath lengths being available. Under endoscopic guidance, the access sheath is introduced into the ureteral orifice over a standard 0.038-in guidewire. The access sheath is then advanced to a level just below the ureteral calculus, which is confirmed using fluoroscopy. When used with flexible ureteroscopy in the kidney, the sheath can be positioned at or just below the ureteropelvic junction. A hydrophilic coat aids in advancing the sheath. An inner dilator with a tapered distal end provides a mechanical dilating force to aid in sheath advancement. Once the access sheath is advanced to the proper level, the inner dilator is then removed, and the ureteroscope may be inserted into the sheath for subsequent stone removal or fragmentation.

In one series, ureteroscopic stone removal assisted by an access sheath was associated with decreased operative time and costs, and facilitated direct visualization and simple ureteral re-entry. Further, when ureteral dilation was required, dilation done with the access sheath was associated with a significantly lower amount of postoperative symptoms when compared with balloon dilation *(14)*. Evidence suggests that routine use of an access sheath can be done safely, with no increased incidence of ureteral stricture formation *(16)*. Although concern has been raised regarding the risk of ureteral ischemia with use of a sheath, it has been shown that the decrease in blood flow is transient and it appears that access catheters are safe for use in ureteroscopy *(17)*.

Choice of Ureteroscope

A wide variety of ureteroscopes now exist for the treatment of urinary calculi. Historically, rigid ureteroscopes were used for treatment of calculi within the distal ureter. Rigid ureteroscopes have the advantage of good image transmission and larger working channels. For this reason they are ideal for calculus extraction using a variety of ureteroscopic instruments, such as forceps and baskets. The tortuosity of the ureter proximal to the iliac vessels makes rigid ureteroscopy in this region more difficult in some cases. For this reason, flexible ureteroscopes are often used above the level of the iliac vessels, where their flexibility allows for better navigation. Owing to their flexibility, these ureteroscopes are most commonly advanced over a guidewire to direct navigation and prevent buckling of the instrument.

Rigid ureteroscopes are also more easily used by a single operator because the instrument can be controlled with one hand as instruments are manipulated using the other hand. In contrast, it often requires both hands to manipulate a flexible ureteroscope. Therefore, a more experienced and better trained assistant may be needed when performing flexible ureteroscopy. Another disadvantage of flexible ureteroscopy is their relative fragility. Landman et al. *(18)* have found that flexible ureteroscope failure is expected after 9 to 25 cases. Repairs are expensive and may lead to annual costs of $10 to 50,000 depending on frequency of use.

Lithotripsy

In many cases, the treatment of ureteral calculi will require lithotripsy. Following lithotripsy, remaining stone fragments can either be extracted utilizing previously described techniques, or allowed to pass with or without the aid of a ureteral stent. Several types of intracorporeal lithotriptors exist for the management of caluculi, including pneumatic lithotriptors (PLs), electrohydraulic lithotriptors (EHLs), ultrasonic lithotriptors (ULs), and laser lithotriptors (LLs).

PLs fragment calculi through the transfer of mechanical energy to an inflexible object, such as a urinary stone. PLs are effective in fragmenting calculi throughout the length of the urinary tract. One major advantage of PL lies in their margin of safety, which is significantly better than EHL, UL, or LL *(19)*. The rigidity of the PLs, however, generally prevent them from being used with flexible ureteroscopes.

Ultrasonic lithotripsy is based on the generation of ultrasonic vibrations that are used to fragment urinary calculi. UL is an effective modality in the treatment of stone disease as demonstrated in many studies *(19–21)*. The major advantage to UL lies in its ability to combine stone fragementation with stone removal, which is particularly helpful when treating large kidney stones percutaneously. This is accomplished through an aspiration port as part of the lithotriptor probe. UL probes have the major disadvantage of being inflexible, limiting their use to a ureteroscope with a straight working channel. They may also cause significant ureteral injury. In general, UL has been replaced by more effective and safer options.

EHL fragment calculi through energy produced following an underwater discharge of electrical current. EHL is effective in stone fragmentation and has the advantage of flexible probes, which allow for the treatment of more proximal stones *(21)*. EHL also may cause significant ureteral injury and is not commonly used with ureteroscopy as a result of the development of better lithotripsy devices.

Biri et al. *(20)* compared PL, UL, and EHL in the treatment of 1121 patients with lower ureteral calculi. In their series, patients treated with PL had the highest stone-free rates, while those treated with EHL had the highest rate of complications. All forms of intracorporeal lithotripsy were more efficacious in the treatment of calculi than SWL, with stone-free rates ranging from 89 to 96%. The effectiveness of these various intracorporeal lithotriptors has been confirmed in other studies *(21)*.

Lasers

The use of laser energy in the treatment of urinary calculi disease has dramatically improved the ability to manage stone disease endoscopically. Laser energy was first utilized in the treatment of urinary stone disease in the form of a ruby laser *(22)*. Since its first use in lithotripsy, laser technology has been significantly refined and now is an important modality used in the the treatment of urinary calculi.

The holmium:yttrium-aluminium-garnet (Ho:YAG) laser is currently the most commonly used laser in the treatment of urinary calculi. Lithotripsy via Ho:YAG laser is achieved via a photothermal mechanism. The Ho:YAG laser emits energy at a wavelength of 2100 nm with a corresponding tissue penetration depth of less than 0.5 mm. Although the Ho:YAG laser can cause ureteral perforation, it is unlikely to cause significant trauma owing to its limited depth of penetration.

The efficacy of Ho:YAG lithotripsy has been demonstrated in multiple studies *(23–25)*. This efficacy has been proven irrespective of stone type or stone location within the ureter or kidney. Stone-free rates of 98,100, and 97% were demonstrated using retrograde Ho:YAG laser lithotripsy for calculi in the distal, middle, and proximal ureter, respectively. In the same series, however, retrograde treatment of renal calculi dropped to 84% *(23)*. This is largely the result of issues related to stone accessibility rather than effectiveness of the laser. Prospective series have also suggested efficacy of Ho:YAG laser lithotripsy regardless of stone burden *(24)*. The mechanism of stone fragmentation accomplished via Ho:YAG laser is also effective for all stone types, including cystine stones *(22)*.

Ho:YAG laser lithotripsy has also been established as a safe form of intracorporeal lithotripsy. Ureteral perforation and stricture are potential complications of laser lithotripsy. Nonetheless, laser-related complications have been shown to occur in less than 1% of cases *(26,27)*. Further, laser ureteroscopy has been shown to have no deleterious effects on renal function *(28)*. Reports have demonstrated cyanide production as a result of Ho:YAG lithotripsy of uric acid calculi. However, the level produced is generally considered clinically insignificant *(29)*.

Other forms of laser lithotripsy have been successfully used to treat urinary calculi. Dye lasers use an organic dye excited by another light source. Although effective stone free rates using dye laser have been shown in many series, this form of laser lithotripsy is expensive and involves complicated maintenance requirements owing to the need to change the liquid dye at regular intervals *(22,30–32)*. The use of the alexandrite laser has also been evaluated in several series *(33–35)*. In these reports, stone-free rates following lithotripsy for ureteral calculi ranged from 67 to 95%, with one series citing an overall stone-free rate of 80%. Efficacy was found to be dependent on both stone burden and ureteral location *(33,34)*. In their series, Denstedt et al concluded that the alexandrite laser was inferior to other laser systems when used for intracorporeal lithotripsy *(35)*.

The erbium:YAG laser emits light energy at a wavelength of 2940 nm with a depth of tissue penetration of 3 to 6 mm. Recently, the mechanism of lithotripsy with this laser has been evaluated for prospective use in the clinical setting. This evaluation has led authors to suggest a future use in lithotripsy, stating that Er:YAG lasers may deliver energy in a more efficient and safe manner than Ho:YAG lasers *(36)*.

Regardless of laser chosen for lithotripsy, proper technique must be utilized to minimize the incidence of laser-related complications. Protective eye wear must be worn by the surgeon, all operating room personnel, and the patient in all cases utilizing the Ho:YAG laser. Prior to intracorporeal use, the laser fiber must be inspected for breakage. Unrecognized fiber breakage can result in laser emission proximal to the fiber end with surrounding tissue injury or damage to the ureteroscope. Laser energy emitted in this fashion can also be transmitted through the ureteroscope itself, resulting in tissue damage. The optical fiber must always be visualized directly on the stone prior to discharge of laser energy to prevent injury to tissue structures surrounding the targeted calculus. Aggressive irrigation during lithotripsy may aid in visualizing the optical fiber and in keeping the operating field clear of stone debris.

Proximal Stone Migration

The prevention of retrograde stone migration is a technical challenge often encountered during ureteroscopy. In a series by Cheung et al. *(24)*, stone clearance rates for calculi in the proximal ureter were found to be higher for larger stones. This finding is likely owing to the fact that larger stones were less likely to migrate during the process of lithotripsy. If retrograde stone migration into the renal collecting system does occur, the technical difficulty of the procedure is often greater as a flexible ureteroscope is often needed to manage such displaced calculi.

Several techniques exist to help prevent retrograde fragment migration. Although excellent visualization is necessary to both allow for lithotripsy and prevent inadvertent ureteral injury, decreasing the irrigant force during stone fragmentation may help prevent migration. Positioning the operating table in reverse trendelenberg can also be helpful in some cases. Alternatively, the lithotriptor probe may be positioned at the anterior aspect of the calculus and a mild amount of posterior pressure may be applied to hold the stone against the posterior ureteral wall during the lithotripsy. If retrograde migration is observed during lithotripsy, the stone may be pulled distally in the ureter using ureteroscopic graspers prior to continuing with lithotripsy.

The choice of lithotriptor is an important consideration in minimizing the risk of proximal migration. Pneumatic lithotriptors, for example, are accompanied by a high rate of stone propulsion and subsequent migration. Migration rates during PL range from 2 to 17% *(37)*. Stone migration rates during EHL have also been significant, with one series reporting proximal migration rates of 14% *(38)*. In contrast, significant proximal migration during Ho:YAG laser lithotripsy appears to be less of a problem *(39)*.

The Dretler stone cone (Medsource, Norwell, MA) offers a new technique to prevent retrograde migration. The device functions also as a guidewire and may be passed proximally into the renal pelvis. A radio-opaque marker delineates the location of the stone cone. The marker is introduced past the site of the calculus at which point the stone cone is deployed. In one series utilizing the Dretler stone cone, only 6 of 50 patients had residual stone fragments and no patients required auxiliary procedures *(40)*.

Finally, ureteral caliber in an important risk factor for stone migration. If ureteral stents have been placed prior to attempting lithotripsy, the dilated ureter may increase the risk of migration. In this setting, utilization of the previously described techniques to prevent stone migration is more important. In addition, the ureter proximal to an obstructing stone is often dilated, thus increasing the risk of proximal calculus movement. In general, stone migration is best managed by avoiding the problem. However, appropriate use of flexible ureteroscopy usually will allow the surgeon to manage this problem effectively and avoid the need for secondary procedures to treat the stone.

Stentless Ureteroscopy

Placement of ureteral stents following ureteroscopic stone extraction has been common since the advent of ureteroscopy. Routine ureteral stenting following ureteroscopy has been suggested to decrease postoperative pain and stricture formation *(41,42)*. Reports of stricture rates following ureteroscopy currently range from 2 to 4% *(43)*. Recent studies have demonstrated that stents do not need to be routinely inserted following uncomplicated ureteroscopic stone extraction. Borboroglu et al. *(44)* demonstrated a comparable stone-free rate when comparing patients undergoing stented vs stentless ureteroscopy for the treatment of distal ureteral stones. Similar success has been shown using stentless ureterscopy to manage stones in all ureteral locations *(44,45)*. Although proponents of stented ureterscopic stone extraction cite decreased postoperative pain to be associated with stent placement, recent studies have found postoperative pain, narcotic use, and urinary symptoms to be higher in stented groups of patients *(44,46)*. Finally, a significant saving in cost is associated with stentless ureteroscopy *(45)*.

Identifying cases where stentless ureteroscopy can be performed safely continues to be a challenge. Hollenbeck et al. *(47)* performed a multivariate analysis to identify factors predictive of postoperative morbidity in patients undergoing stentless ureteroscopy. Risk factors associated with a higher prevalance of postoperative morbidity included renal pelvic stone location, history of urolithiasis, and history of urinary tract infections. Further operative variables predictive of postoperative morbidity included bilateral unstented procedures and operative time of greater than 45 minutes with concomitant use of lithotripsy *(47)*. Stents most commonly should be placed if there is significant ureteral edema or inflammation, when ureteral perforation has occurred, or if there are significant residual stone fragments.

TIPS AND DIFFICULT SITUATIONS

Difficult Ureteral Access

Patients with urinary diversions are at increased risk of forming kidney stones. In a literature review, Beiko et al. *(48)* reported that the incidence of stone development for patients with colonic conduits, ileal conduits, the Kock pouch, ileal ureter, continent cecal reservoirs, the Mitrofanoff procedure, and vesicostomies was 3 to 4, 10 to 12, 16.7, 17, 20, 10 to 27 and 33%, respectively. Special considerations are important in the management of patients with these various types of diversions who form ureteral and renal calculi.

Endoscopic management of calculi in patients with urinary diversions and large caliber stomas can be accomplished using a transstomal approach *(49)*. Because of the risk of injuring the underlying continence mechanism, Patel and Bellman *(50)* recommend using a percutaneous endoscopic approach when a small caliber stoma, such as commonly seen with the Mitrofanoff diversion, is encountered. Standard endoscopic techniques may be used when treating stones within urinary diversions; however, care must be taken to avoid injury to the diversion itself. In addition, visualization is often limited by the mucosal folds of the pouch.

Orthotopic neobladder creation has become increasing utilized for diversion following radical cystectomy. Management of ureteral stones in patients with orthotopic neobladders poses a challenge to urologists. Ureteral access is often difficult as a result of the lack of standard anatomical landmarks associated with neobladders. Therefore, localization of the ureteral opening into the neobladder may be very difficult. In addition, angulation of the ureteral entry may also severely limit retrograde access to the ureter. As such, antegrade access is often required for the treatment of ureteral stones.

Nelson et al. *(51)* have described a small experience involving retrograde ureteral access in patients with orthotopic neobladders. In 10 of 13 patients, the ureters and renal pelvis were successfully accessed. In most cases, the authors were able to access the ureters under direct visualization using a 0.035-in. directional glidewire. A cystogram was routinely performed, which often helped to delineate the afferent limb owing to reflux and aid in identification of the ureteral orifices. The ureters were anastomosed to an afferent limb in 11 of the patients in this series, while in the remaining 2 they were anastomosed to the neobladder dome. Administration of intravenous indigo carmine may also be helpful in identifying the ureter.

Treatment of Calculi Located Within Caliceal Diverticula

The treatment of calculi located within caliceal diverticula continues to remain a challenge for even the advanced ureteroscopic surgeon. Patients with caliceal diverticula often present with pain and recurrent urinary tract infection, and such diverticula are often associated with calculi owing to urinary stasis *(52)*. A variety of surgical approaches exist to treat stones located within caliceal diverticula, including SWL, retrograde ureteroscopy, laparoscopy, percutaneous nephrolithotripsy, and open surgical management.

In their comparison of ureteroscopy and percutaneous lithotripsy for the treatment of symptomatic caliceal diverticula, Auge et al. *(53)* reported only a 19% stone-free rate following ureteroscopic management. In 24% of the patients undergoing ureteroscopic management, it was not possible for Auge et al. to identify the ostium and 41% of these patients ultimately underwent percutaneous management. This experience led the authors to conclude that complex posterior caliceal diverticula should be managed in a percutaneous fashion *(53)*. Percutaneous management of calculi located within anterior caliceal diverticula may be especially challenging as percutaneous access and subsequent passage through the diverticular ostium is difficult to achieve *(54)*. In this situation, a retrograde approach may be indicated.

When ureteroscopy is utilized to treat diverticular calculi, a standard retrograde approach is used. A working knowledge of the diverticular anatomy is crucial, as the diverticular neck and ostium are often difficult to locate. A preoperative computed tomography may aid in defining the diverticular anatomy and should be available during the operative procedure. Once the diverticular neck has been identified, a ureteral catheter should be used to inject contrast medium within the diverticulum to define the relevant anatomy. A guidewire should then be advanced into the diverticulum. As most caliceal diverticula have a narrow or stenotic neck, a short balloon dilating system should then be used to achieve mechanical dilation. The diverticulum is then accessed with a flexible ureteroscope and lithotripsy is performed in standard fashion. Stone fragments are then removed using ureteroscopic forceps or a tipless basket.

For larger stone burdens and calculi within long-necked diverticula, Grasso et al. *(55)* describe a combined antegrade and retrograde approach. In Grasso's technique, the ostium is indentified and opacified in a standard retrograde approach. Following opacification of the diverticulum, a percuteanous guidewire was directed into the diverticulum and pulled into the ureter via a ureteroscopic basket. After establishing through and through access, percutaneous management of the diverticular calculus was performed *(55)*.

Ureteroscopic Management of Lower Pole Calculi

Lower pole calculi are often difficult to manage. Historically, these stones were difficult to reach even with flexible ureteroscopes. With technological advances, ureteroscopes with greater active and secondary flexibility have been developed. Although these new ureteroscopes have made accessing lower pole stones easier, lithotripsy is often limited by the flexibility of the various laser fibers and other instruments for stone extraction. Because of these limitations, percutaneous nephrolithotomy (PCNL) or SWL have often been used for the treatment of lower pole calculi.

Although SWL offers a minimally invasive modality for the treatment of these stones, clearance rates are often low *(56)*. Infundibulopelvic angle and caliceal pelvic height measurements have both been used to predict success of SWL of lower pole stones *(57)*. Though PCNL offers better stone-free rates, this approach is more invasive and is associated with a higher rate of complications, ranging from 13 to 38% *(58)*.

A technique of calculus displacement has been described, in which lower pole calculi are ureteroscopically repositioned to the renal pelvis or upper calyces where lithotripsy can then be undertaken *(59–61)*. Such a technique may be useful when access to lower pole calculi is limited by the flexibility of the laser fiber or other lithotripsy instruments. Repositioning of the calculi within middle or upper pole calyces then allows for successful laser lithotripsy. Stone-free rates of 83 to 90% have been reported following ureteroscopic lithotripsy of calculi within the lower pole. In these series, stones were treated *in situ* or via stone repositioning when *in situ* lithotripsy was not possible *(60,61)*.

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7

Ureteropyeloscopy for Calculi

Michael J. Conlin, MD, FACS

CONTENTS

SUMMARY

Improved flexible ureteroscopes and the holmium: YAG laser have improved our ability to access and treat intrarenal calculi. Current indications for the treatment of patients with renal calculi using flexible ureteroscopy include difficult to visualize stones, body habitus that precludes shockwave lithotripsy (SWL), bleeding diathesis, need for stone-free state, concomitant stricture or infundibular stenosis, and lower pole stones. However, flexible ureteroscopy can be used to treat any moderate sized renal calculi because of equivalent or superior stone-free rates compared with SWL. The use of ureteral access sheaths to facilitate removal of stone fragments, the holmium: YAG laser to fragment stones or incise an infundibulum or stricture, and nitinol baskets to displace lower pole stones or retrieve fragments has improved stone-free rates and reduced access failures. Lastly, selective use of post-ureteroscopy ureteral stents can potentially reduce the morbidity of ureteroscopic treatment of renal caculi.

Key Words: Ureteral access; flexible ureteroscopy; secondary deflection; laser lithotriopsy; stone basket.

INTRODUCTION

Ureteroscopy might become the treatment of choice for most renal calculi. However, there are clearly hurdles to this proposition that are most evident within the area of

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flexible ureteroscopy. Continued progress in flexible ureteroscope design and manufacturing as well as in our endoscopic techniques have improved our ability to ureteroscopically treat intrarenal calculi. Future research and development might allow us to overcome current limitations to successfully treat most, if not all, renal calculi with ureteroscopy.

Currently, flexible ureteroscopy can be used for the primary treatment of intrarenal calculi and for the treatment of patients who have failed other modalities. This chapter will describe the instrumentation, technique, and results of ureteroscopy for the treatment of renal calculi.

HISTORY

The history of flexible ureteroscopy is closely tied to the development of flexible fiberoptics. When light travels in a transparent medium such as glass, internal reflection of the light occurs at the interface between that medium and its surroundings. John Tyndall of London first demonstrated this physical property of internal reflection, which allows bending of light within flexible glass, in 1854 *(1)*. However, the first patent for light transmission using flexible glass fibers was not submitted until 1927. Current medical fiberoptic technology is based on this physical property first demonstrated nearly 150 years ago.

Marshall *(2)* in 1964 and later Takagi et al. *(3)*, and Bush et al. *(4)* reported the first flexible ureteroscopic procedures which actually predated the first reports of routine rigid ureteroscopy. These early experimental flexible ureteroscopes could be used for visualization of the upper urinary tract but had no integrated deflecting mechanism or working channel. Although they could be used diagnostically, little could be done therapeutically with these endoscopes. Because of these limitations, as well as the introduction of shockwave lithotripsy (SWL), flexible ureteroscopy for the treatment of stones was not widely utilized until much later.

Ureteroscopic treatment of renal calculi was made possible only with the recent evolution in flexible ureteroscopes. Current flexible ureteroscopes allow access to the entire intrarenal collecting system in 94 to 100% of patients *(5,6)*. Likewise an efficient means of destroying the stone once reached is necessary. Although electrohydraulic lithotripsy was used in the past, the introduction of the holmium:YAG laser for use as an intraluminal lithotripsy device in the early 1990s greatly improved the precision and effectiveness of ureteroscopic lithotripsy *(7–10)*.

INDICATIONS

The treatment of urolithiasis is the most common indication for ureteroscopy. With improvements in ureteroscopes and working instruments and the advent of the holmium laser, stone-free rates following ureteroscopic treatment of urolithiasis above the iliac vessels continue to improve, and in some reports, exceed those of SWL *(11,12)*. The flexible ureteroscope has clearly become the preferred instrument for the endoscopic treatment of urolithiasis proximal to the iliac vessels. Although extracorporeal SWL remains a valuable and more widely used initial treatment option, there are certain clinical situations when ureteroscopy may be preferred. These situations include: radiolucent or difficult-to-visualize calculi, patients who require assurance of being stone-free (e.g., aircraft pilots) *(13)*, morbid obesity, musculoskeletal deformities, bleeding diathesis, concomitant obstruction, poor passage of lower pole fragments, and difficult-to-fragment dense

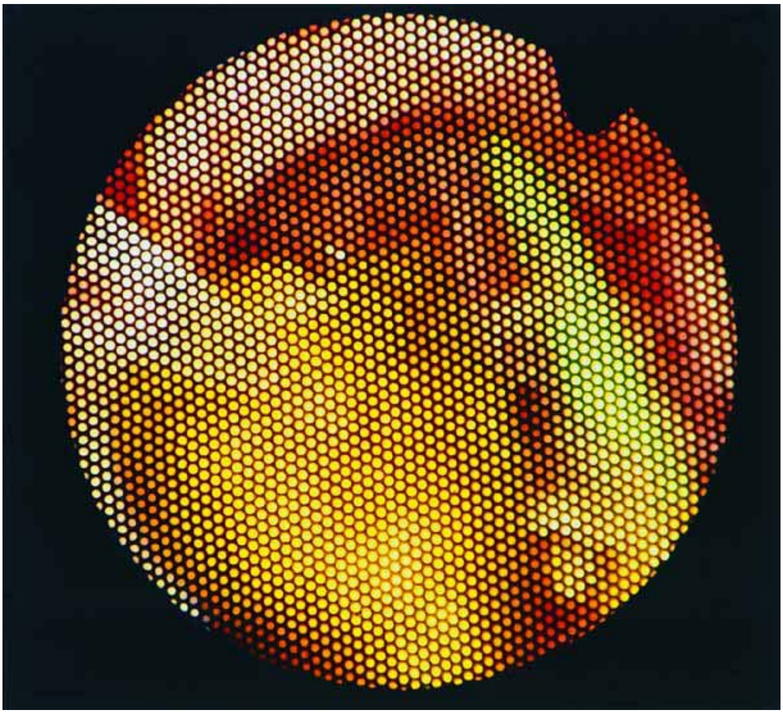

Fig. 1. Ureteroscopic laser lithotripsy of a calyceal stone.

compositions of calculi. These conditions can each be dealt with successfully using flexible ureteroscopy. The advantages of the flexible ureteroscopic treatment of urolithiasis include:

1. The ability to fragment the calculus under direct vision.
2. Treating concomitant upper urinary tract obstruction.
3. Removing the fragments of calculi at the time of the procedure.
4. Moving lower pole calculi into a more favorable upper pole position.
5. Fragmenting all compositions of calculi by the holmium laser (Fig. 1).

Ureteroscopy for stones has been shown to be safe in patients on anticoagulants and those with uncorrected bleeding diathesis *(14)*. Morbidly obese patients (those with a body mass index >28) have been shown to be poor candidates for SWL. The problems that might exist are that the patients can exceed the weight limit of many shockwave lithotriptors, the distance to the stone may exceed the focal length of the lithotriptor, and the stone may be difficult to image owing to the patients size. In contrast, these morbidly obese patients can be treated successfully with standard ureteroscopic instrumentation *(15,16)*.

INSTRUMENT LIST

Flexible Ureteroscopes

The basic components of flexible ureteroscopes include the optical system, deflection mechanism, and working channel. The optical system consists of the flexible fiberoptic image and light bundles. These fiberoptic bundles are created from molten glass that has been pulled into small diameter fibers. "Cladding" each fiber of glass with a second layer of glass of a different refractive index improves the internal reflection and light transmission. This cladding also improves the durability of the image bundles. The meshlike appearance of the image from flexible ureteroscopes is the result of the lack of light transmission through this cladding. These fibers uniformly transmit light from one end of the fiber to the other proportional to the light input. When the fibers are bundled randomly, such as those within the light bundle, they provide excellent light transmission for illumination, but no image. When the fibers are bundled with identical fiber orientation at each end (i.e., coherent), the light from each fiber within the bundle will coalesce to transmit images. Small lenses attached to the proximal and distal ends of the image bundle create a telescope with image magnification, increased field of view, and focusing ability. Improvements in image bundle construction have allowed closer packing of more fibers, resulting in improved images, smaller outer diameters, and larger working channels in both rigid and flexible ureteroscopes. Another recent design modification of the light bundle is the splitting of this bundle distally into more than one point of light transmission. This permits a more centrally placed working channel, as well as better distribution of the light within the working field of view *(1)*.

The deflection mechanism of flexible ureteroscopes permits complete maneuverability within the intrarenal collecting system. Most deflecting mechanisms consist of control wires running down the length of the ureteroscope attached on the proximal end to a manually operated lever mechanism. Distally the wires run through moveable metal rings to the distal tip where they are fixed. Moving the lever up or down will pull the control wire and move the tip. When the tip moves in the same direction as the lever, the deflection is said to be "intuitive" (i.e., down is down and up is up). Modern flexible ureteroscopes allow both up and down deflection in a single plane. This plane of deflection is marked by the reticle seen as a notch within the field of view of the ureteroscope. Improvements in the design of the deflecting mechanism with each new generation of flexible ureteroscopes have improved their durability *(1)*.

Modern flexible ureteroscopes permit down deflection of approx 180°. A study, investigating the angle between the major axis of the ureter and the lower pole infundibula (ureteroinfundibular angle) in 30 patients, reported the average angle to be 140° with a maximum of 175° *(17)*. Active deflection of the ureteroscope of 180° should allow visualization of the lower pole in most patients. However, reaching into the lower pole calyx with the tip of the ureteroscope can still be difficult. The secondary, passive deflection mechanism permits this. All flexible ureteroscopes have a more flexible segment of the ureteroscope owing to a weakness in the durometer of the sheath, located just proximal to the point of active deflection. By passively bending the tip of the ureteroscope off of the superior margin of the renal pelvis, the point of deflection is moved more proximally on the ureteroscope, effectively extending the tip of the ureteroscope. When this passive deflection is used, the lower pole calyx can be reached in more than 90% of patients. The ability to engage the passive secondary deflection depends on the ability to passively bend this portion of the ureteroscope off of the superior portion of the renal pelvis. This can be difficult or impossible in patients with significant hydronephrosis. Additionally, once the tip of the ureteroscope has been extended into the lower pole calyx, the ability to manipulate working instruments and work within the calyx, using active primary deflection, can be challenging.

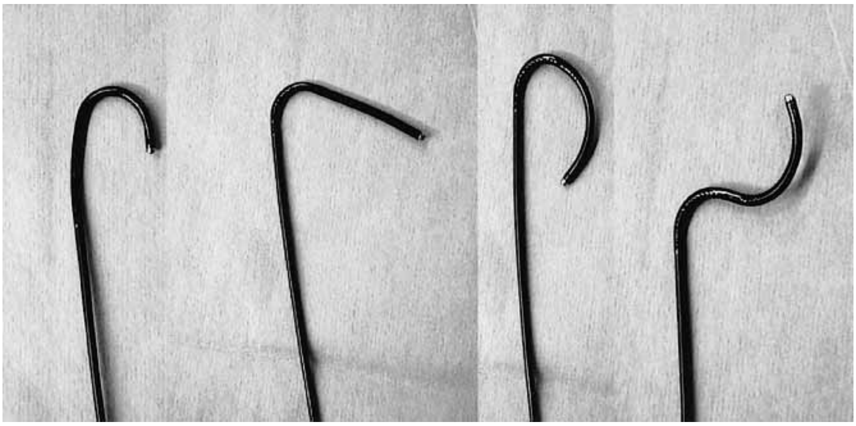

Fig. 2. Deflection capabilities of the DUR-8 Elite (Circon ACMI, Stamford, CT) ureteroscope.

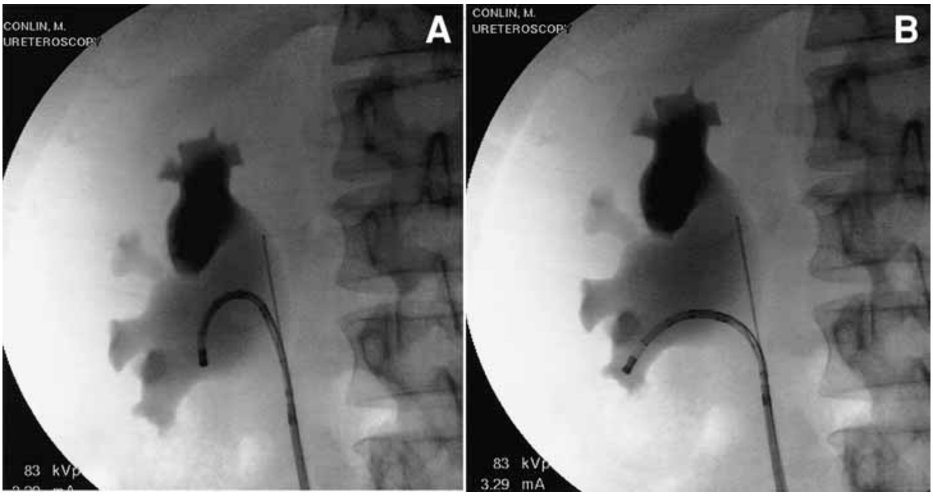

Fig. 3. (A) Inability to access the lower pole calyx with primary deflection. **(B)** Successful lower pole access using active secondary deflection.

Two new innovations to the standard deflecting mechanism address this problem. The DUR-8 Elite (Circon ACMI, Stamford, CT) is the first flexible ureteroscope to incorporate active secondary deflection *(18)*. In addition to the active primary deflection (185° down, 175° up) the secondary deflection is now active, 165° down. It is controlled with an additional lever opposite the existing primary deflection lever and can be locked in place. Secondary deflection is not dependant on passive manipulation of the scope off of the upper portion of the renal pelvis. The degree of secondary deflection is not dependant upon the position of the scope or how hard you advance the scope but is controlled with the deflecting lever. Severe hydronephrosis will not preclude the use of secondary deflection. Locking the secondary deflection in place can simplify manipulation of the primary deflection within the lower pole calyx (Figs. 2 and 3).

Karl Storz Endoscopy (Tuttlingen, Germany) has introduced "exaggerated deflection" with their Flex-X model flexible ureteroscope (the other new innovation mentioned in the previous paragraph) *(19)*. This modification of the deflection mechanism

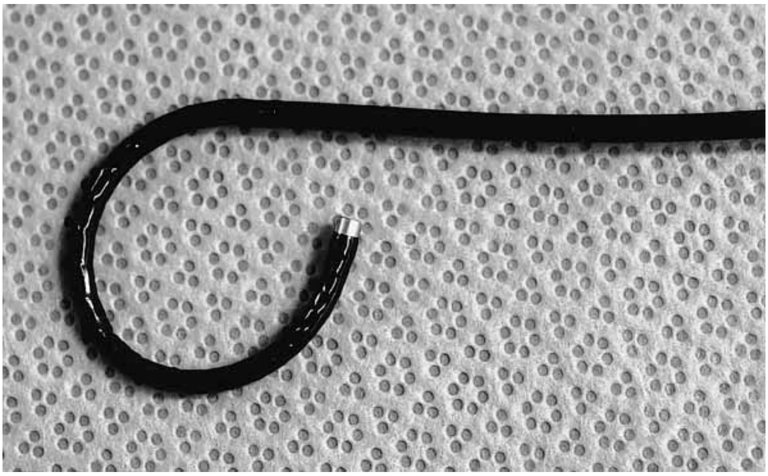

Fig. 4. Exaggerated deflection with the Flex-X (Karl Storz Endoscopy, Tuttlingen, Germany) uretero-

permits active primary deflection to greater than 300°. When approaching the lower pole calyx, the tip will extend out as it is deflected against the lower pole infundibulum. This improvement of the deflection mechanism results in easier lower pole access and improved deflection when using working instruments (Fig. 4).

All currently available flexible ureteroscopes have working channels of at least 3.6-Fr size. This allows use of instruments up to 3 Fr, while still permitting adequate irrigation. The specifications of currently available flexible ureteroscopes are detailed in Table 1.

Holmium Laser

The holmium laser has dramatically improved intraluminal lithotripsy and has become the intraluminal lithotripsy energy of choice for most urologists. It has a wavelength of 2100 nm, which is absorbed in 3 mm of water and 0.4 mm of tissue, making it very safe for use in urology. Fragmentation of calculi is produced by a photothermal reaction with the crystalline matrix of calculi. By not relying on shockwave generation for stone fragmentation, the photothermal reaction produces stone dust rather than fragments, effectively removing a moderate volume of the stone. The flexible quartz fibers can be used with both rigid and flexible ureteroscopes, and are reusable. These fibers are available in various sizes. The smallest fiber has a diameter of 200 µ, and will limit the deflection of the ureteroscope less than the larger fibers. The holmium laser will fragment any composition of calculi *(20)*.

Stone Retrieval Devices

Essentially any working instrument 3 Fr or less in size can be used through the flexible ureteroscope. These include a variety of stone-graspers and baskets, electrodes, cup biopsy forceps, and intraluminal lithotripsy devices. Three-pronged stone grasping forceps are the safest instruments for removing calculi with the flexible ureteroscope. They permit disengagement of calculi that have been found to be too large to be safely removed from the ureter. This is critical when performing flexible ureteroscopy because there is no second channel to permit fragmentation of an unyielding stone trapped within a basket.

Table 1
Characteristics of the Currently Available Flexible Ureteroscopes

	Circon ACMI			*Olympus*	*Karl Storz*		*Richard Wolf*	
Characteristics	*AUR-7*	*DUR-8*	*DUR 8 Elite*	*URF-P3*	*11274AA*	*Flex-X*	*7330.072*	*7325.172*
Tip diameter (Fr)	7.5	6.75	6.75	6.9	7.5	7.5		6.8
Shaft diameter (Fr)	7.5	8.6	8.6	8.4	8.0	8.4	9.0	7.5
Working length (cm)	65	65	65	70	70	70	70	70
Channel size (Fr)	3.7	3.6	3.6	3.6	3.6	3.6	4.5	3.6
Active deflection up (degrees)	100	175	175	180	120	>300	130	130
Active deflection down (degrees)	160	185	185	100	170	>300	160	160
Active secondary deflection (degrees)	0	0	165	0	0	0	0	0
Angle of view (degrees)	0	12	12	0	6	6	0	0
Field of view (degrees)	80 + 5	80 + 5	80 + 5	90	90	90	65	65
Depth of field (mm)	2–40	2–40	2–40	1–50	2–50	2–50	2–40	2–40
Magnification	30×	30×	30×	52×	40×	40×	50×	50×

Stone baskets are available in the usual helical and flatwire designs. Helical baskets are most useful when used in the ureter where they are opened above the stone and pulled down and rotated to engage the stone. The helical design is not particularly useful when working within the intrarenal collecting system. Perhaps the most useful basket designed for use with the flexible ureteroscope is the tipless, nickel-titanium (Nitinol) basket. The soft Nitinol wires have memory, and resist kinking, and therefore open safely and reliably. These baskets are particularly useful for percutaneous applications, but, because they may permit safer disengagement of larger calculi, can also be used within the intrarenal collecting system through the flexible ureteroscope.

Other newer devices designed to prevent stone migration (such as the Stone Cone, Boston Scientific, Natick, MA) are in general unnecessary while working on stones within the kidney as the stones can be immobilized within a calyx.

Ureteral Access Sheaths

Ureteral access sheaths are available that can facilitate repeated ureteroscopic access to the intrarenal collecting system. These 12- to 14-Fr sheaths allow repeated passage of the ureteroscope without requiring passage of the ureteroscope over a guidewire. The primary disadvantage is related to their size and the (small) potential for ureteral injury *(21)*. Ureteral access sheaths can be useful when multiple fragments of stone require ureteroscopic removal. The majority of stones treated within the kidney will require only a single passage of the ureteroscope to access and fully fragment the stone. For these cases, an access sheath is usually unnecessary. A new sheath (Aquaguide, Bard Urology, Covington, GA) is available with a built in second channel that permits irrigation of

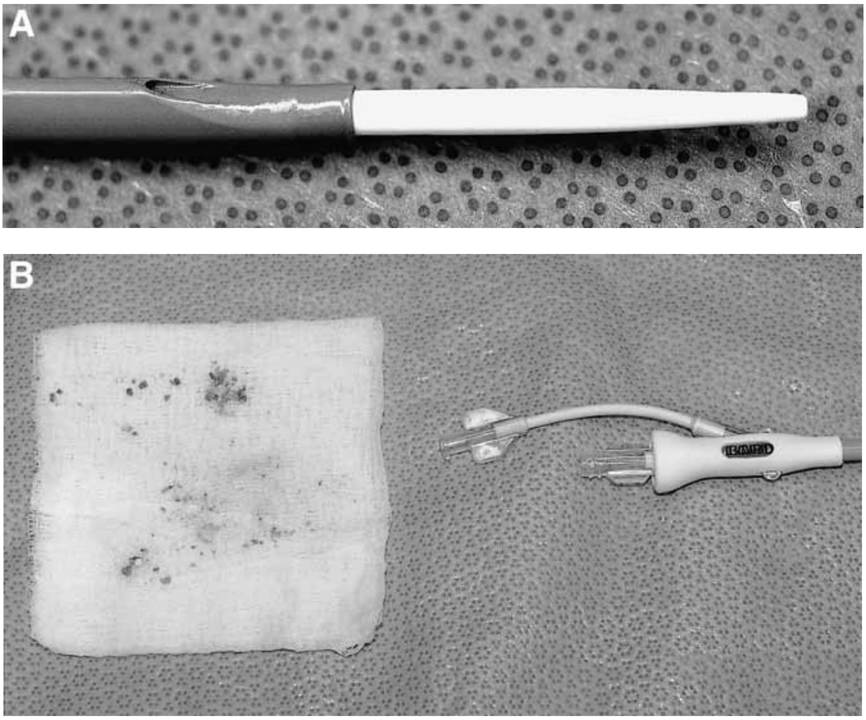

Fig. 5. **(A)** Two lumens of the Aquaguide (Bard Urology, Covington, GA) ureteral access sheath. **(B)** Fragments of stone irrigated out of the kidney using the Aquaguide (Bard Urology, Covington, GA) sheath.

small fragments of stone out of the kidney during the procedure (Fig. 5). This can improve visibility and may facilitate treatment of larger stone burdens within the kidney.

Endourological procedures should be performed in an operating room environment equipped with all instrumentation that may be necessary. The urologist should be prepared for any problem encountered. Special guidewires, such as angled hydrophilic, Nitinol core, and extra-stiff wires, should be readily available. Dilation devices including dilating catheters, high-pressure balloon catheters, and zero-tipped balloon catheters are standard. Torque-able angled catheters are useful for manipulating around impacted calculi or tortuous ureters. In addition to back-up flexible ureteroscopes, semirigid ureteroscopes should also be available to treat unanticipated pathology below the iliac vessels. The standard supplies necessary for ureteroscopic treatment of renal calculi are listed in Table 2.

TECHNIQUE

Preoperative patient preparation includes imaging of the stone to be treated and the upper urinary tract to determine the size, location, and associated anatomy. A noncontrast helical computed tomography scan is the most sensitive study for stones and is usually adequate for urolithiasis patients. A urinalysis is performed and if indicated a urine culture. Urinary tract infections should be treated preoperatively and undrained infections behind impacted ureteral calculi are drained. A routine preoperative antibiotic is given. Anesthesia can be general, regional, or local with sedation. Fluoroscopy is needed for initial ureteral access, monitoring during the ureteroscopy, and during stent placement. Although tables designed for urological endoscopy with fixed fluoroscopy units are available, mobile

Table 2
Supplies for Ureteroscopy for Stones

- **Endoscopes**
  - *Rigid ureteroscopes*
    - 7-Fr or smaller semirigid ureteroscope
    - larger ureteroscope with straight working channel (optional)
  - *Flexible ureteroscopes*
    - 7.5 Fr
    - 8.6 Fr or larger
    - Secondary deflection or exaggerated deflection capable ureteroscope
- **Disposable supplies**
  - *Guidewires*
    - 0.038-in. angled hydrophilic
    - 0.038-in. straight Teflon coated
    - 0.038-in. Nitinol core, polyurethane coated
    - 0.038-in. extra-stiff
  - *Irrigation*
    - Power irrigation (60 cc syringes, extension tubing)
    - High pressure working port seal
  - *Stone retrieval devices (3.0 Fr or smaller)*
    - helical basket
    - tipless basket
    - three pronged grasping forceps
  - *Catheters*
    - Dual lumen catheter
    - 6–12-Fr dilating catheter
    - 5-Fr open-ended catheter
    - 5-Fr angled tip torque-able catheter
  - *Dilation devices*
    - high pressure ureteral dilating balloons (5–7 mm)
    - “zero-tip” ureteral dilating balloon
  - *Ureteral stents*
    - 5–7 Fr, 20–28 cm, double-pigtail
- **Intraluminal lithotripsy devices**
  - *Holmium laser*
  - *Pneumatic (optional)*
  - *Electrohydraulic (optional)*

C-arm fluoroscopy is preferable. These C-arm fluoroscopy units allow greater mobility, improved image quality, and less radiation exposure for the surgeon because the X-ray source is below the patient rather than above. Modern C-arm fluoroscopy units utilize “last image hold” and digital imaging which greatly reduce the amount of radiation exposure for the patient and surgeon. The urologist should control the fluoroscopy unit with foot pedal control which will facilitate the speed of the case and minimize excessive fluoroscopy time.

Prior to flexible ureteroscopy, cystoscopy of the patient is performed to place a safety guidewire and fully inspect the bladder. A safety guidewire is critical during ureteroscopy to maintain access and allow placement of a ureteral stent if any problems are encountered. A 0.038-in. diameter flexible tipped Teflon-coated guidewire is usually sufficient. Care must be taken when trying to gain access around an impacted stone as the ureter can be easily perforated. Manipulation of the guidewire around the stone may require use of an angled hydrophilic-coated wire, an angled torque-able catheter, or both. A hydrophilic wire is generally not secure enough to be used as a safety wire, so it is exchanged for a standard Teflon-coated guidewire. Following placement of the initial guidewire, the bladder is drained to permit accumulation of fluid during ureteroscopy, and minimize buckling of the flexible ureteroscope into the bladder. The cystoscope is removed and a dual lumen catheter is passed over the initial guidewire. This dual lumen catheter is 10 Fr, which will gently dilate the ureteral orifice and allow placement of a second 0.038-in. Teflon-coated flexible tipped wire to serve as the working wire. The flexible ureteroscope is then passed in a monorail fashion over the taut working wire to the point of the pathology being treated. Dilation of the ureteral orifice with the dual lumen catheter is usually sufficient to permit passage of the flexible ureteroscope. If difficulty in passing the flexible ureteroscope through the ureteral orifice is still encountered, a 6- to 12-Fr tapered dilating catheter (Nottingham) or a dilating balloon catheter can be used to dilate the ureteral orifice. Dilation of the orifice beyond 15 Fr is rarely necessary for routine ureteroscopy. In most flexible ureteroscopy series, the need for formal dilation is between 8 and 25%, and has decreased with the advent of the smaller diameter flexible ureteroscopes *(22–24)*.

Irrigation through the ureteroscope can be provided with a pressurized irrigation bag, roller pump, or handheld syringe. Normal saline should be used to prevent accumulation and absorption of hypotonic solution and resultant “transurethral resection syndrome”.

The basic movements of the flexible ureteroscope include deflection, rotation, and advancing and retracting the ureteroscope. The reticle of the flexible ureteroscope marks the plane of deflection, and rotation of the ureteroscope is often necessary to align this plane of deflection in the direction desired. Failure to adequately rotate the ureteroscope is a common mistake of the novice ureteroscopist.

When the holmium laser is used, it is important to pass the laser fiber through a straightened flexible ureteroscope to prevent damage to the working channel. The straightness of the ureteroscope should be confirmed fluoroscopically. Once the fiber is passed beyond the tip, the ureteroscope can be deflected appropriately. The most commonly used sizes of holmium laser fibers include the 365-μ fiber and the 200-μ fiber. When significant deflection of the ureteroscope is needed, the 200-μ fiber is preferred, as it does not limit the deflection of the ureteroscope as much as the larger fibers. The tip of the fiber must be in contact with the stone during treatment because the holmium laser energy is absorbed in 3 mm of water. The holmium laser can damage the ureteroscope, the guidewire, and the ureteral wall. These problems can be avoided by not activating the laser unless the tip of the fiber is seen in contact with the stone *(25)*. In addition, if the helium-neon aiming beam is not seen, the laser should not be activated as this may be an indication of fiber damage. Firing the holmium laser through a broken fiber can cause significant damage to the ureteroscope.

Complete destruction of the calculus with the holmium laser is usually the goal. This can best be achieved by ablating the stone while keeping the tip of the fiber moving across the surface of the stone. Alternatively, the stone can be broken into fragments small enough to remove. With this technique, the stone can be broken along its natural cleavage planes and the fragments removed with stone-grasping forceps. Alternatively, a “drill and core” technique can be used. In this technique the central portion of the stone is slowly ablated, leaving a shell of stone that is then fractured using the holmium laser and the fragments removed. If multiple fragments require removal, repeated passage of the flexible ureteroscope can be facilitated with the use of a small ureteral access

Table 3
Current Results With Ureteroscopic Treatment of Renal Calculi In Adults

Author	*Year*	*Energy*	*Number*	*Stone-free (%)*	*Stricture*	*Comment*
Bligasem et al.	2003	Holmium	29	90	0	<1 cm stones
Schuster et al.	2002	Holmium	78	76	0	Lower pole
Dash et al.	2002	Holmium	57	72	0	Included morbidly obese patients
Sofer et al.	2002	Holmium	54	84	0.35	Stricture rate for ureteral and renal stone patients
El-Anany et al.	2001	Holmium	35	77	0	Stones >2 cm
Kourambas et al.	2000	Holmium	36	85	0	Lower pole
Grasso et al.	1999	Holmium	78	76	0	Lower pole
Tawfiek and Bagley	1999	Holmium	59	80	0	
Menezes et al.	1999	EHL	22	64	0	
Grasso et al.	1998	Holmium	45	91	0	Stones >2 cm
Fabrizio et al.	1998	EHL/holmium	100	77	0	
Elashry et al.	1996	EHL	45	92	0	Ureteral and renal

EHL, electrohydraulic lithotritors.

sheath, as described under "Ureteral Access Sheaths." A ureteral stent is generally placed and left indwelling for 3–5 days after ureteroscopy for renal calculi. Perioperative oral fluoroquinolone is given for 2 to 3 days. Postoperative pain management can be facilitated with the use of a cyclo-oxygenase-2 inhibitor.

RESULTS

Current results with the ureteroscopic management of urolithiasis in adults are presented in Table 3 *(16,24,26–35)*. The series listed primarily used flexible ureteroscopy, but rigid ureteroscopes were used in some patients with additional distal calculi.

Percutaneous nephrostolithotomy is the treatment of choice for large (>2 cm) intrarenal calculi. However, in patients with significant comorbidities that would make percutaneous nephrostolithotomy dangerous, flexible ureteroscopy has been successfully used. In a recent series, stone-free rates of 76% with a single ureteroscopy session and 91% following a second-look ureteroscopy were achieved in patients with stones greater than 2 cm *(30)*.

Successful treatment of lower pole calculi can be a challenging problem, and unfortunately, the incidence of lower pole calculi seems to be increasing. Of all intrarenal stones, those located within the lower pole are the least successfully treated with SWL. In 2001, the lower pole study group reported their experience treating lower pole calculi *(36)*. This multi-institutional randomized trial compared the efficacy of SWL and percutaneous nephrostolithotomy for the treatment of lower pole calculi. SWL of lower pole stones greater than 1 cm in size resulted in a stone-free rate of 21%. Clearly better results were achieved with percutaneous management, when a stone-free rate of 91% was achieved. This well-designed study did not include ureteroscopic management as a treatment option. Lower Pole Study II is currently underway to evaluate the effectiveness of ureteroscopic management of lower pole calculi. The theoretical advantages of ureteroscopic treatment of lower pole calculi compared with SWL include the ability to reposition the calculi from the lower pole calyx into a more favorable location such as the upper pole. Fragmentation of the calculi in the upper pole would result in potentially easier passage of any residual fragments out of the kidney. Also, a significant volume of the stone is ablated and effectively removed with the use of the holmium laser. Reports of ureteroscopic management of lower pole stones show a good success rate. In a review of prior studies, the average success rate for ureteroscopic treatment of lower pole calculi was reported as 83% *(36a)*.

Significant complications following flexible ureteroscopy are rare. Urinary tract infections can be prevented with perioperative antibiotics. Mild gross hematuria is normal, and quickly resolves following stent removal. The most significant complication following ureteroscopy is ureteral stricture formation. Previous reports of ureteral stricture rates following ureteroscopy were unacceptably high. With the advent of smaller flexible ureteroscopes and the decreased need for ureteral dilation, the rates of ureteral stricture have decreased significantly. Several modern ureteroscopy (both rigid and flexible) series have reported ureteral stricture rates of 0.5% or lower *(24,35,37,38)*.

The most troubling problem following flexible ureteroscopy is the patient's discomfort from the indwelling ureteral stent. After ureteroscopic treatment of renal calculi, a stent is usually left for only 3 to 5 days. However, the need for routine ureteral stenting following ureteroscopy is controversial. Several reports of successful ureteroscopic treatment of ureteral calculi without ureteral stenting have been published. Patients were not stented if there were no residual stone fragments, no significant ureteral trauma, and ureteral dilation was not performed *(39–44)*. Although these reports have had small numbers of patients, there were no significant complications. A better definition of which patients will require ureteral stenting and improvements in stent design and manufacture, should decrease patient discomfort following flexible ureteroscopy.

TIPS AND TRICKS

Access to the ureter can be challenging in a variety of situations. The first problem that can be encountered is obtaining access to the ureteral orifice for intubation with the guidewire. Several problems and potential solutions will be presented. Inflammation and distortion of the ureteral orifice from an impacted stone in the intramural tunnel can make passage of the guidewire into the ureter difficult. Use of an angled-tip hydrophilic coated guidewire through an angled-tip tourqable catheter will often allow the wire to pass alongside the stone. A severely enlarged prostatic median lobe can make it difficult to reach the ureteral orifice with a rigid cystoscope. This can be overcome by initially accessing the ureteral orifice with the flexible cystoscope, placing the guidewire, and then exchanging the guidewire with a super-stiff wire. This will help hold the median lobe out of the way for passage of the ureteroscope. Severe bladder trabeculation can make identification of the ureteral orifice difficult, but can usually be helped by administering intravenous Indigo Carmine. Scarring or obliteration of the ureteral orifice from prior bladder tumor resection may require resecting scar over the orifice, endoluminal ultrasound inspection of the trigone to identify the location of the ureter, or a percutaneous approach to obtain "above and below" access. Patients with intestinal diversion of urine can have difficult-to-identify ureterointestinal connections. One of the problems with ileal conduits is the difficulty distending the conduit for appropriate visibility. Placing a 10-mm laparoscopic port into the loose stoma can help prevent egress of irrigation fluid around the flexible cystoscope and out of the conduit. Distention of the conduit, and administration of Indigo Carmine if necessary, will help identify the ureteral orifice in patients with intestinal diversion.

The next potential problem encountered is difficulty in passing the guidewire through the ureter in the kidney. This can be the result of an impacted ureteral calculus, ureteral stricture, ureteropelvic junction obstruction, or a tortuous "kinked" ureter. The use of an angled hydrophilic guidewire through an angled torque-able catheter will overcome most of these problems. The wire and the catheter can each be rotated to "screw" it past the blockage. If this is unsuccessful, direct ureteroscopic inspection can be used to negotiate the wire around the point of obstruction.

Once the guidewire has been placed, passage of the flexible ureteroscope is usually straightforward, but can be hindered by several problems. It is critical to keep the guidewire (over which the ureteroscope is passed) taut. Any slack in this wire will prevent successful passage of the ureteroscope. Rotating the ureteroscope can help present a more streamlined face of the ureteroscope to the ureteral orifice. Balloon dilation of the orifice or a ureteral stricture is always an option if passage of the ureteroscope is not possible. If a small renal calculus is being treated with the holmium laser, and removal of fragments or repositioning of the stone are not necessary, it is reasonable to remove the safety wire to help the passage of the ureteroscope. If anything other than simple holmium laser lithotripsy is planned or later necessary, a safety guidewire is required.

If difficulty in passing the flexible ureteroscope is encountered in the absence of any ureteral stricture, the use of a Nitinol core guidewire (Zebra, or Sensor wires, Microvasive Urology, Natick, MA or Roadrunner, Cook Urological, Spencer, IN) may be helpful. These stiffer, smoother wires enable more efficient transmission of the push from the urologist to the tip of the ureteroscope.

Ureteroscopic access to the lower pole calyx can be challenging for several reasons. With repeated use of the flexible ureteroscope, the primary deflection is often weakened and incomplete, resulting in the inability to reach an acute angle into the lower pole calyx. Even when the angle into the lower pole calyx can be negotiated, extending the tip of the ureteroscope into the calyx may be difficult. The length of the lower pole infundibulum is frequently longer than the length of the primary deflected segment of the ureteroscope. Grasso et al. *(31)* reported their experience with ureteroscopic treatment of lower pole calculi. They measured the effect of the infundibulopelvic angle, degree of hydronephrosis, and lower pole infundibular length on successful ureteroscopic treatment. The one factor they found that negatively affected their ability to reach the lower pole calyx was the lower pole infundibular length. In order to extend the tip of the ureteroscope into the lower pole calyx, current ureteroscope designs rely on a passive secondary deflection mechanism as previously described. The use of secondary deflection effectively extends the length of the deflected segment in order to reach the lower pole calyx. The ability to engage the passive secondary deflection depends on the ability to passively bend this portion of the ureteroscope off of the superior portion of the renal pelvis. This is sometimes not possible with standard flexible ureteroscopes. The latest generation of flexible ureteroscopes, with either active secondary or exaggerated deflection, significantly improve our ability to treat effectively lower pole calculi. Lower pole calculi should be repositioned into the upper collecting system prior to fragmentation with the holmium laser. Auge et al. *(45)* should improved stone free rates for lower pole stones repositioned prior to laser lithotripsy compared with those treated *in situ* in the lower pole (90 vs 83%).

In order to prevent migration of stones fragments into the lower pole calyx while treating stones in the kidney, the patient can be positioned in Trendelenburg position and rotated to elevate the effected side. This will encourage fragment accumulation in the renal pelvis.

When working endoscopically within the kidney, respiratory motion can hinder efficient laser lithotripsy. Endotracheal intubation of the patient will allow the anesthesiologist to control the rate and depth of the patient's respiration there by improving laser lithotripsy access to the stone.

CONCLUSIONS

Improvements in flexible ureteroscopes, working instruments, and endoscopic techniques, have positively affected our ability to treat intrarenal calculi effectively. With continued advances, the role of ureteroscopy in the treatment of intrarenal calculi should continue to grow. Exciting changes can be anticipated within the next decade, improving our ability to treat more complicated upper urinary tract calculi in a minimally invasive fashion.

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8 Percutaneous Stone Removal

Louis Eichel, MD
and Ralph V. Clayman, MD

Contents

SUMMARY

In this chapter the method of percutaneous stone removal is reviewed in its entirety. The indications for percutaneous stone removal in the age of shockwave lithotripsy and ureteroscopy are carefully reviewed: staghorn stones, obstruction and stones (e.g., ureteropelvic junction obstruction and calyceal diverticula), renal anomalies (e.g., horseshoe kidney), stones with difficult lower pole anatomy, and calculi that are extremely hard (i.e., Hounsfield units ≥1000). In addition, the technique is presented with the method for percutaneous access and details of intrarenal lithotripsy. Accompanying this section is a detailed account of the instrumentation available. Some tips and tricks for successful stone removal are presented, such as the use of the ureteral access sheath to improve renal access and stone clearance, as well as the use of various hemostatic agents in lieu of placing a percutaneous nephrostomy tube at the termination of the procedure. Also, a full discussion of complications is provided: prevention, recognition, and treatment.

Key Words: Percutaneous nephrostolithtomy (PCNL); percutaneous stone removal; nephrostomy tube.

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INTRODUCTION

Almost 30 years since the birth of percutaneous nephrolithotomy (PCNL), the mission remains the same as it has always been: to simplify minimally invasive surgeries as much as possible so that both patient and surgeon alike may benefit. Since the original description of stone removal through a percutaneous nephrostomy tract by Fernstrom and Johansson in 1976 *(1)*, percutaneous stone removal has evolved into a highly developed procedure practiced by many urologists. Several new techniques and technologies recently have emerged that simplify the procedure, allow us to take on more challenging cases, and make it safer and less painful for patients. This chapter is designed to serve as both a review of the basics and a guide to recent cutting edge developments in the field.

INDICATIONS

In the last decade, there has been a 63% increase in the number of ureteroscope cases (URS) being performed, whereas the number of shockwave lithotripsies (SWLs) has declined by roughly 11%. Presumably, these changes reflect the ever-improving ureteroscopic technology becoming available and the relative stagnation/decline of SWL technology during the same period. Interestingly, at university centers, the percentage of PCNL cases being performed over the past 10 years has been stable at about 28% of all stones treated *(2)*. The reason for this relative stability is because PCNL is usually indicated in situations that are inappropriate for SWL and URS. Hence, the indications for PCNL have remained relatively constant over time.

Choosing the appropriate modality of treatment for a stone depends on two stone factors (size and hardness) and two environmental factors (stone location and the degree of hydronephrosis). Large meta-analyses have shown that renal stones less than 10 mm can be treated successfully with SWL as first-line therapy. Stones more than 20 mm in size respond best to PCNL *(3)*. Although treatment of stones more than 2 cm is possible with URS, the stone-free rate ranges from only 47 to 60% and complication rates ranging from 6 to 22% have been reported *(4,5)*. Treatment success rates for stones in the 11 to 20 mm range are more variable and these cases must be evaluated on an individual basis. For the 11 to 20 mm "gray zone," stone location, density, and the presence of hydronephrosis play a more crucial role.

For the largest stones, staghorn calculi, the percutaneous approach remains the standard treatment. There is a clear advantage to treating staghorn calculi with PCNL. Historically, it was widely accepted that ancillary procedures (i.e., SWL) would be necessary to achieve complete stone removal. The concept of "sandwich therapy" was originally coined by Streem in 1987. In fact, prior to 1990, ancillary procedure rates as high as 65% were reported with overall success rates of 83 to 86% *(6,7)*. More recently, with the advent of improved endoscopic equipment and imaging capabilities, there has been a trend toward using PCNL as monotherapy. Thus, the use of ancillary procedures and "second looks" has declined *(8)*. Despite this decline in the use of adjunctive SWL, the overall success rate of PCNL for staghorn stones has improved ranging from 87 to 95% *(8,9)*. This improvement has largely been the result of the more frequent use of flexible nephroscopy and the advent of holmium laser lithotripsy.

Several authors have addressed the concept of stone composition and relative response to SWL *(10,11)*. Uric acid and calcium oxalate dihydrate stones are relatively soft. Struvite, apatite, and brushite all have a medium hardness. Cystine, on the other hand, is extremely hard. Results of SWL for cystine stones are therefore generally poor, although, success rates of 50 to 75% have been reported for cystine stones less than 15 mm treated on a HM-3 SWL *(12–14)*. Cystine stones larger than 15 mm are best treated with PCNL; whereas this is the case in general for all other stones that are greater than 20 mm in size. Case reports of URS lithotripsy for larger cystine stones exist but, as previously noted, URS for larger stones is fraught with overall poor stone clearance and multiple procedures *(5,15)*.

Although for years the focus has been on using the computed tomography (CT) scan to predict stone composition in an effort to predict a stone's response to SWL, lately of more importance is stone construction rather than composition. Specifically, ignoring composition and focusing on stone durility (i.e., density as determined by Hounsfield units [HU], a term coined by Dretler in 1988) may be of greater predictive value *(16)*. In general, stones that measure less than 500 HU have an 80 to 100% fragmentation rate with SWL. Stones in the 500 to 1000 HU range have roughly a 70% fragmentation rate and stones greater than 1000 HU generally have fragmentation rates of 25% or less with SWL and hence URS or PCNL would be more advantageous, depending on the stone's size *(16,17)*.

From an environmental standpoint, one anatomic factor of great interest is lower pole anatomy as measured on intravenous pyelography (IVP). Factors such as infundibulopelvic angle (IPA), infundibular length (IL), calyceal pelvic height, and infundibular width (IW) have been found by several authors to affect stone clearance rates. In general, these authors found that patients with lower pole stones 17 mm or less who have favorable anatomy (lower pole infundibulo-pelvic angle >70°, IL <3 cm, and IW >5 mm) are excellent candidates for SWL whereas patients with less favorable anatomy (LIP angle <40°, IL >3 cm, and IW <5 mm) would be better served by PCNL *(18–21)*. Other authors, however, have not found lower pole anatomy to be a major factor *(22,23)*. The concept of lower pole measurements may be moot, however, because computed tomography (CT) is quickly becoming the standard imaging modality for urolithiasis and three-dimensional reconstructions of the urinary collecting system are not yet commonly provided. In the final analysis it is generally accepted that for lower pole stones, especially when larger than 1 cm, PCNL is far more effective than SWL. The reported success rates were 21 vs 95% respectively in one series in which patients with lower pole stones were randomized to SWL vs PCNL *(24)*. In the same study, the success rates for stones 1 cm or less was 63 vs 100% respectively.

The second environmental factor is hydronephrosis. Two studies address this concern directly. Winfield et al. *(25)* compared PCNL with SWL for treatment of staghorn calculi and found that the success rate of SWL in the presence of high-grade hydronephrosis was only 53% compared to 70% without hydronephrosis. Similarly, the ancillary procedure rate was 12 vs 27%, respectively. In the largest series reported to date, Poulakis et al. *(21)* reviewed 701 cases of SWL for lower pole stones and found that patients with evidence of either significant hydronephrosis or lack of peristalsis on IVP had a 51% stone clearance rate vs 80% for patients with a normally peristaltic, nondilated system.

In sum, PCNL is currently indicated in those patients with stones greater than 2 cm, calculi of all sizes in a markedly hydronephrotic system, lower pole stones greater than 1 cm, and for calculi of all sizes with a density exceeding 1000 HU.

Absolute and relative contraindications to PCNL remain few but include:

- Pregnancy (relative).
- Bleeding disorders/contraindication to reversal of anticoagulation (absolute).
- Severe pulmonary dysfunction (relative).
- Severe bodily contortions (relative/absolute).

- Untreated infection (absolute).

SPECIAL CIRCUMSTANCES REQUIRING PERCUTANEOUS STONE REMOVAL

Obstruction

Relative urinary obstruction is a direct indication for considering PCNL or rarely, URS as it precludes SWL. This situation is encountered when calculi occur in association with a calyceal diverticulum, ureteropelvic junction obstruction (UPJO), and congenital/iatrogenic renal/drainage anomalies (e.g., horseshoe, transplant, or pelvic kidney and ileal conduit).

Caliceal Diverticula

Caliceal diverticula are nonsecretory outpouchings of the renal collecting system that communicate with the calyx via a tight neck, usually along the fornix. Up to 50% of patients with calyceal diverticula will have stones within them *(26,27)*. The condition itself does not require treatment. The criteria for treatment are pain and/or infection.

Conventional approaches for the treatment of calyceal diverticula include open surgery, laparoscopy, SWL, URS, and PCNL. Historically, excellent results were reported with open surgery that entailed ligation of the diverticular neck and marsupialization or wedge excision *(28–30)*. This technique has been abandoned, however, because less invasive options now exist. Ramakumar et al. *(31)* reported a series of 12 patients in which a laparoscopic approach to stone removal and marsupialization was used. Sixty-seven percent were salvage procedures after other attempts failed using less invasive techniques. Overall, the objective success rate (complete stone removal and obliteration) was 92%; however, the subjective success rate (pain relief) was only 75%. At present, the laparoscopic approach is reserved mainly as salvage therapy or as primary therapy, in the rare case of a large (i.e., >5 cm) calyceal diverticulum.

Several series have reported treating stones in calyceal diverticula using SWL. There is a fundamental argument against this practice, however, because the cause of the problem (a narrow-necked diverticulum) is not addressed. In reviewing five contemporary series totaling 95 patients with a follow-up range of 3 to 69 months, pain relief was achieved in 70 to 86% despite the fact that only 24% were rendered stone free *(3,32–34)*.

URS is currently the least invasive, potentially curative treatment offered for stones within calyceal diverticula; however, to date, results have been mixed. In reviewing three contemporary series with a combined total of 50 patients, the stone clearance rate was 58% *(35–37)*. Using a URS approach, success rates are best for upper pole diverticula and are dismal when the diverticulum is in the lower pole of the kidney *(35)*. Ideally, the upper pole diverticulum approached with URS should be small (<1.5 cm) and with a minimal stone burden (i.e., <1.5 cm).

The most effective minimally invasive treatment for stones within symptomatic calyceal diverticula is direct percutaneous stone extraction followed by incision of the diverticular neck and fulguration of the diverticular wall with placement of a nephrostomy tube through the dilated neck. This technique provides for both stone extraction and treatment of the primary problem. In reviewing nine series with a combined total of 155 patients with 3- to 85-month follow-up, the overall stone-free rate was 85% and complete obliteration of the diverticulum was achieved in 73% *(5,38–44)*. Further, support for a PCNL approach can be obtained from a recent analysis of 40 patients with symptomatic calyceal diverticula in which 22 were treated with PCNL and 18 were treated with URS), the stone-free rates were 78 vs 19% and the symptom-free rate was 86 vs 35%, respectively *(45)*. Thus, the percutaneous approach to symptomatic calyceal diverticula provides the surest treatment for rendering the patient asymptomatic and stone free. In addition, this therapy will usually eliminate the underlying cause of stone formation: the diverticulum itself.

Ureteropelvic Junction Obstruction

Patients with primary UPJO have a 16 to 30% chance of concomitant renal stones *(26)*. Stasis and, to a lesser extent, metabolic factors are thought to play a role in stone formation in the setting of UPJO *(46–48)*. SWL is contraindicated in the setting of UPJO because of poor distal drainage *(49)*. Occasionally, when the stone sits directly at the UPJ, it can be difficult to discern whether or not the UPJ is obstructed primarily or secondarily, from an impacted stone with edema. In this situation, it is best to first treat the stones percutaneously, leave a nephrostomy tube in place (albeit well away from the UPJ), wait 1 to 2 weeks for resolution of edema, and then assess drainage of the stone-free renal collecting system with a Whitaker test *(26)*.

Open pyelolithotomy and pyeloplasty has long been the gold standard of therapy for UPJO with renal stones. However, with the advent of minimally invasive techniques, several other effective options for treatment have developed. One well-recognized alternative treatment for simultaneous renal stones and UPJO is to perform percutaneous lithotripsy followed by antegrade percutaneous endopyelotomy. Using these combined techniques, patients can be rendered stone free and short-term success rates of 94 to 100% can be achieved in terms of UPJ patency and stone-free rate *(50,51)*. Today, the evaluation of this condition would include a renal scan, as well as a spiral CT angiogram with three-dimensional reconstruction. Patients would then be treated either by PCNL and endopyelotomy or laparoscopic pyelolithotomy and pyeloplasty depending on the degree of hydronephrosis (grade 1, 2 for PCNL), percent renal function (>25% for PCNL), and absence of a crossing vessel at the UPJ (i.e., favors percutaneous approach).

Ectopic Kidneys: Horseshoe, Transplant, and Pelvic Kidneys

Horseshoe kidney is a common renal fusion anomaly that occurs in up to 1 out of every 400 births. In most cases the lower poles of the kidneys are fused. Normal renal ascent is blocked by the inferior mesenteric artery and the inferior longitudinal axis of the kidneys is pulled medially. Rotation of the kidneys is also abnormal such that the pelves and ureters lie anterior to the isthmus and the ureters often insert high on the pelvis. This configuration predisposes to renal calculi which occur in 20–61% of cases and potential UPJO which occurs in 15% *(52)*. The unusual location and rotation of the kidney makes management more challenging; however, the options still include SWL, PCNL, retrograde ureteroscopy, and laparoscopy. The main problems with treating these patients are that access to the lower pole is difficult with the ureteroscope and the dependency of the lower pole along with the anterior insertion of the ureter into the pelvis results in poor clearance after SWL. Hence, PCNL constitutes the most definitive therapy.

SWL is a valid treatment option for stones in horseshoe kidneys provided they reside in the upper and middle calyces as these calculi can usually be targeted in the supine position but lower pole stones often require prone positioning because of the medial and anterior deviation of the lower part of the horseshoe kidney *(53,54)*. Traxer *(26)* recently reviewed the results of seven horseshoe kidney stone series treated with the

Dornier HM-3 and 7 series with patients treated with various electromagnetic lithotripters and noted a 61.9 and 66.7 % stone-free rate among patients with horseshoe kidneys, respectively. They also noted that although the stone-free rates come close to those achieved with conventional kidneys, the retreatment rates tend to be higher, most likely as a result of poor drainage (22.5 and 38.1% for the HM-3 and electromagnetic series, respectively).

PCNL is an effective treatment option for stones in horseshoe kidneys; however, the technique for establishment of the percutaneous tract must be modified owing to the abnormal anatomy. Prior to PCNL, in a horseshoe kidney, it is helpful to obtain a CT of the abdomen to rule out a retrorenal colon. In these patients, the nephrostomy tract usually lies more medial and thus traverses the psoas muscle. Among series reporting results of PCNL in horseshoe kidneys, the stone-free rates are 75 to 89% and ancillary procedure rates are 10 to 70% *(55–57)*. It is also important to remember that PCNL is also appropriate for the simultaneous treatment of UPJO and renal lithiasis even in horseshoe kidneys, as lithotripsy and antegrade endopyelotomy can be performed at the same setting, even in these patients *(56)*. Ureteroscopy has been reported anecdotally as successful for upper and middle calyceal stones, but is less effective for lower pole stones in horseshoe kidneys *(26)*. In general, the highest stone-free rates are achieved with PCNL.

The incidence of renal stone formation in renal transplant recipients is roughly the same as in the population at large, estimated as approx 0.4 to 1% *(58,59)* . Anatomically, transplanted kidneys lie within the pelvis overlying the iliac vessels. They are shielded posteriorly by the sacrum and iliac bones and may have overlying bowel anteriorly. These factors complicate the use of SWL and PCNL as treatment modalities. The ureteral path may be tortuous and, most commonly, the ureter inserts into the bladder at the dome; often the presence of renal calculi is associated with a distal ureteral stricture. Retrograde instrumentation of the ureter can therefore be difficult. There may also be scar tissue encasing the kidney, which can make percutaneous access and endoscopic manipulation difficult. Because of these potential variations, each individual case must be evaluated with regard to stone size, location, the presence of infection, and the individual renal and ureteral anatomy based on both the operative report and a comprehensive radiological evaluation.

Because of the relative rarity of stones in a transplanted kidney, series reported in the literature are small. SWL has been used successfully for the treatment of small stones in transplanted kidneys. The pelvic location of the kidney necessitates modified positioning: patients, if supine, must be positioned such that the shock waves pass just below the sacrosciatic notch *(57)* or they can be turned into the prone position *(54,60)*. Furthermore, it is recommended that only stones 1 cm or less, be treated with SWL because the risk of steinstrasse has much more severe ramifications in this patient population. Retrograde ureteroscopy in the transplanted kidney has been reported for stone treatment, retrieval of migrated stents, and evaluation of funguria and abnormal cytology *(61)*. PCNL is a viable modality of treatment for larger stones in transplant kidneys. The anterior position of the transplanted kidney allows for excellent visualization of the stone and localization for nephrostomy puncture. This puncture is best done under combined ultrasound and fluoroscopic guidance inorder to avoid any possibility of bowel injury. Cases of PCNL for transplanted kidneys in the literature are sporadic but indicate successful results *(62–64)*.

The anatomy of the pelvic kidney has been well described by Dretler et al. *(65)*. Pelvic kidneys are found in a frequency of 1 of every 1000 autopsies and have a 3:2 male to female ratio. Right and left ectopias have an equal frequency; 15% of ectopic kidneys are crossed. In general, pelvic kidneys tend to be smaller and malrotated such that the collecting system faces anteriorly. The pyelocaliceal system may be entirely extrarenal and appear to be dilated because in these kidneys the collecting system is more easily distended with urine. There may be multiple renal vessels that arise from the aorta and common or internal iliac vessels. SWL has also been used for various size stones in ectopic pelvic kidneys. In one series 11 of 12 stones were cleared at 3 months *(66)*.

As with the transplanted kidney, the same issues (potential difficulty accessing the lower pole or negotiating a malrotated kidney) apply to the ectopic pelvic kidney *(26)*. Only sporadic cases of successful ureteroscopic stone treatment in ectopic pelvic kidneys exist in the literature *(61,67)*. In contrast, PCNL for the pelvic kidney is extremely difficult owing to overlying bowel. However, the nephrostomy access has been reported in one case to have been successfully obtained using laparoscopic guidance, this was the first report of laparoscopy being applied to kidney surgery *(68)*. More recently, laparoscopy has been used successfully to remove stones in the pelvic kidney although the indications for this are limited *(69)*.

Ileal Conduits

The ileal urinary conduit, popularized by Bricker *(70)*, has been the standard solution to urinary diversion for the last 50 years. Rates of upper tract stone formation in patients with ileal conduit urinary diversion range from 4.8 to 20% *(71–75)*. SWL, URS, and PCNL alone and in combination can be used to treat upper tract calculi in patients with ileal loop diversions. When opacification of the collecting system is required for SWL or PCNL, a loopogram can be performed on the treatment table. However, because these are usually infection stones, it is essential that the patient receives appropriate antibiotic coverage and has a sterile urine culture, prior to proceeding with stone manipulation or even a loopogram. The choice of treatment depends on stone size, location, and the specific anatomic situation that exists. In patients who require treatment, experienced centers *(76)* have found that renal stones less than 2 cm, in the absence of obstruction, can be treated with SWL with an initial expected success rate of 76%. If a secondary SWL is used to clear residual stones the success rate rises to 92%. PCNL can be used for larger stones with a success rate approaching 100%.

INSTRUMENT LIST

Item	*Manufacturer*	*Order no.*
Preparation		
Nephrostomy drape	Allegiance	
Fluoroscopy compatible OR table		
Split leg positioners	Steris/Amsco Corp.	
Access		
Straight 0.035-in. Nitinol guidewire		
Curved 0.035-in. Nitinol guidewire		
Floppy tip (e.g., Bentson) (PTFE) 0.035-in.		
guidewire Amplatz super-stiff 0.035-in.		
guidewire Exchange guide wire (260 cm)		
0.035-in. 8/10-Fr coaxial ureteral dilatation system and safety wire introducer sheath	Boston Scientific: Microvasive	260-120

Ureteral Access Sheath (various sizes/ lengths)		
SureSeal II adapter	Applied Medical	SEAL-005
12-Fr Foley Catheter		
18-G, 5-cm-long, 15 F fascial incising needle	Cook Urological	090070

INSTRUMENT LIST (*Continued*)

Item	*Manufacturer*	*Order no.*
18-G, 15-cm-long disposable trocar needle	Cook Urological	DTN-18-15.0
5.5-Fr, 40-cm Kumpe Catheter	Cook Urological	023540
Amplatz Renal Dilator Set	Cook Urological	75000
10-mm Nephromax balloon dilator set	Boston Scientific: Microvasive	210-117
Leveen syringe	Boston Scientific: Microvasive	210-110
Endoscopes		
Flexible cystoscope / nephroscope		
Rigid Nephroscope		
Flexible Ureteroscope		
Stone Removal		
Assorted stone graspers and baskets for rigid and flexible nephroscopes		
Ultrasonic Lithotriptor		
Pneumatic Lithotriptor		
Lithoclast Lithotriptor		
Lithoclast Ultra		
Holmium Laser		
Exit Equipment		
Assorted indwelling ureteral stents		
10-Fr Cope loop nephrostomy tube	Cook Urological	085000
Kaye Tamponade Catheter 18 Fr	Cook Urological	086514
FloSeal (Hemostatic Gelatin Matrix)	Baxter	
7.5-Fr, 11.5-mm ureteral occlusion balloon catheter	Boston Scientific: Microvasive	OB/11.7/7/100

TECHNIQUE

Anatomy

The kidneys lie in the retroperitoneum on the quadratus lumborum and psoas muscles, with the superior pole of the kidney resting on the posterior portion of the diaphragm. As such, given the thinning out of these muscles superiorly, the upper pole of each kidney lies closer to the back than the lower pole of the kidney. Each kidney has a thin walled fibrous capsule that is intimately adherent to the parenchyma, which in turn is surrounded by perirenal fat. The perirenal fat is contained by Gerota's fascia, which in turn is surrounded by another layer of fat (i.e., the pararenal fat).

Deep to this, the underlying pleura attaches to the 11th rib which must be considered when a superior pole percutaneous approach is planned, especially on the left where the kid-

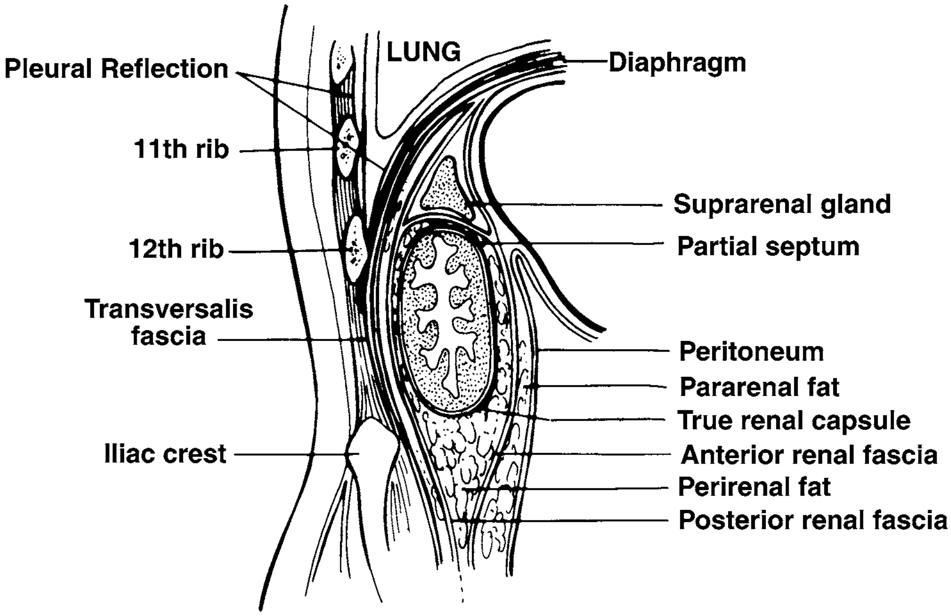

Fig. 1. Sagittal view of the structures surrounding the kidney. (Reprinted from ref. *76a*, with permission.)

ney lies higher in the retroperitoneum (Fig. 1). Thus, a supracostal approach may result in hydrothorax or, rarely, pneumothorax in 8 to 12% of patients *(77–79)*.

A retrorenal colon can be seen on either side in 1 to 10% of percutaneous cases depending on patient positioning; it is more common when the patient is in the prone position. However, this condition is usually limited to patients with a markedly redundant colon (e.g., after jejunal ileal bypass) or patients with a horseshoe kidney *(80)*. Usually the retrorenal colon covers only the lateral most portion of the upper pole of the kidney, thus explaining the rarity with which it is harmed during PCNL.

For anatomic purposes, the kidney can be divided into anterior and posterior segments. The plane of division for these segments rests 30 to 50° posterior to the frontal plane of division for the body as a whole owing to the rotation of the renal axis anteriorly by the psoas major muscle (Fig. 2) *(81)*. The psoas muscle also defines the axis of the kidneys in the longitudinal plane so that the upper pole is medial and posterior while the lower pole is more lateral and anterior *(80)*. As such, the distance from skin to collecting system is shortest at the upper pole and greatest at the lower pole of the kidney.

The decision to gain upper pole or lower pole access is crucial. Upper pole access offers several distinct advantages, but, as mentioned previously, has a slightly higher complication rate because of the risk of hydropneumothorax when access is supracostal *(79)*. Upper pole access offers the shortest distance to the collecting system, a direct line to the UPJ for guidewire passage, the most direct access to the renal pelvis, and excellent access to the lower and middle calyces. In an effort to characterize renal vascular anatomy more specifically in the context of percutaneous renal surgery, Sampaio and coworkers *(82)* performed three-dimensional endocasts of renal collecting systems, arteries, and veins in fresh cadavers. They also studied the extent of vascular injuries sustained from percutaneous punctures of the renal collecting system at various locations *(83)*. They discovered that there is a high likelihood of a significant vascular injury if the

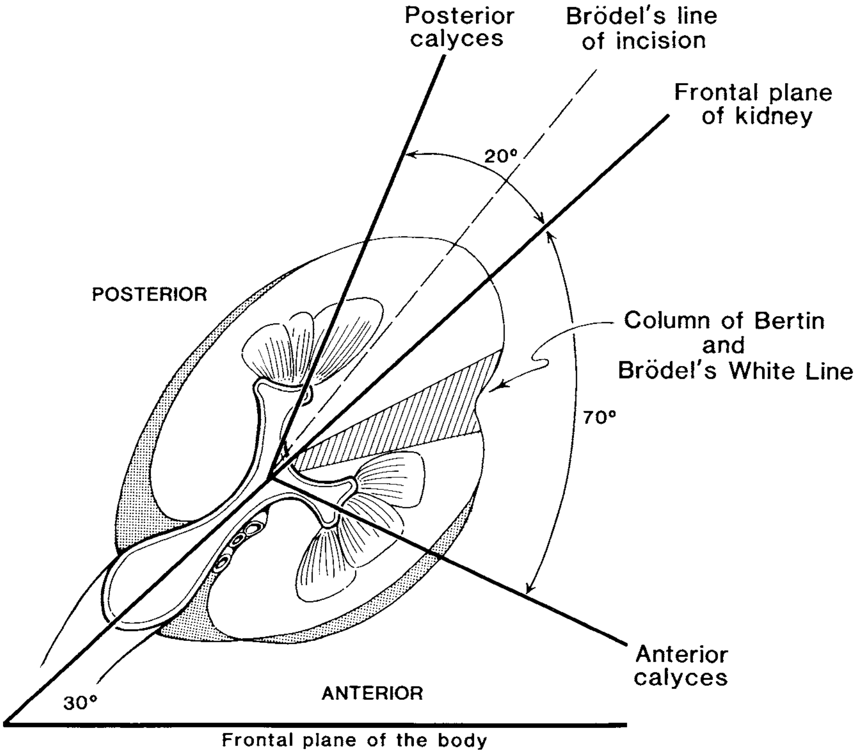

Fig. 2. Coronal view showing the geometric configuration the left kidney and the plane of division between the anterior and posterior segments. (Reprinted from ref. *76a,* with permission.)

collecting system is punctured through an infundibulum or if the renal pelvis is accessed directly because the larger vessels surround these structures. Significant vascular injuries were discovered in 67, 23, and 13% of upper, middle, and lower pole infundibular punctures, respectively. However, when testing true forniceal calyceal punctures, there were no arterial injuries and less than an 8% rate of vascular injury. Thus, puncture of the collecting system should always be performed through a posterior calyx.

In considering the anatomic lie of the kidney and the vascular architecture, the authors believe that it is most advantageous to approach the establishment of a percutaneous tract in the prone position. This will place the posterior calyces in an end on position if puncture of the kidney collecting system is approached at an angle of 30° from the midline (Fig. 3). This makes forniceal (as opposed to infundibular) puncture much more likely. This also greatly increases the likelihood that the nephrostomy path will be established in the relatively avascular zone of the renal parenchyma (Brödels zone) where the most distal end branches of the anterior and posterior arcuate arteries meet. In addition, this approach avoids transgression of other pararenal structures, because it is well out of range of the organs surrounding the kidneys.

More recently, several investigators have explored performing PCNL in the supine position *(84,85)*. The benefits of this technique are avoidance of the ventilatory and positioning issues that are inherent with prone PCNL. In one nonrandomized prospective comparison of prone vs supine PCNL (77 vs 53 patients, respectively), a problem arose in 11% of the supine group owing to anteromedial rotation of the kidney. This was remedied by using manual external compression. Stone clearance rates and retreatment rates in

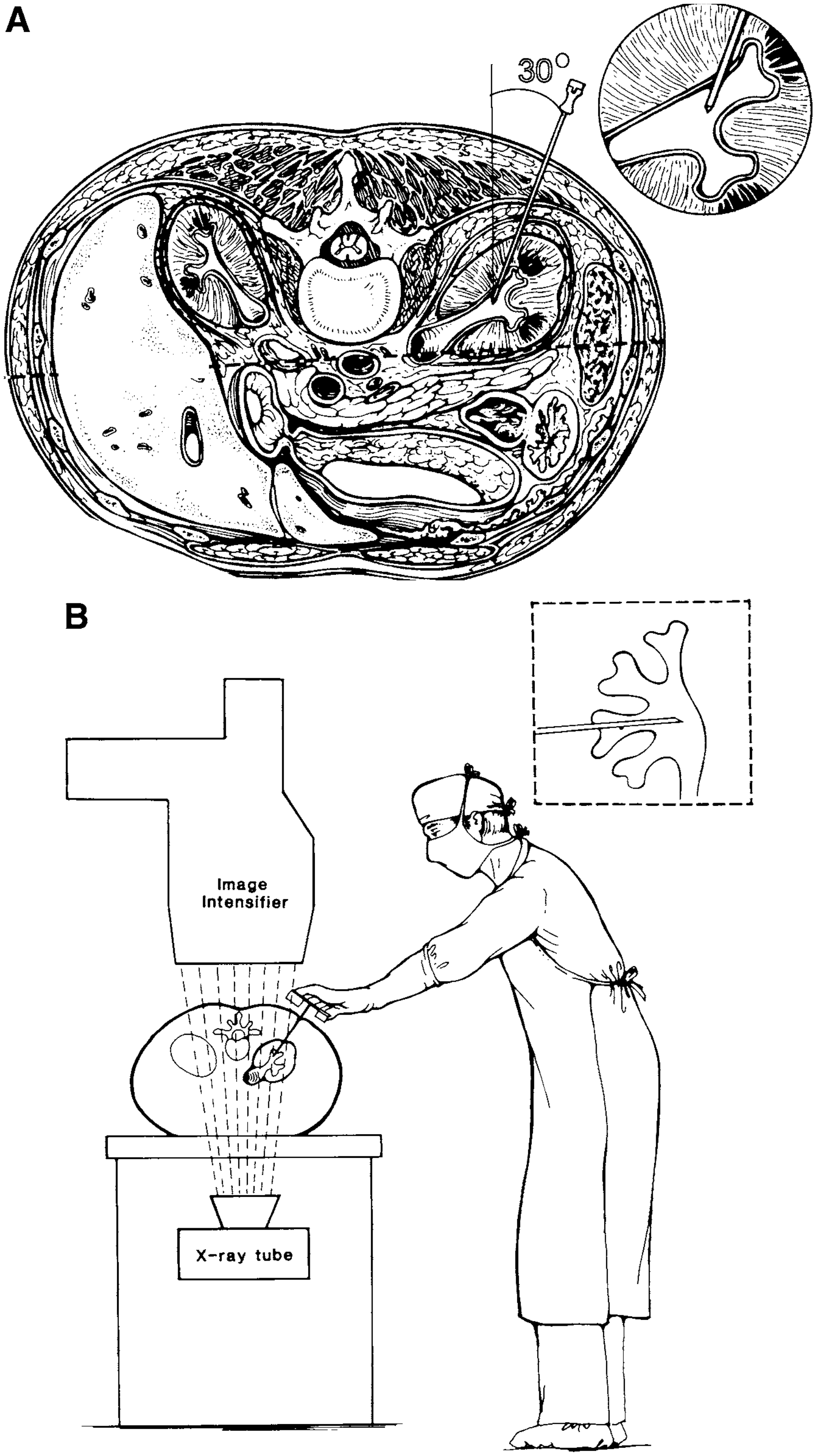

Fig. 3. (A) Puncturing the collecting system at a 30° angle from the midline vertical plane. A forniceal puncture is demonstrated. **(B)** The position of the surgeon in relation to the prone patient and fluoroscopic equipment during puncture. (Reprinted from ref. 76a, with permission.)

the prone and supine groups were similar (84 vs 89% and 6 vs 7%, respectively). The complication rate was 12 vs 17% ($p > 0.05$).

The Ureteral Access Sheath: A Novel Adjunct to PCNL

To facilitate visualization of the collecting system prior to attempting percutaneous puncture of the renal collecting system, most endourologists pass a ureteral catheter or balloon occlusion catheter up to the renal pelvis. The collecting system can then be opacified with contrast/air and distended to aid in targeting the desired calyx. The catheter also serves to help prevent stone fragments from entering the ureter.

Since the development of hydrophilic nonkinking ureteral access sheaths, we have altered our PCNL technique in a manner first developed by Clayman, and subsequently described by Landman et al. *(86)*. Specifically, an appropriate length 12- or 14-Fr access sheath (e.g., 35 cm in females and 55 cm in males) is passed up to the level of the UPJ prior to nephrostomy puncture. Carbon dioxide or air (i.e., 10 cc) can then be gently injected through the sheath's obturator to create an air nephrogram. The authors routinely use air (as do most endourologists); in more than 20 years of practice, the senior author has yet to observe a problem developing from the use of air opacification. Once the nephrostomy tract is established, the obturator is removed. Alternatively, the obturator can be removed prior to establishing access; the flexible ureteroscope can be deployed via the sheath and guided into the selected calyx. Now the entire puncture and subsequent tract dilation is performed under fluoroscopic and endoscopic guidance. The surgeon aims the needle for the tip of the ureteroscope, and the person handling the ureteroscope watches the needle as it punctures the collecting system. Beyond establishing the nephrostomy access, there are numerous advantages to having a ureteral access sheath in place during PCNL. First, if necessary, a flexible ureteroscope can be passed retrograde to aid in lithotripsy or to access a calyx that can not be entered percutaneously (Fig. 4). Second, many small stone fragments rapidly wash down the access sheath during antegrade lithotripsy. Third, the access sheath helps to keep pressure within the collecting system low throughout the procedure. In a cadaveric kidney model comparing irrigation with and without a sheath in place, Rehman and colleagues reported consistently lower intrapelvic pressures (<30) and higher irrigant flow rates when an access sheath was used during ureteropyeloscopy *(87)*. Fourth, the access sheath can be used for passage of a through-and-through guidewire at the end of the procedure. Lastly, it can also be used to facilitate stent placement at the end of the procedure. Using this technique, Landman and colleagues reported a 78% stone-free rate in nine patients with staghorn calculi.

Operative Technique

The operative table must be configured to allow a fluoroscopy C-arm unit to fit underneath and should be outfitted with spreader bars and chest rolls. The patient is anesthetized on a gurney and then rolled into the prone position on the operating room table. The legs are abducted such that the urethra can be accessed. The male is moved down the table so that the phallus hangs free, pointing towards the floor. Adequate padding of the extremities and torso, preferably with gel pads, is paramount. The flank and perineum are then prepared; a nephrostomy drape is placed both at the flank and over the perineum (Fig. 5).

The procedure begins with flexible cystoscopy and passage of a hydrophilic nitinol or standard floppy tip guidewire retrograde up the appropriate ureter. An 8/10-Fr coaxial dilator sheath combination is introduced over the guidewire; the inner 8-Fr catheter is removed

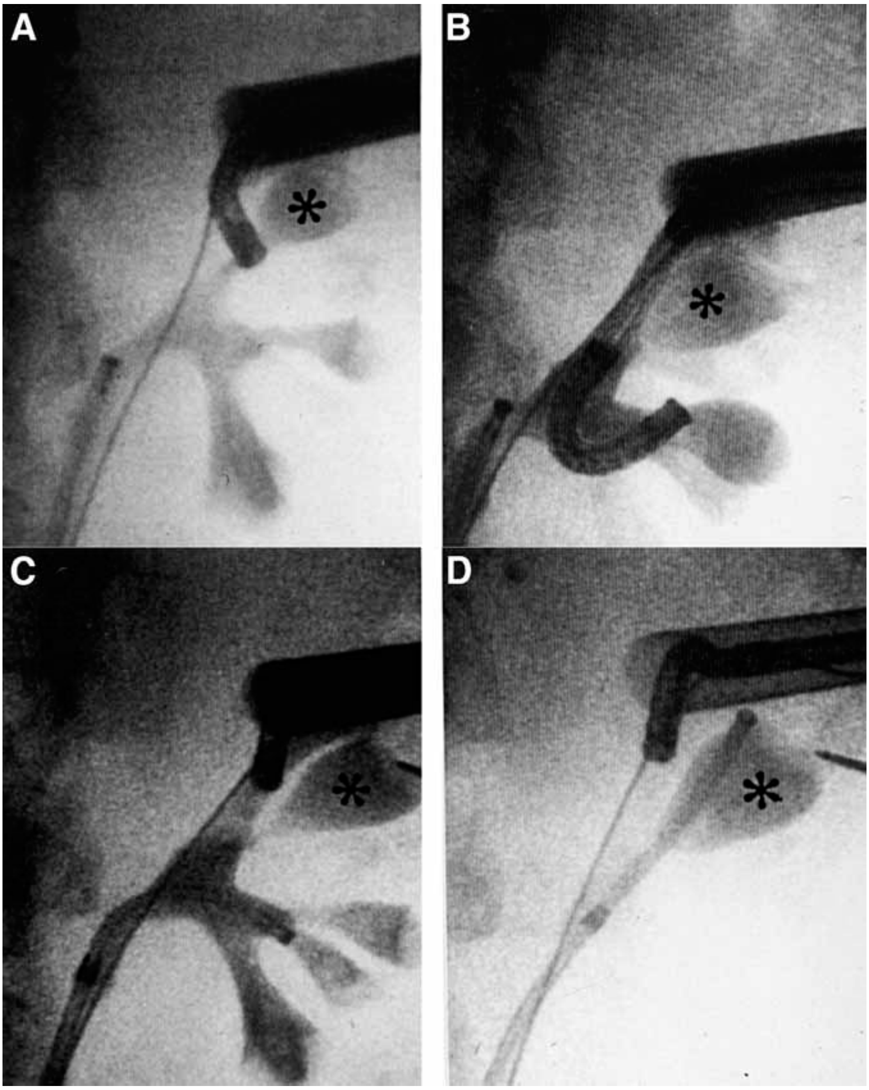

Fig. 4. (A) Radiograph demonstrating a calyx that is inaccessible from the established upper pole access (marked by a $*$). **(B,C)** The collecting system is opacified using radiographic contrast. **(D)** A ureteroscope can then be guided into the desired calyx.

leaving the 10-Fr sheath and original guidewire in the ureter. Through the 10-Fr sheath, an Amplatz super stiff guidewire is passed; if a nitinol guidewire was passed initially, it is now exchanged for a standard floppy tip guidewire. Now the 10-Fr sheath is removed leaving the two guidewires in place. A 12-Fr ureteral access catheter (length = 35 cm for women and 55 cm for men) is then passed over the Amplatz guidewire. The floppy tip guidewire is maintained as a safety wire; a Kelly or tonsil clamp is used to secure the safety guidewire where it exits the urethra, to the perineal drapes. The tip of the 12-Fr access sheath should be positioned at the UPJ. A Foley catheter is inserted along side the 12-Fr sheath in order to drain the bladder. If the ureter is particularly capacious, then a 14-Fr sheath can be used.

Targeting of the desired calyx is accomplished by injecting 10 cc of air into the renal collecting system via the obturator of the access sheath. Because the patient is in the prone

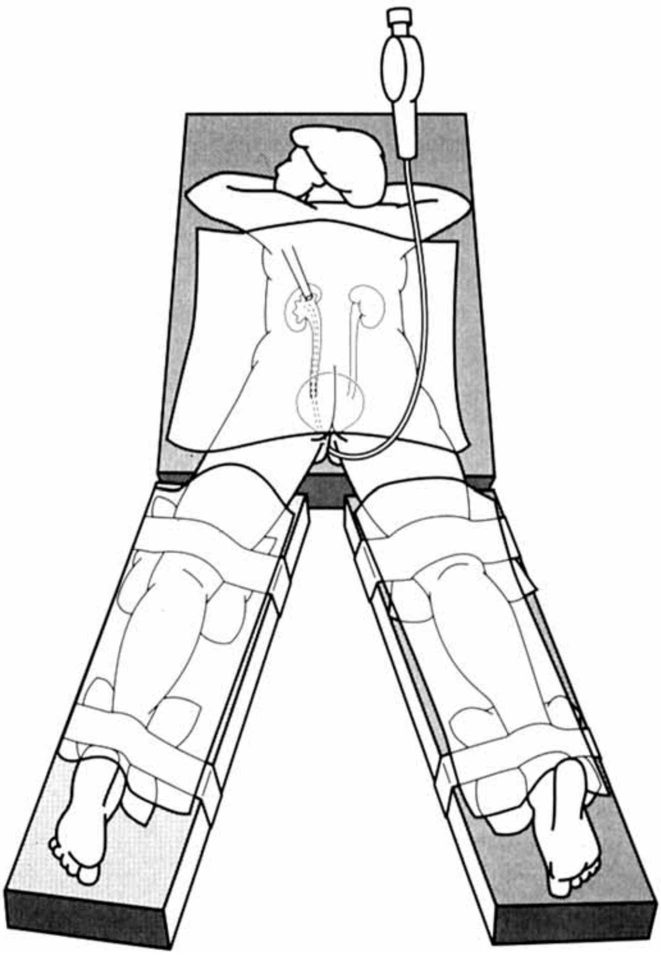

Fig. 5. Diagram demonstrating patient positioning during PCNL. In the split-leg position, retrograde and antegrade access are possible throughout the procedure.

position, the air bubbles rise to the top of the posterior calyces thereby creating a visible target. When using an upper pole approach, the C-arm fluoroscope is angled cephalocaudal by 20 to 30°. The 18-gage nephrostomy needle is similarly aligned and passed into the desired calyceal bubble. When properly aligned in the anterior–posterior plane of the C-arm, the needle appears as a radio-opaque dot on the fluoroscope screen as the tip, shaft, and hub of the needle are all superimposed on one another. The needle is advanced 4 to 6 cm into the flank following which the C-arm fluoroscope can be rotated obliquely thereby "laying out" the path of the needle. The needle is advanced in the same line, only now the surgeon can "see" the tip of the needle as it enters the calyx. When the tip of the needle lies within the air bubble on the anterior–posterior and oblique views fluoroscopically, then removal of the inner cannula of the nephrostomy needle should result in a small expulsion of air through the needle hub followed by urine.

For passage of a guidewire antegrade down the nephrostomy needle and across the renal pelvis and into the ureter, a curved tip nitinol guidewire equipped with a torque control device or a straight-tip nitinol guidewire is used. The obturator is removed from the access sheath at this point. If the guidewire passes into the renal pelvis but will not pass down into the ureter or into the access sheath, then a 5-Fr Kumpe catheter can be passed over the guidewire to provide greater maneuverability.

After a guidewire is passed into the ureter, the tract can be dilated. If the guidewire passes down and out the ureteral access sheath, its urethral end is clamped to maintain through-and-through access. Over the guidewire, a fascial incising needle is passed; this will incise the fascia to 5 mm. Next, an 8/10-Fr coaxial dilator sheath is passed percutaneously. The 8-Fr catheter is removed and an Amplatz super-stiff guidewire is placed down the ureter or into the access sheath. If the 8/10-Fr sheath does not pass easily over the nitinol guidewire, then a 5-Fr open-ended angiographic catheter can be passed; the nitinol guidewire can then be exchanged for an Amplatz type super-stiff guidewire following which the 5-Fr angiographic catheter is removed. Following this, the 8/10-Fr system is passed, and a second guidewire—usually a floppy-tip, 0.035-in. type—is passed into the system. The floppy-tip, guidewire is sutured to the flank with a 0-silk; it thus becomes another "safety" guidewire. The Amplatz super-stiff guidewire thus serves as the "working" guidewire over which all other catheters and dilators will be passed. If access is lost during the case, then the suture is removed from the "safety" guidewire and another "working" guidewire is placed; the "safety" guidewire is then sutured again to the skin.

Next a 30-Fr high-pressure (i.e., rated to 15–20 atm) dilating balloon catheter is passed over the "working" guidewire (i.e., Amplatz super-stiff guidewire) until the tip of the balloon rests within the calyx but proximal to the infundibulum of the calyx. Use of a dilating balloon system has been found to have a 10% transfusion rate vs 25% for use of the Amplatz sequential dilator system *(88)*. The balloon is then inflated and the 30-Fr nephrostomy sheath is passed over the balloon until it too resides within the calyx proximal to the infundibulum. The balloon is then deflated and removed.

Rigid and flexible nephroscopy as well as URS can be performed depending on the stone size and location. For stones that are 1 cm or less, direct removal using stone grasping forceps is a very efficient technique. Grasping forceps or a rigid nitinol basket retriever, as designed by Denstedt, can be used for this purpose. For larger stones, a variety of lithotripters can be used including ultrasonic, pneumatic, combined pneumatic and ultrasonic (e.g., Lithoclast Ultra), Holmium:YAG laser, or rarely, if ever today, the electrohydraulic lithotripter. In our experience, modes of energy that can be applied simultaneously with suction removal of the fragments are the most efficient means of reducing stone burden (i.e., ultrasonic or Lithoclast Ultra). However, the pneumatic or Holmium:YAG laser may be required for particularly hard stones; the former is very efficient at rapidly fragmenting large, hard calculi, whereas the latter is very effective whenever flexible endoscopy is needed. The electrohydraulic lithotriptor is rarely used; its only indication is when loss of flexible endoscope deflection precludes stone access with the holmium laser.

Difficult to reach calyces can be reached using flexible nephroscopy or antegrade or retrograde (i.e., via the access sheath) flexible ureteroscopy (Fig. 4). Prior to exit, a full rigid and flexible nephroscopic and fluoroscopic exam is essential to ensure complete stone removal. If visibility is poor, it is best to place a large-bore (i.e., 20-, 22-, or 24-Fr) nephroureteral tube and plan for a "second look" based on the results of a postoperative day-one CT scan without contrast.

Traditionally, following successful PCNL with a stone-free endoscopic and fluoroscopic status, our preference was to leave a 10-Fr Cope loop nephrostomy tube in the renal collecting system. We have now modified our technique to a "tubeless" approach. This approach, originally championed by Wickham in the mid-1980s never became

Fig. 6. Fluoroscopic image showing an Amplatz nephrostomy sheath pulled back to the junction of the renal collecting system and parenchyma. The ureteral occlusion balloon is inflated at the tip of the sheath to prevent injection of FloSeal into the renal collecting system.

popular in the United States until resurrected and modified by Bellman and colleagues more than a decade later *(89–91)*.

Presently, among endoscopic and fluoroscopic stone-free patients our routine for exiting the nephrostomy tract begins by pulling the nephrostomy sheath back to the junction of renal parenchyma and the collecting system. A guidewire—usually a 260-cm exchange guidewire or a standard 140-cm guidewire in the male and female patient, respectively—is passed through the access sheath; a rigid nephroscope is used to grasp and pull the floppy end of the guidewire out through the nephrostomy tract, thereby creating a "through-and-through" guidewire access. Next, a 7-Fr, 11.5-mm balloon occlusion catheter is passed retrograde over the "through-and-through" ureteral access guidewire until the tip of the balloon lies at the edge of the nephrostomy sheath (Fig. 6) *(92)*. The passage of the occlusion balloon catheter to this point is monitored with the nephroscope; the balloon is inflated at the entry point of the nephrostomy tract into the calyx. A hemostat is placed on the guidewire where it exits the occlusion balloon catheter at the perineal end. The endoscope is withdrawn; now, the long laparoscopic hemostatic gelatin matrix applicator (FloSeal, Baxter Healthcare Corp., Deerfield, IL) is passed into the 30-Fr sheath until the surgeon feels it touching the expanded occlusion balloon. The 30-Fr sheath is withdrawn 1 cm and now the entire tract is filled with FloSeal as the surgeon injects and simultaneously withdraws the applicator with one hand while also retracting the 30-Fr Amplatz sheath with the other hand (Fig. 7). By keeping the "through-and-through" guidewire taut, the occlusion balloon is maintained in its position thereby precluding any of the gelatin matrix from entering the collecting system. Also, once the 30-Fr sheath and applicator are removed, the surgeon can then apply gentle tamponade for up to 10 minutes to the incision in the flank, thereby sandwiching the hemostatic material between a gauze sponge applied to the skin surface and the occlusion balloon *(92)*. The access sheath is pulled back to the midureter and then cut at the urethral end; the solitary "through-and-through" guidewire is pulled retrograde under fluoroscopic control

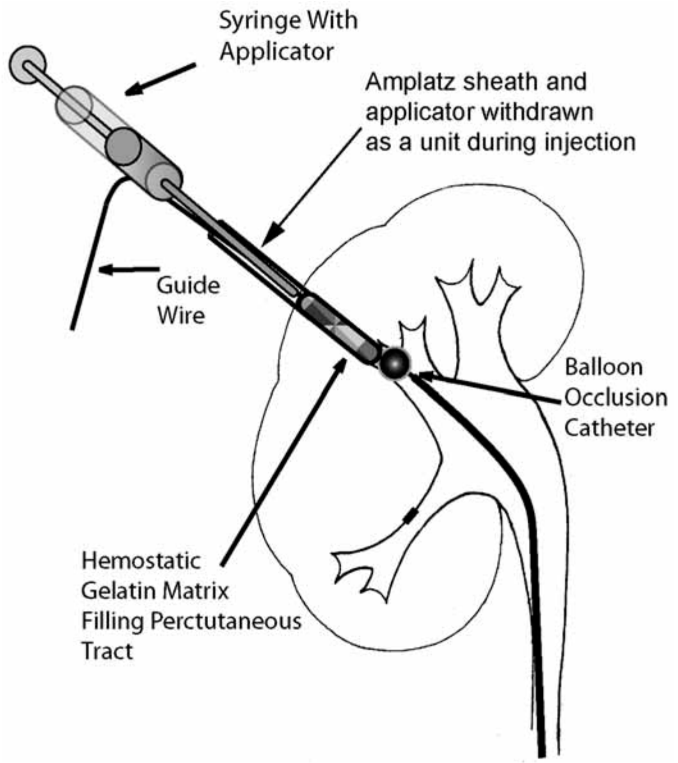

Fig. 7. Demonstration of technique for injecting a percutaneous tract with hemostatic gelatin matrix.

until its tip is seen in the collecting system. The Foley catheter is removed so it will not interfere with stent placement. An internal ureteral stent can then be passed retrograde following which the access catheter is removed followed by removal of the guidewire and then the pusher. For this purpose, a 36-cm "tail stent" (7-Fr proximal to 3-Fr distal) (Microvasive Boston Scientific Corp, Natick, MA) is selected, because these stents have been shown previously to cause less pain and irritable bladder symptoms postoperatively *(93)*. The tail is repositioned from the urethra (in the male) or perineum (in the female) into the bladder (endoscopically in males or with a Kelly clamp in females). A Foley catheter is then passed. The skin is closed with a 4-O absorbable suture placed in a subcuticular fashion. Alternatively, when a second look procedure is planned, a nephroureteral access tube can be fashioned by passing a 70-cm single pigtail catheter through the middle of a 22-Fr Councill tip catheter such that the pigtail catheter rests within the bladder and the Councill tip catheter lies in the renal collecting system. One cubic centimeter of saline is placed into the balloon of the Councill catheter to secure it within the renal collecting system. A plastic side arm adapter fits into the butt end of the Councill catheter; it then can be in turn tightened around the shaft of the 7-Fr pigtail catheter. The Councill catheter is sewn to the skin with two 0-silk sutures. (Fig. 8) This system provides large bore nephrostomy access to the kidney and fail-safe and secure access to the ureter.

COMPLICATIONS

Hemorrhage from the nephrostomy tract is the most common major complication associated with PCNL. The incidence of significant hemorrhage requiring transfusion in mod-

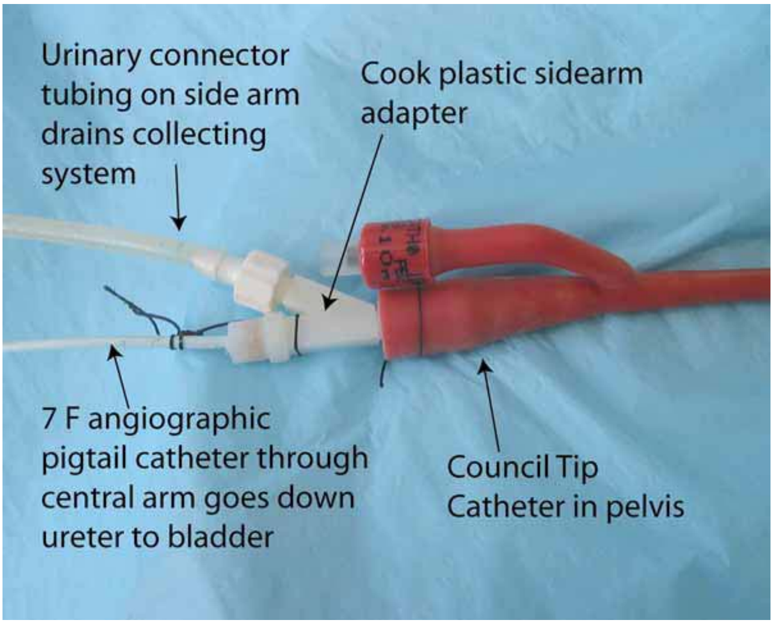

Fig. 8. Photograph of setup of a nephroureteral access tube.

ern reported series of PCNL ranges from 10 to 25% *(88,94)* and embolization is required in approx 0.8% of cases *(95)*. In the event of hemorrhage the endourologist must make a baseline assessment of the degree of hemorrhage. Often, insertion of a large bore (24 Fr) nephrostomy tube is sufficient to tamponade the bleeding. If this is not successful, clamping of the nephrostomy tube is often effective *(94)*. If the surgeon's initial impression is one of severe vascular injury, a Kaye tamponade nephrostomy catheter can be used. This catheter is specifically designed to achieve immediate tamponade of the nephrostomy tract. The large-diameter, occlusive balloon (36 Fr) is carried on a 14-Fr nephrostomy tube which is passed over a 5-Fr ureteral stent. As such, the catheter not only tamponades the nephrostomy tract, but also effectively drains the renal pelvis, while maintaining ureteral access *(96)*. Finally, in the event that severe arterial bleeding does not respond to conservative measures, angioembolization or emergency exploration and possible nephrectomy is indicated. Interestingly, with regard to tubeless PCNL, to date, hemorrhage has not been a reported problem. Thus far, two different agents have been tested clinically. In one series 20 patients injected with fibrin glue (Tisseel, Baxter Healthcare Corp., Deerfield, IL) were compared with 20 patients who did not have the agent injected after PCNL. Nephrostomy tubes were not left in either group. Overall there was a decrease in hospital stay by 0.7 days but no statistically significant difference in percentage drop in hematocrit or analgesic use *(89)*. In another study, eight patients who had hemostatic gelatin matrix injected down the percutaneous tract were compared with eight patients who were left with a Cope loop nephrostomy tube after PCNL. Here again, hospital stay was shorter in the FloSeal group (29 vs 49 hours) but there were no differences seen in analgesic use or fall in hematocrit *(97)*.

Perforation of the renal pelvis may also occur during PCNL. In the event of a perforation the surgeon must make an assessment of the size of the perforation and the degree of extravasation of irrigant because large volumes of fluid can be absorbed from the retroperitoneum causing electrolyte abnormalities. In addition, extravasation of contrast will often make further fluoroscopic imaging difficult. In the event of a significant perforation it is best to abort the procedure and place a large-bore nephroureteral catheter combination (vide supra). A second-look procedure should be postponed until confirmation of no extravasation on a nephrostogram. Following a significant perforation, it is also possible that stone fragments may be extruded into the perinephric space. Attempts at retrieval of these fragments are rarely successful and usually only enlarge the perforation and fill the retroperitoneum with irrigant. Further, these fragments are of little clinical significance unless the stone was infected. Even under the last circumstance, subsequent infection and abscess formation is too rare to justify extensive retroperitoneal manipulation.

Colonic injury during percutaneous stone removal is fortunately a rare event, occuring in less than 1% of procedures. A retrorenal colon occurs in approx 0.6% of patients, but is more common in patients with horseshoe kidney and other ectopias *(98)*. Acute signs of perforation include intraoperative diarrhea, hematochezia, sepsis, or passage of gas and feces from the nephrostomy tube. More often, a transcolonic injury is apparent on a postoperative CT or nephrostogram. If the patient is asymptomatic, the problem can be managed conservatively with placement of an internal ureteral stent plus a Foley catheter and pulling back of the nephrostomy tube into the colon, thereby decompressing both the urinary tract and the colon through separate tubes. If, however, the patient exhibits signs of sepsis or if the injury is transperitoneal, open repair is recommended.

As mentioned earlier in this chapter, because of the close relationship of the pleura and underlying kidney, a supracostal approach may result in a hydrothorax, or rarely a pneumothorax in 8 to 12% of patients *(77,78)*. Traditionally, an upright chest radiograph following PCNL was recommended to detect this complication. However, more recent work by Ogan and colleagues *(99)* have shown that intraoperative fluoroscopy in combination with a postoperative day-one CT scan is a more effective means of detecting hydropneumothorax. If detected on intraoperative fluoroscopy, a percutaneous drain, such as a 10-Fr Cope loop, can be placed fluoroscopically at the end of the PCNL procedure. The drain should be attached to chest tube suction. If a hydropneumothorax is only first detected on the postoperative day one CT then the surgeon must make an assessment of the patient's symptoms to determine if drainage is necessary.

TIPS AND TRICKS

Starting off with the patient in the split leg prone position ensures that the surgeon will have the maximum number of treatment options during PCNL. It takes only a few cases to become adept at prone flexible cystoscopy and, with use of the access sheath, prone flexible ureteroscopy. After mastering this skill, the surgeon not only can obtain endoscopically monitored upper tract access prior to PCNL, but also can use this access to drain the collecting system and evacuate stone fragments during the case by positioning the ureteral access sheath at the level of the UPJ. With the inflow from the nephroscope flowing directly down the 12-Fr access sheath, fragments up to 3 mm in size can be flushed antegrade out of the patient. Also, having an access sheath positioned at the UPJ gives the surgeon the option of passing a flexible ureteroscope retrograde to the collecting system to aid in lithotripsy or in accessing a calyx that is not accessible via the nephrostomy tract. In this situation, the flexible ureteroscope can be used to either fragment the stone in situ or to basket the stone and deliver it into the renal pelvis where it can then be retrieved with the rigid nephroscope.

Another key point that greatly increases the number of options available to the surgeon is the establishment of a "through-and-through" guidewire using a 260-cm long 0.035-in. guidewire. With this guidewire in place, the surgeon can pass any length catheter antegrade or retrograde during the case. It also gives the surgeon the ability to "pull" a catheter up or down the ureter as desired by placing a clamp onto the guide wire behind the catheter after the catheter has been completely loaded on the guidewire; the surgeon can then pull the catheter into the desired position. This guidewire is also ideal for placing an occlusion balloon catheter for subsequent use with FloSeal or for placing an indwelling stent (vide supra).

Tips to Note

1. When positioning a male patient prone with legs on spreader bars, be sure the phallus lies free of the table.
2. 10/12-Fr or 12/14-Fr ureteral access sheaths should be placed with the end of the sheath at the UPJ (i.e., obturator tip would lie in renal pelvis or upper pole infundibulum).
3. Consider entry into an upper pole posterior calyx whenever possible as this provides the most direct path to the ureter and the shortest path into the kidney.
4. Use of retrograde flexible ureteroscopy via the access sheath, allows access to stones in a remote upper pole calyx (juxtaposed to the nephrostomy tract).
5. "Through-and-through" access can be established using a 260-cm exchange guidewire.
6. FloSeal in association with an occlusion balloon catheter can be used to achieve hemostasis in the percutaneous tract.

CONCLUSION

Percutaneous stone removal has progressed significantly over the past 29 years. The advent of improved guide wires (e.g., nitinol), tract dilators (e.g., balloon), lithotriptors (e.g., pneumatic and Holmium), and hemostatic agents has made this procedure more effective and safer. Today, PCNL is capable of rendering more than 90% of patients stone free regardless of stone burden or location.

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9

Calculus Therapy

Combined Approaches

Véronique Tran, MD, *Ramakrishna Venkatesh,* MD, FRCSC, *and Jaime Landman,* MD

CONTENTS

SUMMARY

Advances in ureteroscopic tecnique and technology have increased the scope of urological pathology that can be treated in a retrograde manner. "Combined approaches" that incorporate traditional antegrade access and retrograde access offer the urologist increased flexibility in the management of complex urinary tract pathology. In the following chapter, we review the indications, technique, and results associated with the combined approach to urolithiasis.

Key Words: Kidney; kidney calculi; ureter; nephrostomy; percutaneous; surgical instruments.

INTRODUCTION

Surgical stone management has evolved tremendously over the last two decades. With the advent of shockwave lithotripsy (SWL) in the 1980s, this extracorporeal modality rapidly became the primary treatment of choice for 95% of stone cases. At this time, an endoscopic approach was used less than 5% of the time. Over the past two decades, however, advances in flexible endoscopes, irrigation systems, lasers, and laser fibers (in addition to the introduction of small caliber nitinol instrumentation) have increased the utility of the endoscopic approach for stone disease. Although SWL remains the procedure of choice

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for the majority of stone cases (75%), there remains an important role for endoscopy in stone disease. Currently, the endoscopic (antegrade or retrograde) approach is employed as the primary treatment strategy in approx 25% of stone cases that require intervention.

The endoscopic approach for the management of nephrolithiasis has continued to expand over the last two decades with the development of percutaneous nephrolithotomy (PCNL). In the early conception of PCNL, treatment of large calculi with PCNL was followed by SWL, and then a second-look PCNL. This type of "sandwich therapy" became the standard of care. Refinements in percutaneous surgical techniques have made PCNL with or without a second-look nephroscopy as successful as "sandwich therapy."

As experience and comfort with the antegrade and retrograde approaches to the urinary tract have expanded, a combined approach to endoscopy has evolved. Application of this combined antegrade and retrograde approach allows for unification of the urinary tract. The advantages of both the antegrade and retrograde approaches can be combined for safe and efficient stone ablation in all parts of the upper urinary tract. The following chapter will summarize the indications, techniques, and results of the combined antegrade and retrograde approach to urolithiasis.

INDICATIONS

Percutaneous Nephrolithotomy

The authors currently utilize a combined approach involving simultaneous percutaneous antegrade and retrograde access to stone disease that requires PNCL. Stone characteristics that should be considered when deciding if PCNL is indicated include stone burden (size and number), composition, and location. Larger stones are usually treated with PCNL. Staghorn calculi and nonstaghorn stones greater than 30 mm in size, regardless of other stone-related factors, are best managed with PCNL as first-line treatment.

Depending on stone size and renal anatomy, many lower pole calculi require PCNL. Specifically, Elbahnasy et al. *(1)* identified anatomic characteristics that are associated with poor fragment clearance: infundibulopelvic angle less than 70°, infundibular length greater than 3 cm, and an infundibular width less than 5 mm. Stones located in excluded calyces or associated with ureteropelvic junction (UPJ) obstruction or other anatomically challenging situations are likewise candidates for PCNL. Stone composition is also important. Stones resistant to SWL and lithotrites, such those composed of as cystine, brushite, and calcium oxalate monohydrate, are often candidates for PCNL. Final consideration of whether to utilize PCNL for stone ablation is based on patient characteristics, such as body habitus, infection, poorly controlled hypertension, and renal failure.

The introduction of the contemporary ureteral access sheath has expanded the utility of the retrograde approach to stone disease. Initially, we applied the combined antegrade and retrograde approach for PCNL only to partial or complete staghorn calculi. Prior to application of the combined approach, we used an occlusion balloon to prevent migration of stone fragments down the ureter. At first, the ureteral access sheath was used in place of the occlusion balloon to allow passage of stone fragments from the urinary tract instead of being trapped in the renal collecting system where they have to be manually removed (Fig. 1). It quickly became evident that there were multiple advantages to applying the access sheath in this setting.

The ureteral access sheath has improved upon standard PCNL in a variety of ways. First, the access sheath allows passage of stone fragments out of the urinary tract. Second, the ureteral access sheath permits passage of a ureteroscope into the upper and middle calyces

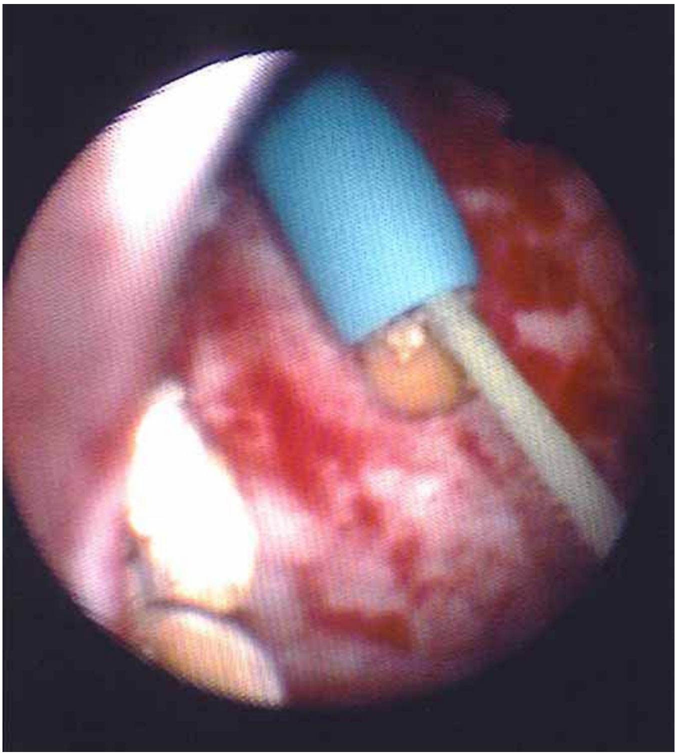

Fig. 1. Stone fragment passing down access sheath properly positioned at ureteropelvic junction as seen from antegrade access.

of the kidney to directly fragment and/or remove stones remote from the nephrostomy tract; the ureteroscope can be readily passed in and out of the renal collecting system in an expeditious and atraumatic manner to complement the percutaneous access and improve access to the entire collecting system. As such, larger stones can be completely ablated using a single lower pole access. Placement of the access sheath therefore decreases the need for additional percutaneous access and obviates the need for upper pole access, thereby eliminating the risk of pleural transgression. Finally, we have demonstrated that use of the ureteral access sheath improves endoscopic visualization by increasing irrigant flow while minimizing pressure within the collecting system *(2,3)*. Currently, we utilize the combined approach for the vast majority of our PCNL procedures.

Renal and Ureteral Stones Associated With Urinary Diversions

The combined approach can also enhance management of ureteral calculi in patients with urinary diversions. Frequently, in patients with ileal conduits or neobladders, retrograde access to the ureters is challenging, as the ureteral orifices may be difficult to identify. Initial percutaneous access allows negotiation of a wire down the ureter into the neobladder or conduit, thereby providing through-and-through access. Once the guidewire is retrieved from the conduit or neobladder, a retrograde approach can be utilized. If required, additional access can also be achieved in an antegrade fashion.

Large Ureteral Stones

Large ureteral stones are uncommon, but can be very challenging. Although open and laparoscopic ureterolithotomy have been performed in this setting *(4,5)*, the laparoscopic approach is significantly more invasive than a combined endoscopic approach and requires reconstructive laparoscopic skills. From a retrograde approach, large ureteral stones can be technically challenging and time consuming as the diminutive ureteroscopes and laser fibers limit the rate of stone ablation. Application of a combined antegrade and retrograde approach with two surgical teams simultaneously performing endoscopic lithotripsy can expedite stone ablation.

INSTRUMENT LIST

Antegrade Percutaneous Access

16-Fr Flexible cystoscope (Olympus, Melville, NY)
22-Fr Rigid cystoscope (Karl Storz, Tuttlingen, Germany)
Black tip grasper (Olympus)
4-Prong grasper (Olympus)
0.035-in. Bentson guidewire (Microvasive, Natick, MA)
0.035-in. Amplatz superstiff guidewire (Boston Scientific, Miami, FL)
0.035-in. Terumo Glidewire (Meditech, Watertown, MA)
0.035-in., 260-cm exchange wire (Cook, Bloomington, IN)
5-Fr Angiographic catheter (Microvasive)
7.1-Fr Angiographic catheter (Cook)
Tractmaster balloon with Amplatz sheath (Microvasive)
LeVeen syringe (Microvasive)
Kumpe Catheter (Cook)
Kaye tamponade balloon (Cook)
18 gage × 15 cm trocar needle (Cook)
Fascial incising needle (Cook)
22-Fr Foley catheter (Bard)
No. 10 blade

Retrograde Access

Flexible cystoscope (Olympus)
Small caliber flexible ureteroscope (ACMI, Storz, Olympus, or Wolf)
1.8-Fr coaxial (8/10) dilator (Microvasive)
0.035-in. Bentson guidewire (Microvasive)
0.035-in. Superstiff guidewire (Boston Scientific)
0.035-in. Terumo glide wire (Meditech)
55-cm, 12/14-Fr ureteral access sheath (Applied Medical, Rancho Santa Margarita, CA or Cook Urological, Spencer, IN)
35-cm, 12/14-Fr ureteral access sheath (Applied Medical, or Cook Urological)
10-Fr grasping forceps (Karl Storz)

TECHNIQUE

Percutaneous Nephrolithotomy

Prior to initiating the procedure informed consent for ureteroscopy and PCNL is obtained. Blood is obtained for type and crossmatch for 2 *u* of packed red blood cells. Typically, 1 g of cefazolin is administered before the procedure. If the clinical presentation is consistent with struvite calculi, broadened antimicrobial coverage (i.e., ampicillin and gentamicin) is administered. General endotrachial anesthesia is induced and

Fig. 2. Patient in prone split-leg position for combined retrograde and antegrade access with all pressure points padded and pneumatic compression boots in place. The phallus is positioned off the end of the table to facilitate retrograde access.

the patient is placed prone on the operative table with the legs on spreader bars (Fig. 2). The patient is secured with padded straps, chest rolls are placed, and the upper and lower extremities are padded to prevent pressure injuries. The flank and perineum are then prepared and draped in the standard manner.

Flexible prone cystoscopy is performed. Although it is initially challenging, prone cystoscopy rapidly becomes familiar to the urologist and the need for repositioning is eliminated. The ipsilateral ureteral orifice is identified and a Bentson guidewire is passed into the renal collecting system under fluoroscopic guidance. The flexible cystoscope is removed. A 1.8-Fr coaxial dilation and safety wire introducer sheath, commonly referred to as an 8/10-Fr dilator, is passed over the guidewire to the midureter. The 8/10-Fr dilator is used to gently dilate the ureteral orifice and to place an Amplatz super-stiff guidewire into the renal collecting system. With the Amplatz super-stiff wire in place, a 12/14-Fr ureteral access sheath is advanced to the UPJ under fluoroscopic guidance and the guidewire is removed. In males, a 55-cm access sheath is usually required, whereas in females, a 35-cm access sheath is usually sufficient to reach the ureteropelvic junction. The renal anatomy can then be well delineated fluoroscopically by injecting 5 to 10 mL of air through the ureteral access sheath to produce an air pyelogram (Fig. 3). The position of the external component of the ureteral access sheath should be noted at obturator removal. If the ureteral access sheath is caudad to the UPJ, the obturator and guidewire can be reinserted and the sheath can be gently advanced.

Once proper position for lower pole access has been determined fluoroscopically, renal access is achieved using a disposable 18 gage × 15 cm trocar needle. We routinely use only lower pole access in the majority of procedures to minimize pulmonary complications. While gaining percutaneous access, normal saline irrigation is infused at low pressure via the access sheath. Retrograde irrigation facilitates needle and guidewire access by dilating the target collecting system. The irrigation also prevents decompression

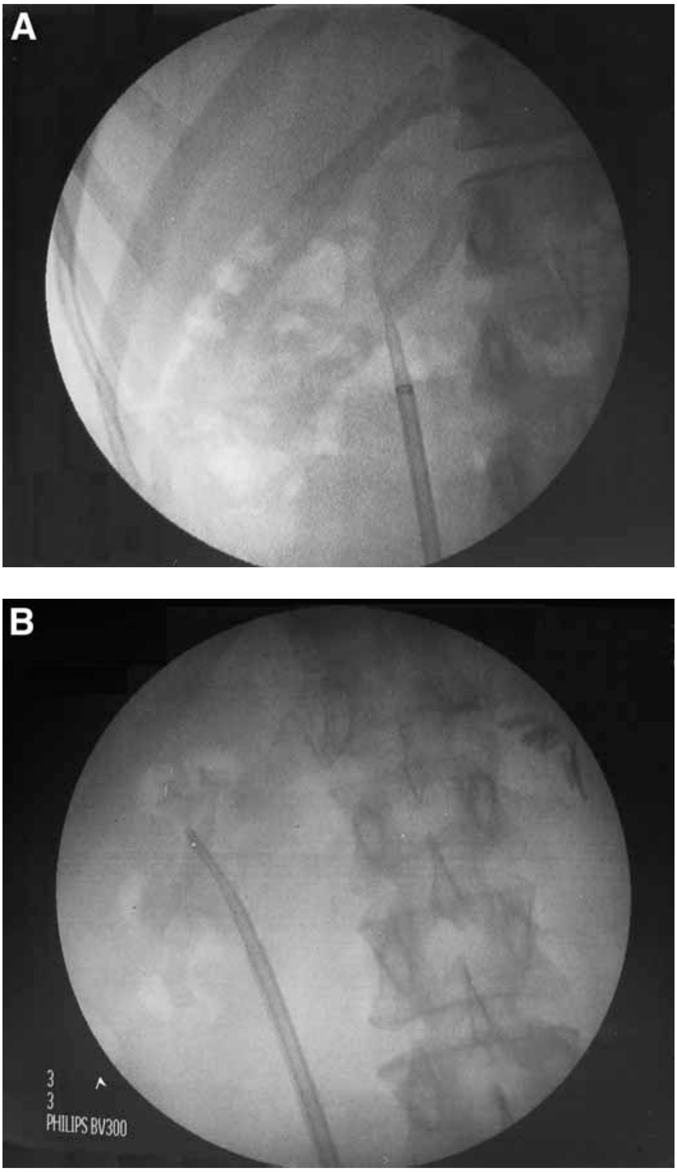

Fig. 3. (A) Fluoroscopic image of air pyelogram produced by injecting through the ureteral access sheath. **(B)** Air pyelogram surrounding a faintly radiopaque staghorn calculus in a different patient.

of the renal collecting system after the needle has been placed. Irrigation is continued while a guidewire is advanced into the collecting system to the ureteropelvic junction. Through a 5.5-Fr (40 cm) Kumpe access catheter, a Glidewire™ can usually be negotiated into and through the ureteral access sheath, providing through-and-through access. This maneuver is simplified by briefly pulling the distal end of the ureteral access sheath into the proximal ureter. In this manner the UPJ serves as a funnel, guiding the wire into the access sheath. After the wire is advanced into the access sheath it easily passes out of the urethra, where it is anchored with a hemostat clamp. The ureteral access sheath is then repositioned to the UPJ. The whole procedure can be completed with this single through-and-through wire in position.

A dilating balloon is advanced antegrade over the guidewire into the desired calyx and inflated to dilate the nephrostomy tract. Care should be taken to prevent dilation of the associated infundibulum. A 30-Fr working sheath is passed over the balloon into the calyx under fluoroscopic guidance and the balloon is removed. Rigid nephroscopy is then performed. The stone is ablated with the ultrasonic probe, which allows the simultaneous fragmentation and aspiration of stone fragments. Alternatively electrohydraulic, pneumatic, or holmium laser lithotripsy may be performed. A flexible cystoscope is often used to access upper and mid pole calices via the lower pole access tract. Using the combined antegrade and retrograde technique complete staghorn calculi may be ablated using a single lower pole access. Our operative staff has noted an increased irrigant requirement for PCNL performed with the ureteral access sheath. As such, we irrigate only with warmed irrigation fluid to prevent systemic hypothermia. If two light sources are available, simultaneous retrograde ureteroscopic laser or electrohydraulic stone ablation via the ureteral access sheath may expedite renal stone ablation. In addition, retrograde ureteroscopy can be used to fragment and grasp upper pole calculi. The ureteroscope is then used to present these stones to the rigid nephroscope for extraction or expedited fragmentation.

Before terminating the procedure, all renal calices are inspected with a flexible cystoscope through the nephrostomy tract. Calices that are not adequately examined with the flexible cystoscope may be accessed by retrograde ureteroscopy via the ureteral access sheath. Renal or ureteral drainage via a stent or nephrostomy tube is left according to surgeon preference. Postoperative chest X-ray is not required because lower pole renal access is not associated with pleural injury.

Stone protocol spiral computed tomography (CT) is performed on the first postoperative day. If residual stone fragments are identified, second-look PCNL is performed the next day in the standard manner. If residual stones are located in a position that may be difficult to access through the percutaneous tract (for example, a parallel calyx), the patient may be placed in the split-leg position and ureteroscopic access from below may again be used to facilitate stone extraction.

Follow-up evaluation includes spiral stone protocol CT or plain abdominal X-ray with CT 1 month after the procedure. Plain X-ray is performed only when the stones were known to be clearly visible on plain X-ray of the kidneys, ureters, and bladder. Patients with small residual fragments undergo repeat radiographic evaluation 3 months postoperatively.

Renal and Ureteral Stones Associated With Urinary Diversions

Preoperative measures including consent, availability of blood, and perioperative antibiotics are performed as described in the Subheading entitled "Percutaneous Nephrolithotomy" under "Techniques." After induction of general anesthesia the patient is positioned prone as previously described and then prepared and draped. The prone position is modified with bolsters such that adequate access to the urostomy can be achieved. Occasionally, retrograde access to the ureters can be achieved by inspection of the urinary diversion with a flexible cystoscope after the intravenous administration of indigo carmine or methylene blue. However, attempts to identify the ureteral orifices are frequently frustrating, and retrograde access cannot be reliably achieved. If preoperative imaging demonstrates that the affected kidney manifests hydronephrosis, we typically gain renal access in the operating room under C-arm fluoroscopic guidance. If the renal collecting system is decompressed, renal access is significantly more challenging and access is gained preoperatively in a radiology suite owing to the availability of superior imaging devices. After per-

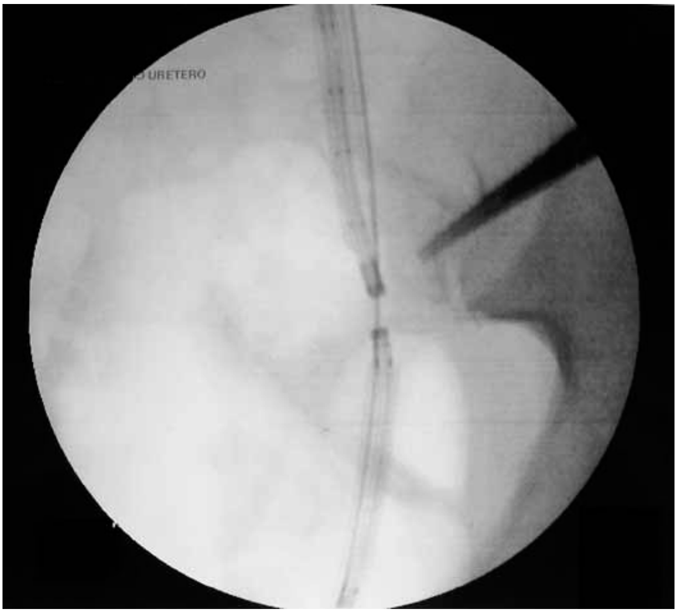

Fig. 4. Placement of access sheath in the ureter and percutaneous nephrostomy tract.

cutaneous renal access has been gained, a guidewire is negotiated past the stone, down the ureter, and into the urinary diversion for through-and-through access. Use of a Glidewire with a torquing device is helpful to negotiate the wire down the ureter.

With through-and-through access, retrograde endoscopy is easily performed. An access sheath may be gently passed in a retrograde manner. Care should be taken to avoid damage to the ureteroenteric anastomosis. If resistance is encountered, attempts to pass the access sheath should be aborted. If the stone burden is limited, retrograde access may suffice for expeditious stone clearance. However, if the stone burden is significant, the combined antegrade and retrograde approach can be very useful. If there is a large renal stone burden, dilation up to 30-Fr and placement of a large sheath as described in the Subheading entitled "Percutaneous Nephrolithotomy" under Techniques" may be performed. However, if only limited access to the kidney and ureter are required, we frequently advance an access sheath in an antegrade manner into the renal collecting system or ureter (Fig. 4). The access sheath generally passes easily and atraumatically antegrade into the renal collecting system after skin incision. Additionally, passage of an antegrade access sheath has not been associated with significant risk of hemorrhage. If antegrade and retrograde access sheaths are used, two surgical teams may work simultaneously to ablate renal and ureteral stones.

If the surgeon is confident that complete stone clearance has been achieved, a 7.1-Fr, single pigtail catheter is passed retrograde into the renal pelvis with the distal end protruding out of the stoma. If we suspect residual calculi that may require second-look flexible nephroscopy, a nephroureteral stent is deployed in an antegrade fashion.

Follow-up on the first postoperative day includes a spiral CT scan to evaluate for residual stone fragments. If the stones are radiopaque, follow-up imaging is performed with plain X-ray films as per the surgeon's preference.

Large Ureteral Stones

After appropriate preoperative and perioperative measures are taken as previously described, general endotracheal anesthesia induced. The patient is positioned into the prone split-leg position as previously indicated. Initial access is gained in a retrograde manner preferably using a 0.035-in. Terumo guidewire to bypass the ureteral calculus under fluoroscopic guidance. After the Glidewire has been passed, the 8/10 dilator or a 5-Fr ureteral catheter is used to exchanged the Glidewire for a more secure wire (Bentson or Amplatz super-stiff) into the renal collecting system. A ureteral access sheath is deployed to the level of the ureteral stone. Great care is taken not to traumatize the ureter by deploying the access sheath at the level of the stone. As these cases routinely require significant time in the ureter, it is imperative that the endoscopic field remains free of blood and debris as long as possible.

Antegrade access is then achieved as described earlier. Although we typically gain access to the lower pole for PCNL procedures, access for ureteral procedures for large calculi is gained through a middle or upper pole calyx depending on the individual renal anatomy. Access through the lower pole creates an acute angle for passage of the access sheath and instruments into the ureter and may limit the ability to access the large ureteral stone. Stone ablation can be performed using both the antegrade and retrograde routes individually or simultaneously. We prefer to use both access routes simultaneously with application of two endoscopic towers and two holmium lasers. However, if two lasers are not available, simultaneous ablation with the holmium laser and electrohydraulic lithotripsy has also been performed with success.

RESULTS

Percutaneous Nephrolithotomy

Our combined approach was applied initially to staghorn or large renal calculi. In this population, our initial experience involved nine patients *(7)*. In this series, the mean patient age was 46 years and mean body mass index was 31.4. In the study group there were six complete and three partial staghorn calculi. Mean stone size was 6.2 cm (range 5.5–8 cm) in greatest diameter. The primary stone composition was struvite in five cases, calcium oxalate monohydrate in two and uric acid in two.

Table 1 lists individual stone characteristics, operative parameters, hospital stay, and complications. Mean operative time for the primary procedure was 3.1 hours. Mean estimated blood loss was 290 mL and patients required an average of 33.2 mg of MSO_4 equivalents. Mean hospital stay was 3.2 days. There were no major and four minor (44%) complications. No patient required transfusion. One patient experienced venous bleeding from the percutaneous nephrostomy tract and required that a tamponade balloon be inflated intraoperatively for 20 minutes to control the bleeding. This patient experienced intercostal muscle injury during transport and required additional parenteral analgesics that extended the hospital stay for 1 day.

Another patient, who required significant analgesic medication postoperatively, had decreased oxygen saturation on pulse oximetry. Complete evaluation, including arterial blood gases, electrocardiography, chest CT angiography, and pulmonary function tests, revealed only atelectasis as the etiology of desaturation. Despite a 4-mm residual fragment, this patient did not undergo a second look procedure owing to the pulmonary complication. Two additional minor complications included transient paresthesia on the ipsilateral lateral thigh that resolved with observation within 1 month and an asymptomatic 4-cm perirenal hematoma that was not associated with a significant decrease in hematocrit.

Table 1
Operative and Postoperative Parameters[a]

Pt. no.	*Stone*	*Composition*	*Operative time (hours)*	*Estimated blood loss (mL)*	*Analgesic requirement ($MgMSO_4$ equivalents)*	*Second-look procedure*	*Hospital stay (days)*	*Residual stone fragments*	*Complications*
1	Complete	Uric acid	3.9	250	76	No	5	Single 4 mm.	Atelectasis
2	Complete	Struvite	2.3	200	24	Yes	3	None	None
3	Partial staghorn	Struvite	2.2	150	7.5	Yes	3	None	Ipsilateral leg paresthesia
4	Complete	Calcium oxalate monohydrate	4.3	750	43	Yes	4	Multiple lower pole	Pulled intercostal muscle
5	Complete	Uric acid	3.3	250	36	Yes	3	None	None
6	Partial	Struvite	1.8	200	22	Yes	3	None	None
7	Partial	Calcium oxalate monohydrate	4.1	350	28	Yes	3	None	4-cm perirenal hematoma
8	Complete	Struvite	3.4	250	36	Yes	3	None	None
9	Complete	Struvite	2.8	200	26	No	2	None	None

[a] Individual stone characteristics, operative parameters, hospital stay, and complications.

Complete stone clearance was achieved in seven of the nine patients (78%). A second-look procedure was not done in one case because of pulmonary complications. This patient had a 4-mm uric acid residual fragment and underwent oral alkalinization, which resulted in stone resolution at the 3-months follow-up evaluation. Another patient had multiple small fragments in the lower pole at 1 month of follow-up. This patient subsequently required ureteroscopic stone extraction for stone clearance.

Subsequently, as a result of the success and efficiency of the combined approach for very large calculi, we now apply the combined approach for all patients undergoing PCNL. Presently, we have performed 64 PCNL procedures using the combined technique, including 26 procedures for staghorn or partial staghorn calculi. Only five (7.8%) procedures required more than one percutaneous access for stone ablation. Each remaining case was completed with a single lower pole access. Three patients (4.6%) required blood transfusion. With CT scan performed at 3 months, 89% (57/64) of patients were stone-free.

Little published data is available regarding the combined antegrade and retrograde technique for patients with urinary diversions or large ureteral stones. However, the combined approach has been applied successfully by the authors and others for management of these challenging patients.

TIPS AND TRICKS

1. The use of an Amplatz super-stiff wire facilitated placement of the ureteral access sheath in either an antegrade or retrograde manner.
2. An air pyelogram is typically performed to delineate the renal anatomy. Instillation of air instead rather than contrast material provides an excellent pyelogram and avoids the use of contrast, which can mask stones. Combination of air and contrast simultaneously can also help delineate posterior calyces for puncture as air will rise posteriorly when the patient is in the prone position.
3. Use of retrograde irrigation is helpful in dilating the collecting system and keeping the collecting system dilated while gaining percutaneous access to the kidney.
4. When applying the combined approach for PCNL there is high fluid turnover. Application of warmed irrigant will help prevent patient hypothermia.
5. One milligram of intravenous glucagon and gentle retrograde pressure on the access sheath may be used to overcome muscle spasm encountered during passage of an access sheath. Never force the access sheath as ureteral injury may result.

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III

INCISIONAL THERAPY

10 Antegrade Endopyelotomy

Beng Jit Tan, MD, PhD, *Assaad El-Hakim,* MD,
Benjamin R. Lee, MD, *and Arthur D. Smith,* MD

CONTENTS

SUMMARY

The popularity of minimally invasive surgical techniques, such as endopyelotomy, has increased markedly among urologists in recent years. Antegrade endopyelotomy has become a well-established alternative to open operative pyeloplasty for management of both primary and secondary ureteropelvic junction obstruction (UPJO). Endopyelotomy results in significantly less morbidity, and should this technique fail, subsequent open pyeloplasty is still technically feasible. Although several variations of the technique have been described, the goal in all cases is to develop a full thickness incision though the obstructing proximal ureter that extends out to the peripyeloureteral fat and heals over an internal stent. Antegrade endopyelotomy is particularly valuable in the setting of upper tract stones that can then be managed simultaneously. Contraindications to antegrade endoscopic incision of the UPJ include a long stricture, sepsis, a large redundant renal pelvis, poor renal function, and the presence of crossing lower vessel as the cause of the UPJO. The role of percutaneous endopyelotomy in children remains undefined. Although successful results have been reported in infants, the relative morbidity and long-term success of open pyeloplasty in this age group are excellent, thus limiting the relative advantage of an endoscopic approach. However, there may be a role for endopyelotomy in older children and in those patients with secondary obstruction who have failed open

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surgery. Postoperatively, it is generally recommended that the stent be left in place for a minimum of 6 weeks following endoscopic incision of the UPJ though successful results have been reported with much shorter stenting intervals of a few days. Complications of the procedure include bleeding that may require blood transfusion, sepsis, injury to abdominal organs, and contrast allergic reactions. Overall, endopyelotomy is a safe and effective treatment for primary and secondary UPJO for most patients.

Key Words: Percutaneous endopyelotomy; antegrade endopyelotomy; ureteropelvic junction obstruction; endourology.

INTRODUCTION

The technique of antegrade endopyelotomy is based on principles elaborated early in the 20th century. Using a canine model in the 1950s, Oppenheimer and Hinman *(1)* were able to determine that the stented ureter healed not by contracture of the connective tissue but by smooth muscle regeneration. Later, Smart *(2)* reported his results on 20 consecutive patients treated by intubated ureterotomy.

Although the use of a percutaneous nephrostomy tube was first reported in 1955 *(3)*, it was not until 1976 that Fernström and Johansson modified a radiological technique that had been used to remove common bile duct stones *(4)*, and performed the first percutaneous pyelolithotomy *(5)*. Finally, Ramsay et al. *(6)* combined the technique of percutaneous surgery with Davis' principle of intubated ureterotomy and reported their series of elective percutaneous pyelolysis. Smith *(7)*, who coined the term "endopyelotomy," then popularized this technique in the United States in the 1980s and other investigators followed suit *(8)*. Although this procedure has been slightly modified since its initial description, including the duration and type of stent used and the type of cutting instrument, these really amount to minor variations on a well-established theme *(9–11)*.

INDICATIONS

Indications to intervene in a patient with ureteropelvic junction obstruction (UPJO) include the presence of symptoms, the progressive impairment of renal function, the development of upper tract stones or infection, and, rarely, hypertension. In such cases, the primary goal of intervention is relief of symptoms and preservation or improvement of renal function. Although an endourological approach is often selected as a first-line therapy, it is also specifically indicated for patients who have already failed open operative intervention *(12)*. In addition, a percutaneous approach ideally is suited for patients with pyelocaliceal stones, which can be managed simultaneously.

Contraindications to a percutaneous endopyelotomy include a long segment (>2 cm) of obstruction, active infection, or untreated coagulopathy. The impact of crossing vessels is controversial *(13–16)*. Although some surgeons believe the presence of such vessels portends a significantly poorer prognosis for an endopyelotomy, others do not consider the presence of crossing vessels as a contraindication to endopyelotomy. However, significant entanglement of the UPJ by crossing vessels can occasionally be identified and, when present, will generally reduce the success rate of any endourological approach. When such entanglement is suggested by intravenous or retrograde pyelography, it can be reliably proven using three-dimensional helical computed tomography (CT) *(17)*.

PROGNOSTIC FACTORS

Length of Stricture

Long avascular strictures, total obliteration of the UPJ, and severe periureteral fibrosis are clear contraindications to endourological procedures. Overall results have, in general, been unsatisfactory *(18–20)*. Patients with these features should be treated by open repair or laparoscopic surgery whenever possible.

Degree of Hydronephrosis

Initial experience has shown that a large size of the renal pelvis had a negative influence on the results of endopyelotomy *(21)*. Antegrade endopyelotomy may be favored in cases of massive hydronephrosis for technical reasons: the UPJ may be more easily identified, incised, and drained antegrade when the UPJ is massively hydronephrotic. Whereas endourological procedures can address intrinsic factors of obstruction, they cannot correct extrinsic factors or reduce the size of a massively dilated renal pelvis. The degree of hydronephrosis was of statistical significance when combined with the presence or absence of crossing vessels. The final success rate decreased from an overall success rate of 81 to 85 % for those with moderate hydronephrosis to 50 to 54% when high-grade hydronephrosis was present *(14,22,23)*.

Renal Function

Renal function is a significant prognostic factor. A high risk of failure has been reported when the function of the affected kidney is greatly impaired (*13,14,21,24,25*). Preoperative high-grade hydronephrosis, as well as poor renal function, are significant causes of failure *(14)*. Unfortunately, the isolated impact of this factor is difficult to assess because no prospective data have been collected. In most series, preoperative function of the involved kidney has been systematically assessed only recently or in selected cases, and its influence cannot be dissociated from that of the degree of hydronephrosis. Nevertheless, Gupta et al. *(14)* reported that of the 205 patients with known renal function who underwent endopyelotomy at a single institution, success rates for endopyelotomy were 92, 80, and 54% for good renal function (differential renal function greater than 40%), moderate renal function (differential renal function between 25 and 40%), and poor renal function (differential renal function less than 25%), respectively. Nephrectomy is the treatment of choice if the differential renal function falls below 15%.

Primary vs Secondary UPJO

Both primary and secondary cases of UPJO can be successfully treated endoscopically. Cumulative success rates for endopyelotomy of 62 to 94% rate for primary obstruction and 67 to 100% for secondary obstruction have been achieved *(14,26–34)*. Although laparoscopic pyeloplasty has yielded higher success rates of 92 to 98% for primary UPJO and 83 to 89% for secondary obstruction *(35–37),* it is associated with other problems.

Age and Sex of the Patient and the Side of Obstruction

Currently, the role of endopyelotomy remains unclear in children age 6 or less, and there is only a limited reported series in the pediatric population *(19,38–44)*. Many younger children have long proximal ureteral strictures, especially in the proximal one-third of the ureter. In addition, their ureters are of small caliber requiring small-sized stents. Both these indications make endopyelotomy challenging in young children. In addition, narrow lumen stents in young children can easily be obstructed. In these children, open pyeloplasty is still the preferred procedure owing to its consistently superior results, especially in primary cases. In secondary cases of UPJO, such as failures of open pyeloplasty, endopyelotomy can be safe and effective. With further refinements and miniaturization of equipment, it ultimately might become a preferred option *(38,41,43)*.

In elderly patients, endopyelotomy offers results comparable with those in the adult group *(29,45)*. Not surprisingly, neither the sex of the patient nor the side of the obstruction influences the outcome *(14)*.

Crossing Vessels

The significance of vessels crossing the UPJ remains a matter of debate and their role in the pathogenesis of the obstruction, as well as their influence on the results of various endourological procedures, is controversial *(13–15,18,22–23,46)*. The presence of crossing vessels does not necessarily cause UPJO. However, significant entanglement of the UPJ by crossing vessels can occasionally be identified and, recently, spiral CT *(47,48)* and endoluminal ultrasonography *(49,50)* have been used to identify crossing vessels. In cases when the crossing vessel is the primary cause of UPJO, it has been found to reduce the success rate of endopyelotomy. In such cases, laparoscopic or open dismembered pyeloplasty have yielded a success rate of 97% *(50,51)*. An extensive historical review addressing these issues has been published recently *(23)*.

INSTRUMENTS AND EQUIPMENT

The recommended equipment and instruments for antegrade endopyelotomy include the following (*See* Fig. 1):

Nephroscope, 0° lens with 26-Fr sheath.
Cystoscopes, 30 and 70° lenses.
Urethrotome or transurethral reaction resectoscope.
Amplatz dilator set (8–30-Fr dilators and sheaths) or balloon dilation set.
0.038-in. J-tip guidewire.
0.038-in. stiff torque wire.
18-Gage access needle.
6-Fr open ended ureteral catheter.
14/7-Fr endopyelotomy stent.
Fluoroscopic X-ray.
Nephroscope graspers.
Endopyelotomy knife (cold knife, hook-knife, half moon, or straight).
Hypaque, diluted 30%.

TECHNIQUE

Patient Selection and Preparation

The preoperative evaluation should include a search for any concomitant medical condition impacting on the risk of anesthesia. As in any elective operative procedure, a complete history and physical examination should be performed. The patient should be a good candidate for general or regional anesthesia. Standard blood studies should include

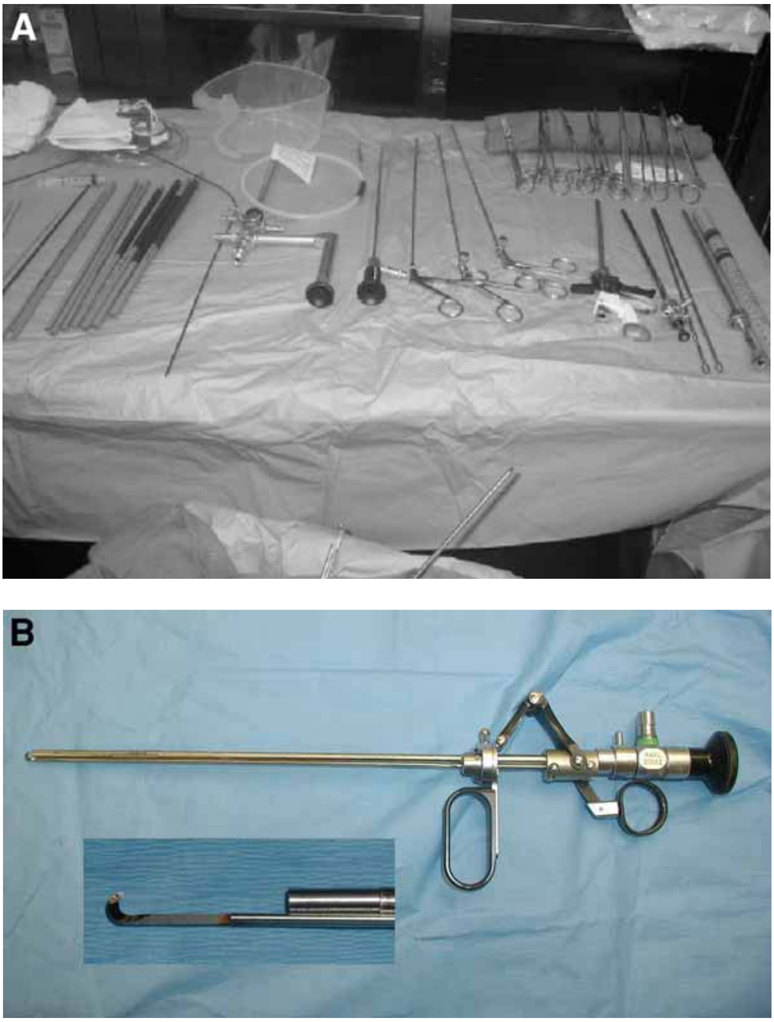

Fig. 1. (A) Percutaneous endopyelotomy table setup. Standard procedure setup includes nephroscope, Amplatz dilator set, 18-gage access needle, J-tip and stiff guidewire, nephroscope graspers, and endopyelotomy knife. **(B)** Standard endopyelotome with close-up view of hook blade (inset).

a prothrombin and partial thromboplastin time if the history is suggestive of a bleeding disorder. Because there is a risk of bleeding that would require blood transfusion, the patient's blood should also be typed and screened. Any urinary tract infection should be treated and sterile urine should be ensured at the time of definitive intervention. If upper urinary tract infection cannot be cleared because of obstruction, temporization should be accomplished using internal stenting or percutaneous nephrostomy drainage alone.

In many patients, the diagnosis is obvious when the patient presents with flank pain (often aggravated by fluid intake) and when urography reveals obstruction at the UPJ. In such circumstances, other diagnostic measures are not indicated. In equivocal cases, diuretic renograms, diuretic urograms, or Whitaker pressure-perfusion tests are obtained. Although theoretically any UPJO could be treated endoscopically, such treatment is best when the UPJ is relatively dependent and there are no gross anatomic abnormalities. The patient's anatomy should be such that access is practical and safe.

When counseling a patient, the surgeon should outline the open operative procedure and other endourological treatment options, each of which has its own advantages and disadvantages, so that the patient can provide informed consent. The patient should be counseled regarding the risks and benefits of the procedure, including the fact that the success rate of any endourological approach, such as percutaneous endopyelotomy, will be less than that of standard open operative intervention. In advising patients, it is important to consider factors such as age, sex, associated pathology, e.g., stones in the renal pelvis, previous renal surgery, the availability of equipment and resources, whether or not a nephrostomy tube is already in position, the surgeon's experience, and cost *(52)*.

Technique, Helpful Tips, and Tricks

Percutaneous access to the urinary tract has been described in detail in Chapter 3. Therefore, only the important steps and helpful tips for achieving percutaneous access will be highlighted in this section.

PATIENT POSITIONING

All patients undergoing any endopyelotomy procedure are given a general anesthetic. Complete evaluation of the renal collecting system is imperative prior to definitive percutaneous puncture for access tract creation. The patient is placed in a lithotomy position. Cystoscopy and retrograde urography is performed to delineate the ureteral anatomy distal to the obstruction, the exact location, degree, and, sometimes, length of the obstruction. A 6-Fr ureteral catheter is left in place to allow retrograde injection of contrast. A 16-Fr Foley catheter is inserted and attached to a drainage bag concurrent with the 6-Fr catheter.

The patient is then positioned prone to allow access to the posterior flank. All bony prominences are padded and protected. The chest and abdomen are elevated on two rolls that extend from the shoulder to the hip to reduce resistance to breathing (Fig. 2).

TECHNIQUE FOR CREATING ACCESS TRACTS

The percutaneous nephrostomy is created by way of an upper or middle calyx with the aid of C-arm fluoroscopy. Thorough evaluation of the renal collecting system anatomy is essential before definitive percutaneous puncture for access tract creation. A posterolateral transparenchymal puncture minimizes the chance of injury to the major renal vessels. The ideal percutaneous access tract is located in the posterior axillary line, via the posterior calyx because major vessels surrounding the pelvis can be avoided (Fig. 3). The ideal tract courses through the posterior lateral flank, in a direct line with the middle of the renal pelvis, through the renal parenchyma, into the tip of a posterolateral calyx, and into the renal pelvis. The transparenchymal portion of the tract stabilizes the nephrostomy tube and provides a seal around the tube, preventing urine extravasation into the perinephric space. Generally, a midposterior or superolateral calix is chosen, although occasionally, an inferolateral calix may be used *(53)*. A target midpole calyx or upper pole calyx is optimal over a lower pole initial access in order to allow subsequent instrument maneuverability without tearing renal parenchyma.

The skin insertion site may be placed more lateral in obese patients in whom the lateral segment of the colon is displaced ventrally. In patients with abnormal abdominal anatomy, such as following jejunal–ilial bypass or horseshoe kidneys, the position of the kidney rel-

Fig. 2. Correct patient positioning for endopyelotomy. All bony prominences are padded and protected. The chest and abdomen are elevated on two rolls that extend from the shoulder to the hip to reduce resistance to breathing. Great care is taken to pad all joints. Additionally, bolsters can be used under the chest to elevate the upper torso.

ative to the colon may be distorted. These patients are at higher risk for a transcolonic needle placement. For horseshoe kidneys, the access tract is virtually perpendicular to the plane of the back, in a paraspinous, medial position. One must take into consideration as well that a more medial insertion site is uncomfortable for the patient who invariably lies supine after the procedure, and can lead to compression and kinking of the external portion of the nephrostomy tube into the back. A subcostal approach lowers the risk of pneumothorax. Puncture of anterior calices is required only if access to the posterior calyces is not possible. Access from an anterior calices to the renal pelvis is very difficult because of the inherent difficulty in directing a wire backwards. Direct puncture of the renal pelvis should also be avoided, owing to the significant risk of injury to the posterior branch of the renal artery.

C-arm fluoroscopy is used to help localize the target calyx, using a triangulation method of two different views. A Seldinger-technique based access is employed to gain access into the renal collecting system. Details of obtaining percutaneous access to the urinary tract have been described in detail in Chapter 3. Dilation of the tract is performed using Amplatz dilators or balloon dilation. Normal saline is the irrigant of choice because it prevents hyponatremia that can result from intravascular absorption when hyposmotic solutions are used. Care is taken to avoid inadvertent over advancement of instruments or the access sheath, as this will likely cause a laceration of a renal infundibulum or renal pelvis.

Once the UPJ has been bridged with a 0.038-in. super-stiff guidewire (the guidewire is in position from the flank through the urethral meatus), an 8-Fr Teflon catheter is advanced

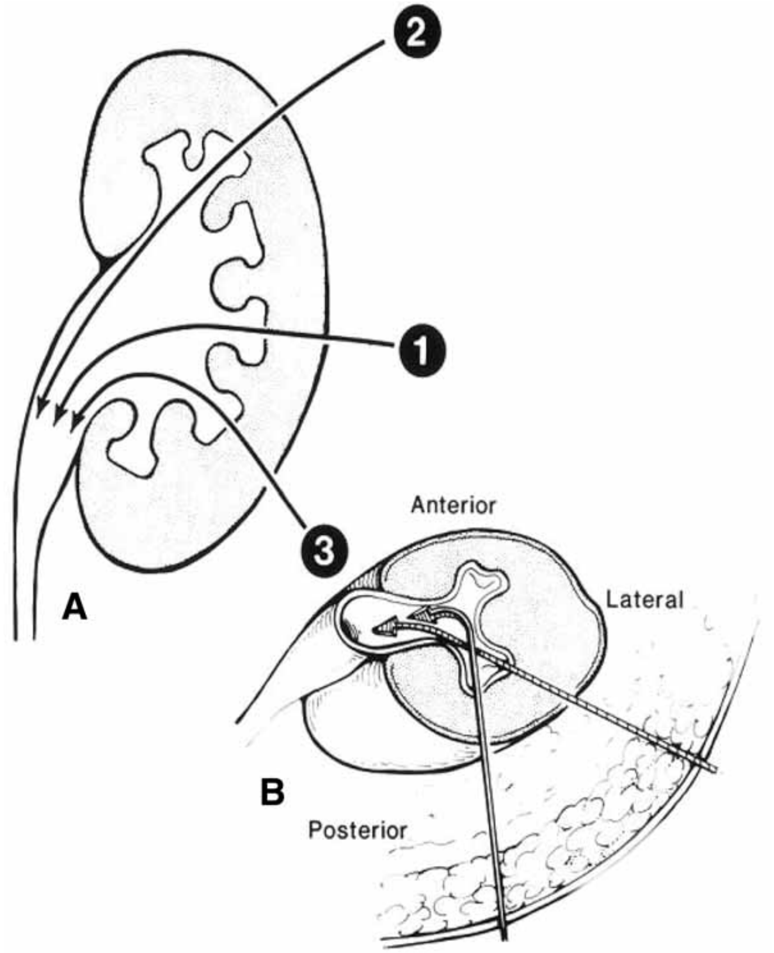

Fig. 3. Access tract placement. (**A**) Tract 1 is the preferred route. Tract 2 (through the superior calyx) is also possible, although it may result in chest complications. Tract 3 (through an inferior calyx) is not an adequate route for this procedure because it will not provide good visibility of the ureteropelvic junction (UPJ). (**B**) Kidney in supine orientation. To achieve a smooth curve to the UPJ, the approach should be posterolateral (solid line) and not directly posterior (dotted line).

across the UPJ and into the ureter. Under fluoroscopic guidance, an 18-Fr dilator is advanced down the UPJ over the 8-Fr catheter in order to dilate the UPJ to allow introduction of the incising device. Alternatively, an 12-Fr ureteral dilating balloon should be used for this rather than a larger 15- to 18-Fr balloon, as larger balloons may tear the UPJ.

ENDOPYELOTOMY TECHNIQUES

Several devices have been used to incise the UPJ including laser incision, cold knives, and semilunar or hook knives.

An urethrotome with a hook-shaped cold knife (Karl Storz Endoscopy-America) or a hookknife is passed through a rigid nephroscope (Olympus Medical Systems, Olympus America) over the guidewire (Fig. 4). Because of the anatomic findings described by Sampaio *(15,53–55)* regarding the location of crossing vessels, the incision is now made posterolaterally. The posterolateral position is determined by orienting the knife with the

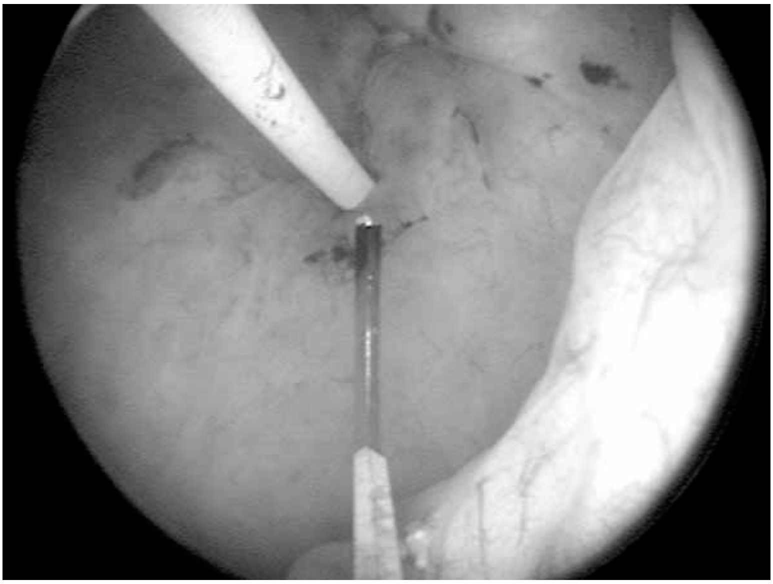

Fig. 4. Guidewire runs from the flank through the urethral meatus and bridging the ureteropelvic junction (UPJ). Photo showing a hook-shaped cold knife approaching the UPJ to enter the ureter.

posterolateral position of the patient's flank while referencing the position of the kidney on intravenous pyelography or CT. This is usually easy to perform and is complicated only when kidneys are malrotated. However, in cases when the ureter inserts into the renal pelvis on the anterior or posterior wall, the incision should instead marsupialize the proximal ureter into the renal pelvis such that an anterior or posterior incision may be required. When such incisions are made under direct vision, any crossing vessel can be directly visualized and avoided. When the patient has undergone previous UPJ repair, the previous surgical record should be consulted because the position of the UPJ relative to the vascular supply of the kidney could have changed. The knife should slide through the UPJ yielding a clean cut. The incision should be extended down the ureter for approx 1 cm beyond the area of obstruction and should be continued laterally up into the renal pelvis for 1 to 2 cm. The incision is performed under direct vision so that the operator can identify the exact location of the cut and identify and avoid extrapelvic structures such as aberrant or polar vessels. In contrast to blind techniques in which the location of a repeat cut (if necessary) cannot be exactly determined, the antegrade endopyelotomy incision can be lengthened with precision.

The UPJO is incised full thickness in a posterolateral position until the periureteral fat or wispy retroperitoneal tissue is visible and the UPJ appears wide open (Fig. 5). In patients undergoing reoperation, previous scarring can make determining the proper depth of the incision difficult. Direct vision permits avoidance of crossing a vessel at this point. The incision must be extensive enough that one is able to look into the proximal ureter (Fig. 6).

A holmium laser can be used in a similar manner to incise the UPJ. The 365-mm fiber is introduced through the 8-Fr ureteral catheter placed in the nephroscope and, under direct vision, the UPJ is incised (Fig. 7). Another alternative is cutting the UPJ with scissors. A small full-thickness puncture is made into the renal pelvis in a posterolateral position, as far as 1 cm away from the UPJ, with the scissors in the closed position. Then, the scissors are opened under constant visual control until the peripelvic space is reached (Fig.

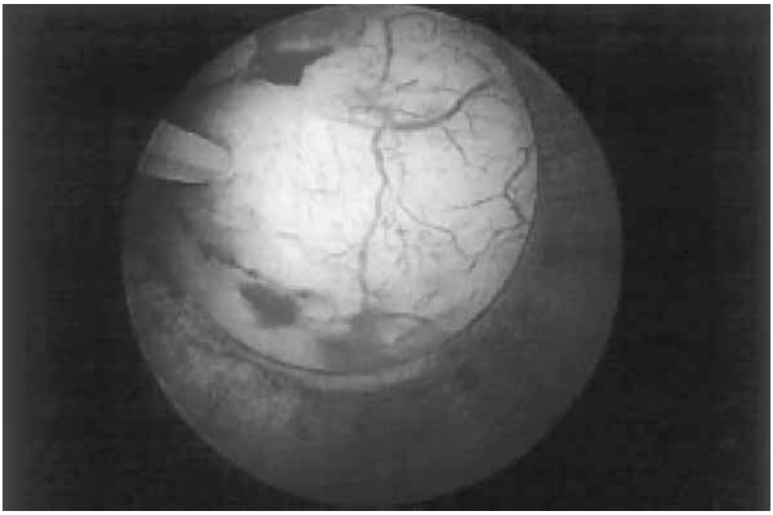

Fig. 5. Hook-shaped cold knife previously introduced in the proximal ureter is withdrawn in a retrograde direction, cutting the ureteropelvic junction.

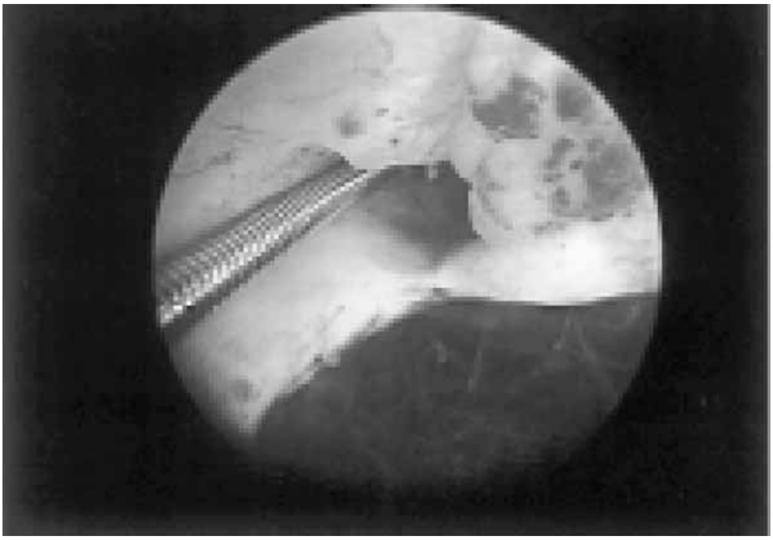

Fig. 6. Full thickness incision has been carried out through the muscle into the surrounding periurethral fat as seen in the inferior area of the picture. The incision should be extensive enough that one is able to look into the proximal ureter with the guidewire inside. The periuretral space should be seen through the incision.

Fig. 7. *(Opposite Page)* Technique of incision with laser: **(A)** Using the guidewire as a marker, the Laser fiber approaches the ureteropelvic junction (UPJ) posterolaterally. **(B)** The 365-mm fiber is introduced through a conventional stent pusher placed in the nephroscope. Under direct vision, the UPJ is incised in the posterolateral position, showing the anteromedial surface of the ureter with the guidewire inside. **(C)** The fiber reaches the peripelvic space, permitting observation and coagulation of bleeding vessels. The external face of the ureteral wall is exposed.

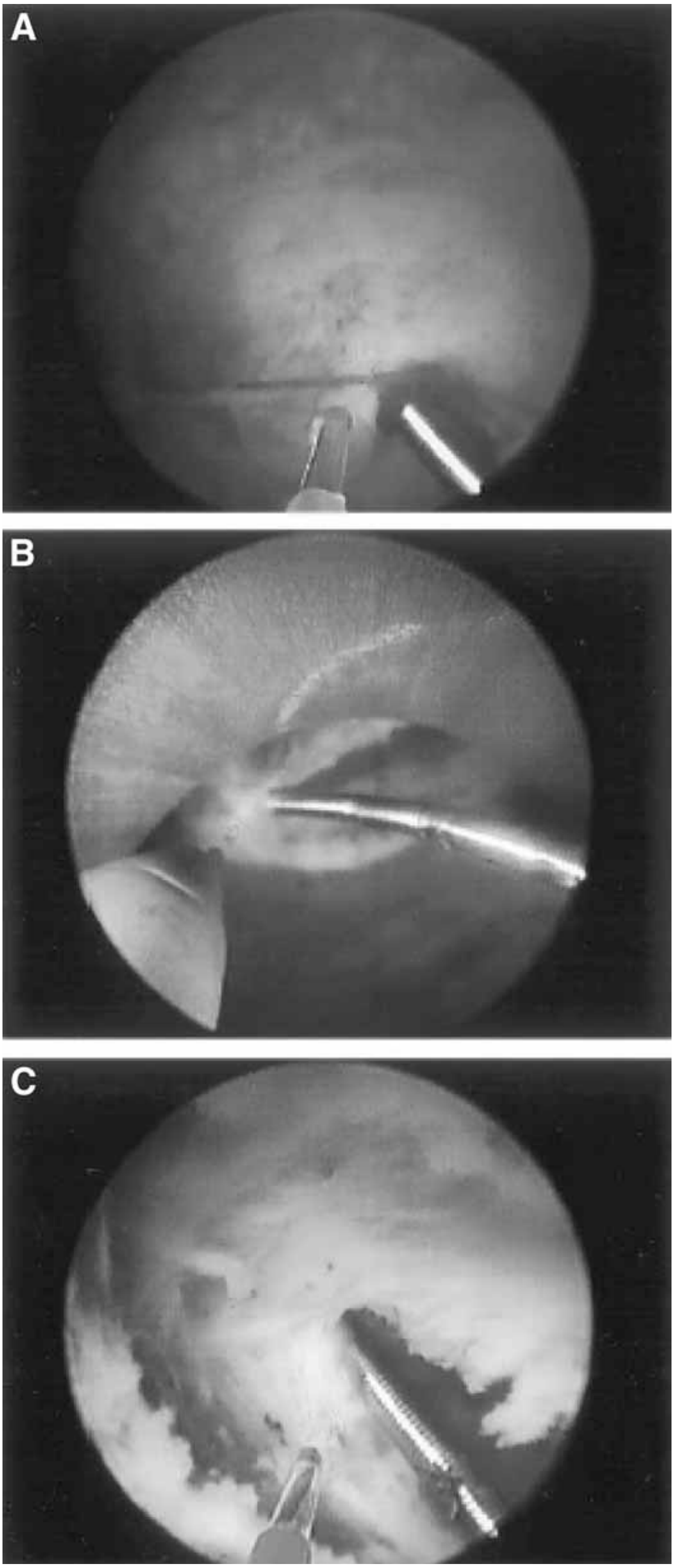
A
B
C

Fig. 8. Endopyelotomy with scissors. After ensuring that the ureteropelvic junction (UPJ) is bridged with a guidewire, a small, full-thickness puncture is made into the renal pelvis in a posterolateral position, as far as 1 cm away from the UPJ.

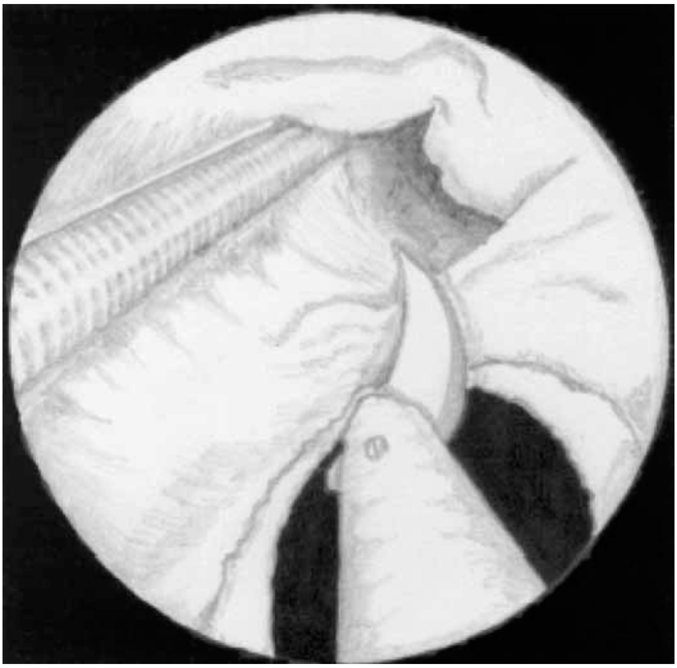

Fig. 9. The scissors complete the incision of the pelvic wall starting at the puncture and running through the ureteropelvic junction.

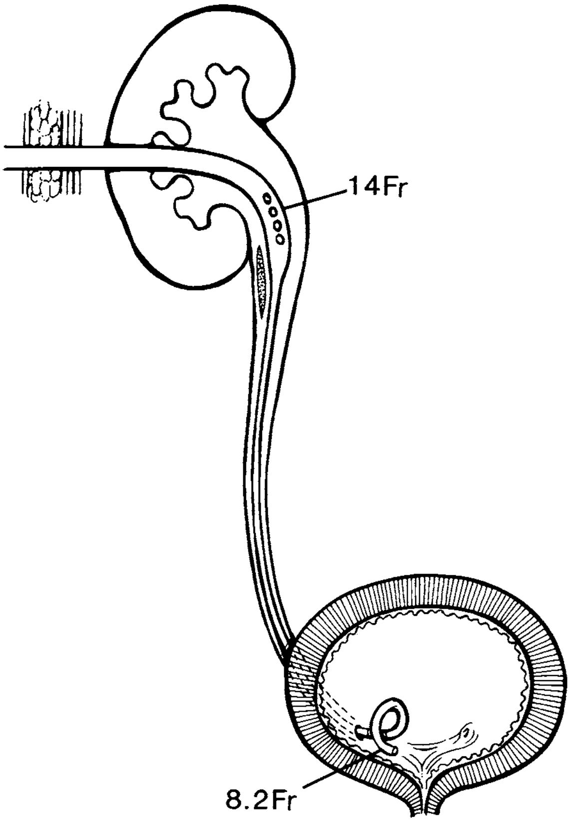

Fig. 10. The 14/8.2-Fr endopyelotomy stent is placed with the 14-Fr upper end positioned across the ureteropelvic junction (UPJ) and the drainage holes positioned above the UPJ. The 8.2-Fr distal coil is in the bladder.

8). The incision of the pelvic wall is completed with the scissors, running through the UPJ, keeping any anomalous vessel under visual control and avoiding bleeding (Fig. 9). The window opening in the pelvic wall shows the ureter inserted anteriorly and medially into the renal pelvis and bridged by the guidewire. The incision of the ureteral wall is made while the scissors progress distally into the ureter. The incision must be extensive enough that one is able to look into the proximal ureter. Incision into the renal pelvis opening the retroperitoneum may allow observation of any crossing vessels.

An endopyelotomy stent is then placed. This stent is constructed of polyurethane and is 14 Fr at the UPJ and 8.2 Fr distally, with a single coil at the distal end. The endopyelotomy stent is placed in an antegrade fashion over the guidewire, with the large-diameter end of the stent positioned across the UPJ and the drainage holes positioned above the UPJ and the distal coil in the bladder (Fig. 10). Alternatively, the Smith Universal stent is placed (Fig. 11). This is a uniform 8-Fr stent along its length. The proximal end drains externally or is capped for internal drainage. It is composed of silicone rubber and is placed with the aid of a Teflon peel-away introducer. The most important feature is that access to the kidney is always available if required. In some cases, especially when the patient has not been prestented, passage of this large-caliber stent may be difficult. In these instances, a standard 8-Fr internal stent can be used without compromising the ultimate outcome. The other class of stent is the tapered endoureterotomy

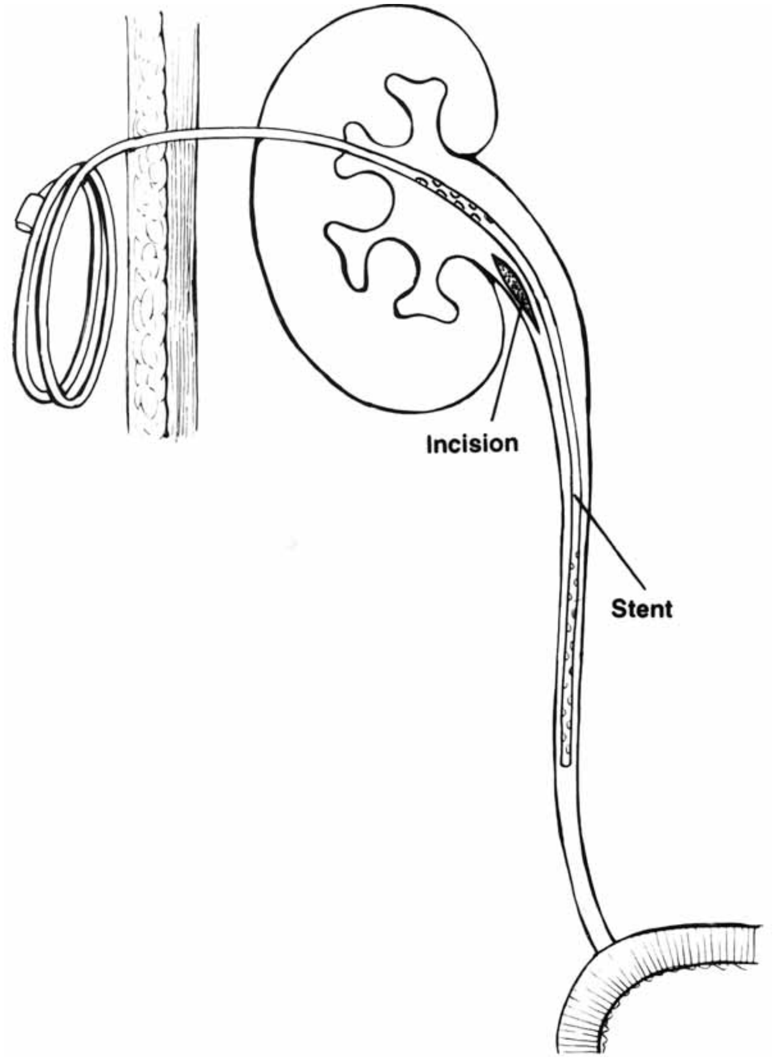

Fig. 11. The Smith Universal stent is a uniform 8 Fr along its length. The proximal end drains externally or is capped for internal drainage. The distal end was originally passed to the level of the pelvic brim, but ureteral stricture formation necessitated passage into the bladder. It is composed of silicone rubber and is placed with the aid of a Teflon peel-away introducer.

stent, which requires a Council catheter placement as a nephrostomy tube for 48 hours. Although this stent has been used safely in many patients, a major concern has always been that the stent is inaccessible if it becomes obstructed after the nephrostomy tube is removed and that the proximal coil can migrate outside the endopyelotomy site and into the retroperitoneum. Once proper positioning of the stent is determined fluoroscopically, any remaining safety wires are withdrawn. A Foley catheter is placed and nephrostomy tube secured to the skin to prevent inadvertent dislodgement.

All patients undergoing endopyelotomy should have a stent placed. The type of stent does not influence the outcome *(14)*. The size of the stent, *(29,32,56)* the length of time it should remain in place *(1,57,58)*, and the type of stent material are issues that remain unanswered. In a nonrandomized, retrospective study, Danuser and et al. *(32)* reported superior short-term (83 vs 94%, respectively) and long-term (71 and 93%, respectively) success rates in patients in whom a modified 27/14/8.2-Fr nephroureteral stent was placed compared to patients who had the standard, 14/8.2-Fr graduated. Similarly, Hwang and co-workers *(56)*, in an earlier study, reported they had better overall success rates with the 14/7 endopyelotomy stent compared to the 6-Fr internal ureteral stent (93.3 and 84%, respectively). However, the difference in success rate was not statistically significant. Accommodating these large diameter stents often require placing a double-J stent to dilate the ureter for several days in order to decrease the difficulty of inserting the larger endopyelotomy stent down the ureter or, as Danuser and co-workers have done, making a 3 to 5 cm incision that extended well into the normal renal pelvis and ureter. Some feel that a stent serves as a mold around which healing takes place and that the largest possible diameter stent is preferable to induce formation of a sufficient caliber lumen but without causing ischemia. Others believe that the stent acts as a scaffold to orient regenerating muscle fibers and, therefore, a smaller caliber stent is just as effective. Several retrospective, nonrandomized series have demonstrated comparable success rates using standard size stents. Stent size has been considered an insignificant factor based on two animal studies that showed no significant difference in success using 7- or 14-Fr and 7- or 12-Fr stents, respectively *(10,59)* as well as in clinical studies *(14,27,29)*. Thus, only a prospective, randomized study comparing large diameter stents to standard caliber stents, using universally accepted criteria for obstruction, will answer the question of optimal stent size after endopyelotomy definitively.

Most urologists leave the stent in place for 6 weeks based on initial animal studies showing 90% regeneration of smooth muscle and muscular continuity within 6 to 7 weeks of stenting *(1,57,60,61)*. The conclusion was that stenting is important until the epithelium regrowth pattern is established. However, using a porcine model, Kerbl et al. *(11)* showed that stenting beyond 1 week resulted in lower healing scores and inflammation associated with a chronic indwelling stent is a source of late fibrosis. Several clinical studies have reported that stents can be removed earlier without untoward sequelae *(58,63,63)*. For example, in a prospective, randomized trial, Mandhani et al. *(58)* found that a 2-weeks duration of stenting is sufficient duration to allow functional restoration across the UPJ after endopyelotomy. They suggested that a stent is important as long as epithelium regrowth occurs. However, after this point a stent induces greater inflammation and fibrosis. In addition, short-stent duration helps decrease morbidity including pain, bladder irritation, and urinary tract infection. However more prospective, randomized studies comparing duration of stenting are needed to definitively answer the question of optimal stent duration after endopyelotomy.

In a modification to the classical endopyelotomy approach as described above, the ureteral stent is placed prior to antegrade endopyelotomy. Again, percutaneous access is established. A wire traverses the UPJ percutaneously and passes antegrade across the ureterovesical junction into the bladder. It is advantageous to pass a stent before performing the actual endopyelotomy incision. The purpose of this action is twofold. First, having the stent in place at the outset of the procedure obviates concern about avulsing the UPJ during placement of a stent after the UPJ has already been incised. Second, placement of the stent before the incision serves to better define the UPJ, allowing a more precise incision. The UPJ and proximal ureter can often be seen to bulge into the renal pelvis, so that the subsequent endopyelotomy is equivalent to a ureteral meatotomy at the ureterovesical junction. With the stent in place, an acorn tip Bugbee electrode or, alternatively, a Collins knife on a 24-Fr resectoscope is used to marsupialize the proximal ureter into the renal pelvis. In the setting of a high insertion, the incision can often be extended

Fig. 12. Nephrostography performed 48 hours after endopyelotomy demonstrating that the mucosal bridge is already healed and no extravastion of urine is evident.

all the way to the dependent portion of the renal pelvis under direct vision, bridging the gap between the lateral wall of the ureter and the medial wall of the pelvis across the periureteral and peripelvic fat. When a cautery incision is performed, the stent will insulate the remainder of the ureter from thermal injury; however, care must be taken not to have a noninsulated safety wire in place because it can act to transmit the current if touched by an active electrode. Once the incision is complete, the stent is already in place, and the procedure is essentially complete. Nephrostomy tube drainage is instituted for 24 to 48 hours.

Percutaneous management is ideal when the UPJO is associated with upper tract stone disease because the stones can be managed concomitantly. In such cases, percutaneous access is established with a wire across the UPJ. The stone should be removed before the endopyelotomy so that stone fragments do not migrate into the peripyeloureteral tissue.

POSTOPERATIVE CARE

Although "tubeless" percutaneous endourological procedures have been reported *(64–70)*, most endourologists prefer to leave a nephrostomy tube indwelling for 24 to 48 hours, at which time a nephrostogram is performed to ensure proper positioning of a patent stent. Nephrostogram is performed either through the endopyelotomy stent or the Council catheter used as a nephrostomy tube (Fig. 12). If the endopyelotomy stent is in a good position and no extravasation is evident, the stent is capped, and the patient is discharged from the hospital. The duration of stenting is 6 weeks on the basis of the study of Oppenheimer and Hinman *(1)*, which showed that a 6-week period is necessary for regeneration of the muscular wall of the ureter. An excretory urogram is obtained 1 month after stent removal. A successful result means that the patient is symptom free and has improved urographic findings.

Most patients can return to average levels of activity after 5 to 7 days. Patients return in 6 weeks for cystoscopic stent removal. Strenuous activity should be avoided for 8 to 10 days following the procedure. The optimal time for postendopyelotomy stenting has not been determined, although 4 to 6 weeks seems adequate. It is advisable to give daily prophylactic antibiotics while the stent is indwelling. Once the stent is removed, the patient is seen 1 month later for clinical follow-up and radiographic evaluation. This follow-up generally includes an intravenous pyelogram with or without a diuretic renogram. If the patient remains asymptomatic and the degree of calicectasis is diminished from preoperative studies, or if the $T_{1/2}$ of a diuretic renogram is in a nonobstructing range, re-evaluation is performed at 6- and then 12-month intervals for at least 2 years.

Persistent obstruction is unusual in the early postoperative period because of the internal stent. Occasionally, the stent can be obstructed from blood clots, and continued nephrostomy drainage for a few extra days will almost always allow the problem to resolve spontaneously with lysis of any clots. In rare instances when stent obstruction persists, the stent can be changed over a wire in an antegrade or retrograde fashion, taking care not to lose access across the UPJ.

RESULTS

The immediate and long-term results of percutaneous endopyelotomy are well established. Clearly, percutaneous endopyelotomy compares favorably with open operative pyeloplasty in terms of postoperative pain, the length of hospital stay, and the return to prehospitalization activities *(8,71–73)*. Although these outcomes are important, the goal of any intervention for UPJO should be relief of obstruction as determined by the relief (if not improvement) of symptoms and stabilization, in ipsilateral renal function. What actually constitutes a good result is controversial. Although some clinicians suggest that objective measures, such as renograms, are necessary, others maintain that an improved urogram and relief of symptoms are sufficient.

Antegrade endopyelotomy is a proven technique performed worldwide by a multitude of surgeons with a good success rate ranging between 57 and 100%, depending on the size of the series, length of follow-up, experience of the surgeon and whether or not the UPJ was a primary or secondary obstruction *(6,12,14,22,25,26,29,74)*. The mean success rate is 81%. Currently, success rates approaching 85 to 90% are reported at experienced centers, with little difference in outcome noted in patients undergoing the procedure for primary vs secondary UPJO *(13,18,29,73)*. Although one would expect that the treatment of failed previous repairs would be less successful, the literature suggests that the results in these patients are approximately equal to those in primary UPJO.

The main advantages of this technique are a small incision, minimal morbidity, good postoperative drainage of the kidney, and that the surgeon is able to visualize the obstruction to avoid incising a crossing vessel *(16,19,34,75)*. Of all the techniques of endopyelotomy, the antegrade approach has by far the largest series with the longest follow-up. Although the results for antegrade endopyelotomy are not as impressive as those from open pyeloplasty, antegrade endopyelotomy results in significantly less morbidity, and should this technique fail, subsequent open or laparoscopic pyeloplasty is still technically feasible *(18,25)*.

One of the major criticisms of antegrade endopyelotomy is the inability to move a crossing vessel. There has been a recent resurgence in the debate of the role of the crossing vessel in UPJO with the increased popularity of endopyelotomy *(13–15,46,54,55)*. However, the mere presence of a crossing vessel close to the UPJ does not mean that it is the primary cause of the UPJO. Sampaio and Favorito *(54,55)* showed that 71% of kidneys will have a vessel (artery or vein) crossing within 1.5 cm of the UPJ; most (91%) are located anterior to the UPJ and the rest are posterior. Rarely are these vessels located posterolateral to the UPJ; and hence the UPJ is usually cut posterolaterally *(54)*. Most of these vessels are not aberrant arteries but rather arise from the aorta or main renal artery and can supply up to half the renal parenchyma.

When crossing vessels are the primary cause of the UPJO, they have a statistically significant negative influence on the outcome of endoureteropyelotomy *(28,73)*. In a prospective study, Van Cangh et al. *(22)* demonstrated that the presence of a crossing vessel on intra-arterial digital subtraction angiography predicts a lower success rate of percutaneous antegrade endopyelotomy. In 26 of 67 (39%) patients who underwent endoureteropyelotomy, vessels were demonstrated in close contact with the site of the obstruction. The degree of hydronephrosis was also a negative factor but was of lesser significance. The influence of the combination of both factors on final outcome was highly significant, with a 95% success rate attained when there was no crossing vessel and only a moderate degree of hydronephrosis compared with a 39% success rate when a crossing vessel was associated with high-grade hydronephrosis (odds ratio, 28.29; 95% confidence interval, 24.91 to 31.66; $p < 0.001$).

Van Cangh and co-workers *(23)* subsequently reported on the preoperative vascular anatomy in 86 patients with a follow-up extending more than 12 years (mean, 6.5 years). The importance of the previously mentioned prognostic factors was confirmed. Significant size of crossing vessels was demonstrated in 15 of 18 (83%) patients undergoing secondary open pyeloplasty for endopyelotomy failure; concomitant high-grade hydronephrosis was present in 13 instances*(23)*. Figenshau and colleagues *(38)* reported a similar experience with percutaneous endopyelotomy in children and Lim and Walker *(76)* identified crossing vessels in two of three recurrent UPJO after pyeloplasty in children.

On the other hand, Gupta et al. *(14,46)* reported an overall 85% success rate for antegrade endopyelotomy in 401 patients, the largest series reported to date. A crossing vessel was found in only 13 of 54 patients during open exploration and, thus, could only possibly be the cause of failed antegrade endopyelotomy in 4% of patients. The most common finding at exploration was severe fibrosis of the UPJ, suggesting an intrinsic defect.

If failure occurs, a salvage open or laparoscopic procedure is not compromised by the endopyelotomy. The reported incidence of late failures or recurrences is diverse. Some investigators have found that failures occur early, and that late failures or recurrences are distinctly uncommon *(14,18)*. Gupta and co-workers *(14)* report that 92% of failures occurred in the first year after surgery. Kletscher and co-workers *(29)* reported that all failures occurred in the first 2 months. However, a higher incidence of late failures or recurrences was reported by Van Cangh et al. *(23)*. Seven of the eighteen failures occurred after 1 year; and one occurred 6 years postoperatively. In 15 of the 18 failures treated by open pyeloplasty, a crossing vessel was found. Clearly, long-term success can be achieved in the presence of crossing vessels. In those instances, the operation succeeds in correcting both the intrinsic and the extrinsic factors of obstruction. The functional patency of the UPJ is re-established and the crossing vessels become somewhat fixed in a silent nonobstructing position. In recurrences, perhaps either or both outcomes are insufficient, or the quality of the hypotonic renal pelvic musculature is inadequate and thereby irreparable. Even with limited diuresis, the renal pelvis balloon out and protrudes through the vascular window, making recurrence inevitable. Yet another cause of failure is the formation of postendopyelotomy adhesions between the vessels and the UPJ, resulting in a fixed extrinsic compression of the UPJ *(14)*.

Although the importance of crossing vessel is controversial, there is general agreement that marked hydronephrosis impacts on the failure rate. Gupta and co-workers *(14)* reviewed the records of 401 antegrade endopyelotomies performed over a 12-year period. Fifty-four of sixty failures were explored. Severe extrinsic fibrosis was the most common finding as a cause of failure. Failure was strongly correlated with marked hydronephrosis and poor initial renal function but not with crossing vessels.

Other disadvantages of antegrade endopyelotomy include the need for a nephrostomy tube, the risk of bleeding with the possibility of emergency embolization, a 2- to 4-day hospitalization, a reduction in volume of the renal pelvis dependent on tone, and only a 50% success rate for repeat endopyelotomy. However, the overall decreased morbidity coupled with a high success rate that has been duplicated in many large series of patients at many institutions around the world makes this procedure an excellent choice in most adult patients. To decrease the duration of hospitalization after antegrade endopyelotomy, Bellman et al. *(64)* placed a 14/7-Fr internal endopyelotomy stent in the ureter and left a Councill catheter draining externally from the renal pelvis, which was subsequently removed 2 to 3 hours after surgery when it was clear that the patient was not hemorrhaging. The mean duration of hospitalization in this group was 0.6 day, truly making this an outpatient procedure.

The role of endopyelotomy in cases of horseshoe kidney was first described by Nakamura et al. *(77)*. They reported successful results in three patients, including one in whom open primary pyeloplasty and isthmus division failed. In addition, two patients had associated renal calculi that were extracted at endopyelotomy. Bellman and Yamaguchi *(78)* advocated more posterior, medial, and inferior access to the horseshoe kidney, posterolateral incision, and the use of longer instruments. Jabbour et al. *(79)* reported their experience in four patients with horseshoe kidney who underwent percutaneous antegrade endopyelotomy in the standard fashion. At 2 months endopyelotomy failed in one of the four patients and subsequently ileal interposition was performed. The other three patients remain symptom-free to this date. Similar successful results were reported by Koikawa et al. *(80)*.

When percutaneous endopyelotomy fails, several options exist, including retrograde endopyelotomy, repeat percutaneous endopyelotomy, or laparoscopic or open operative intervention. Although a repeat endopyelotomy can be offered, the results in this setting will be compromised when compared with a primary procedure. Open operative intervention or laparoscopic pyeloplasty should be offered to any patient who has failed an endourological approach. In this setting, the results of standard intervention are not compromised and should exceed 95% *(14,81)*.

COMPLICATIONS

The complications associated with percutaneous endopyelotomy are analogous to the complications associated with percutaneous nephrolithotomy *(82–85)*.

Hemorrhage

Hemorrhage is a risk of any percutaneous procedure, including antegrade endopyelotomy. Bleeding may result from traumatized renal parenchyma or injury to a perinephric vessel. However, because the renal parenchyma in patients with UPJO is generally thinner than that in patients with normal kidneys, and because the collecting system is dilated, this risk seems to be less than in the general population of patients with stones undergoing percutaneous manipulation. Treatment of hemorrhage in this setting should be conservative to start and include immediate tamponade with a large nephrostomy tube placement, bed rest, hydration, and transfusion as necessary. Transfusion rates in antegrade endopyelotomy range between 2 and 23% *(39,71,73,82,84)*. The nephrostomy tube should not be irrigated acutely; rather, it is preferable to allow the pyelocaliceal system to tamponade the bleeding. When bleeding continues despite these conservative measures, the next step is selective angiographic embolization. This procedure is almost uniformly successful and obviates the need for open operative exploration, which may lead to nephrectomy.

Infection

Infection is a risk of any urinary tract manipulation, including percutaneous endopyelotomy. All attempts should be made to sterilize the urinary tract before percutaneous endopyelotomy. The patient is treated with a second-generation cephalosporin 30 minutes prior to the procedure and two doses after the procedure. Consideration can also be given to the use of prophylactic antibiotics while the endopyelotomy stent is indwelling for 1 month following the procedure, especially in women who are more prone to bacteriuria.

Vascular Complications

Vessels crossing the UPJ can be a potential source of serious complications *(83,85)*. Vascular complications of endoureteropyelotomy can be significant and remain an important concern to urologists *(23,71)*. Careful visual inspection of the operative site to direct the incision away from pulsating vessels is strongly advocated with direct visual endourological approaches and is indeed a recognized advantage of endoscopic vs fluoroscopic techniques *(18)*.

Reported vascular complications have been reported *(23)*. Malden and co-workers *(83)* described an arteriovenous fistula complicating antegrade endopyelotomy. Brooks and colleagues *(71)* reported the need to transfuse 3 of 13 (23%) of their patients undergoing antegrade endopyelotomy, while Capolicchio and co-workers *(39)* reported having to transfuse 1 of their 9 pediatric patients (11%) who underwent percutaneous endopyelotomy as a result of bleeding from the nephrostomy tract.

Some investigators believe that such data are of sufficient importance to justify preoperative documentation of crossing vessels and the selection of an alternative approach when they are found (especially when they are associated with high-grade hydronephrosis) *(55,86,87)*. By following these guidelines, hemorrhagic complications have all but disappeared, and success rates have dramatically increased *(86–89)*. Quillin and co-workers *(90)* reported the absence of failures in patients without crossing vessels documented by spiral CT angiography. As the risk of long-term recurrence increases when crossing vessels are present, the documentation of crossing vessels preoperatively has the additional benefit of improving postoperative follow-up planning.

Perforation of the Collecting System or Adjacent Organs

Perforation of the collecting system is managed by nephrostomy drainage. Provided that the collecting system is adequately drained, the urothelium seals within 24 to 48 hours. Adjacent organ injury may occur to the liver, spleen, duodenum, colon, and adjacent structures. Colonic injury is the most common of these and occurs when the nephrostomy is passed through a redundant portion of the colon before entering the kidney. Management of colonic injury includes repositioning the nephrostomy catheter back until it is in the colon and placing an external retrograde ureteral catheter to drain the renal pelvis. The patient needs to be observed closely, and if clinical peritonitis develops, the patient should be returned to the operating room for colostomy. Pleural injury is usually associated with a supracostal approach, resulting in a hydrothorax and/or pneumothorax. Pleurotomy is managed with simple thoracentesis, but rarely, it may require chest-tube placement and drainage for 48 hours.

Contrast Reactions

In patients with known contrast allergy, preoperative steroids should be administered (e.g., prednisone). If a contrast reaction develops intraoperatively, the procedure should be terminated immediately, and antihistamines, steroids, H1 and H2 blockers, plus epinephrine (if needed) are administered to the patient.

CONCLUSION

Clearly, during the past 20 years, the development of new techniques and instrumentation has made open pyeloplasty, as a first-line treatment for ureteropelvic obstruction, obsolete in most adult patients. Antegrade endopyelotomy has become the procedure of choice for patients with UPJO. Overall success rates of 85% can be expected when the procedure is used in a broad spectrum of patients. Contraindications include an uncorrected bleeding diathesis, untreated infection, and any anatomic abnormality precluding safe percutaneous access. Although endoureteropyelotomy represents a significant advance in the management of UPJO, it should not be offered indiscriminately. The goal is to characterize prognostic factors fully in an attempt to achieve better case selection. The length of the stricture, the level of renal function, and the grade of hydronephrosis are generally accepted prognostic factors. Additionally, crossing vessels may have a role and, in association with the grade of hydronephrosis, are major predictive factors of outcome.

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11 Retrograde Endopyelotomy

W. Patrick Springhart, MD
and Glenn M. Preminger, MD

CONTENTS

SUMMARY

Evolving technology has lead to attempts to decrease morbidity associated with open correction of ureteropelvic junction obstruction but without compromising success. Several different methods of treatment have been devised, including the fluoroscopically guided acucise endopyelotomy device, and direct vision retrograde ureteroscopic approaches with multiple cutting devices. This chapter provides insight into the retrograde applications currently available.

Key Words: Endopyelotomy; Acucise; laser; ureteropelvic junction; holmium:YAG.

INTRODUCTION

In 1990, the first retrograde endopyelotomy was described with ureteroscopic incision of the ureteropelvic junction (UPJ). At the time, only rigid ureteroscopes greater than 9 Fr in diameter were available. As a result, concomitant ureteral trauma was a significant possibility, resulting in subsequent iatrogenic ureteral stricture formation in 21% of patients in one series *(1)*. Subsequently, some authors suggested that prestenting patients for 1 to 2 weeks prior to endopyelotomy would facilitate ureteroscopic access and lessen the chance of ureteral stricture *(2,3)*.

Evolutions in endourological equipment have allowed significant advances in endourological techniques, specifically in the performance of ureteroscopic endopyelotomy.

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Specifically, retrograde management of the UPJ obstruction (UPJO) was facilitated greaty by the introduction of small caliber, flexible ureteroscopes and the holmium laser, along with development of the cutting balloon electrode.

INDICATIONS

Patients with a UPJO may present either with and/or without symptoms. The diagnosis may be made as an incidental finding during the work-up of an unrelated problem or with evidence of progressive deterioration of ipsilateral renal function. Nausea and vomiting are typically present and, occasionally, one may see intermittent abdominal pain associated with increased fluid consumption or mild diuretic use (alcohol, caffeine, etc). Indications for treatment are based primarily on whether or not the patient is symptomatic and/or if progressive deterioration of renal function is noted. Location, length, degree of obstruction, and ipsilateral renal function are all factors that should be addressed prior to intervention, as these components have significant predictive impact on outcomes after intervention *(4–6)*. Hence, it is our routine to perform an intravenous or retrograde pyelogram to evaluate location, length, and degree of obstruction. Moreover, a ^{99m}Tm-DTPA renal scan with lasix washout is used to evaluate split renal function and to potentially provoke the diagnosis if clinical symptoms and radiographic studies are equivocal. In addition, the renal scan is used to monitor improvements or progression of obstruction following intervention.

INSTRUMENT LIST

22- to 25-Fr Cystoscope sheath and 0- to 30°-angle lens.
6-Fr Open-ended ureteral stent.
Combination floppy tipped/stiff shaft guidewire.
Flexible or semirigid ureteroscope.
Ureteral access sheath (if using flexible ureteroscope).
Real-time fluoroscopy.
Holmium:YAG laser.
200- or 365-µm holmium laser fibers.
Ureteral dilating balloon.
Acucise balloon catheter (when indicated).
7- or 8-Fr ureteral stent.
16-Fr Foley catheter.

TECHNIQUE

Approaches to endopyelotomy vary from those that undergo asynchronous balloon dilatation prior to incision by cold knife, laser, or electrocautery to retrograde balloon endopyelotomy or Acucise technique, which combines synchronous balloon dilatation with electroincision of the UPJO.

General Technique

The approach to retrograde endopyelotomy should be a standard, disciplined procedure. Each patient is prepared preoperatively by having explained to him or her the procedure in detail outlining the goals, outcomes, potential complications, limitations of the treatment, and expectations during the postoperative convalescence. Preoperative antibiotics are given for prophylaxis of typical uropathogens. After induction of general anesthesia, patients are placed in a dorsolithotomy position.

Balloon dilatation of the UPJ alone has a high failure rate, often requiring repeat intervention. Therefore, our initial treatment modality combines ureteral dilatation (for delineation of the UPJO) followed by immediate retrograde endopyelotomy.

Our standard instrument layout includes: 30 and 70° direction of view rigid cystoscopic lenses, 17- and 22.5-Fr sheaths, a ureteral access sheath, a combination floppy tipped-stiff shaft guidewire, a pressure seal, contrast media, and flexible or semirigid ureteroscopes when indicated.

An open ended ureteral catheter is introduced into the ipsilateral ureteral orifice and a retrograde pyelogram is performed using a 1:1 mixture of normal saline and contrast media. The site of ureteropelvic obstruction is confirmed and marked on the fluoroscopic image screen using a marking pen. For procedures involving direct vision endopyelotomy, a 0.038-in. “combination” guidewire is advanced into the collecting system under intermittent fluoroscopic guidance. The characteristics of this wire allow a relatively atraumatic leading tip, stiff body, and a hydrophilic rear tip to allow easy passage of a ureteroscope, if needed. The open-ended ureteral catheter is then retracted and the cystoscope disassembled, carefully leaving the guidewire in place. Moistened surgical towels are then placed over the guidewire to secure it in place.

An 18-Fr ureteral dilating balloon is advanced across the area of interest. The radio-opaque markers incorporated into the design of the dilating balloon allow precise placement of this device across the stenotic UPJ. The balloon is slowly insufflated, noting the characteristic “waisting” caused by the UPJO, and continues to be inflated until the “waisting” has disappeared. The balloon-dilating catheter is removed, again with care to maintain access to the collecting system with the safety guidewire at all times. The remainder of the procedure depends on the modality of UPJ incision (cold knife, electrocautery, or laser endopyelotomy) or whether a direct vision or fluoroscopically guided UPJ incision is performed.

Owing to the differences in anatomy between each gender, a semirigid ureteroscope is preferred for the initial attempt of direct vision endopyelotomy in females because of its ease in controlling a precise UPJ incision. Semirigid ureteroscopy is generally performed without having to dilate the distal ureter. The scope is gently advanced up to the level of interest with intermittent fluoroscopy to confirm the level of access.

If, however, attempts to reach the UPJ are difficult with the semirigid ureteroscope or the procedure is being performed in a male patient, a flexible ureteroscope may be used. Prior to placement of the flexible ureteroscope, a 12/14-Fr or larger ureteral access sheath is placed to facilitate passage of the flexible ureteroscope *(7)*. The access sheath is advanced over the safety guide wire under fluoroscopic visualization. If the access sheath does not easily advance past the ureterovesical junction, the inner stylet of the access sheath may be used to sequentially dilate the ureter followed by replacement of the stylet into the outer sheath, with a second attempt at access sheath placement. If resistance is still encountered, the narrow portion of the ureter can be dilated with a ureteral-dilating balloon. Once the access sheath is in proper position, the guidewire is secured and placed under a moistened surgical towel to prevent inadvertent removal.

Pressurized normal saline irrigation allows adequate visualization during ureteroscopic endopyelotomy. We prefer an automated pressure device that heats the saline, while maintaining pressure at 200 mm of mercury pressure.

The flexible ureteroscope, if used, is advanced through the access sheath alongside the safety guidewire and up the ureter, while keeping the lumen in the center of the visual field at all times. Importantly, with either the semirigid or flexible ureteroscope, the mucosal surface should be seen moving in the opposite direction, indicating that the ureteroscope is not stuck within the ureter. If blood clots obscure the lumen of the ureter or collecting system, it is best to pass the ureteroscope along the wall of the ureter and attempt to bypass the clot. Special care must be taken to avoid firing the laser within the ureteroscope, as laser injury is the most common cause of flexible ureteroscope damage *(8)*. Once the UPJO is visualized ureteroscopically, the area is inspected for pulsations, which may be transmitted by a crossing vessel. The modality of incising the UPJ is then chosen.

Laser Endopyelotomy

Only the holmium: YAG allows the versatility of stone fragmentation, while creating an equally efficacious incision when compared with other urological lasers. Our preference to use the holmium: YAG laser, rather than other cutting devices, is based on its ease of use, precise incision, and compatibility with flexible and semirigid ureteroscopes, all the while creating a hemostatic incision of the UPJ *(9,10)*. A 200- or 365-µm fiber is placed into the ureteroscope, extending approx 0.5 to 1 cm from the tip of the scope. The power settings are set at 1 J at 15 Hz or 15 W *(10–12)*. The laser fiber is advanced 1 cm proximal to the original area of "waisting" and its position is confirmed fluoroscopically. Incision of the UPJ is far easier to perform as the ureteroscope is withdrawn. Therefore, the ureteroscope with laser fiber is advanced across the UPJO, into the dilated renal pelvis. The fiber is then directed to the lateral aspect of UPJ *(13,14)*. The ureteroscope and laser are withdrawn in unison at a slow rate to ensure a through-and-through incision to approx 1 cm distal to the initial radiographic "waisting." This process may be repeated several times along the initial axis of incision to ensure a controlled incision to the depth of the perinephric fat. If bleeding is encountered the laser is defocused away from the site of bleeding, fired, and the ureter reinspected for hemostasis. Once an adequate incision is accomplished, the laser fiber is withdrawn and contrast solution is injected through the working port of the ureteroscope confirming extravasation outside the UPJ. Following removal of the ureteroscope, a standard 7- or 8-Fr internal ureteral stent is placed through the access sheath, across the UPJ, into the renal pelvis. The access sheath is carefully removed leaving the stent in the correct position. All steps involved in placing the stent are performed under intermittent fluoroscopic guidance. A Foley catheter is placed to prevent reflux of urine across the endopyelotomy incision, and left indwelling for 3 days.

Cold-Knife Endopyelotomy

Cold-knife endopyelotomy mimics the cold-knife urethrotomy, in that the area in question is incised under direct visualization, but through a semirigid ureteroscope. Knife blades come in similar shapes as those found within urethrotomy sets:straight, hook, or half-moon. Other configurations include those that may be cannulated over the indwelling guidewire. However, owing to limited access to the male UPJ with a semirigid ureteroscope, cold-knife endopyelotomy is currently infrequently performed in a retrograde manner. Moreover, there is an higher incidence of bleeding when using a cold knife to make the UPJ incision *(15,16)*.

Electrocautery

Electrocautery incision of the UPJ is performed with small 2- to 3-Fr cutting electrodes *(16,17)*. After routine access is gained to the renal pelvis, the indwelling safety guidewire is covered by a 5-Fr open-ended ureteral stent, which maintains access while avoiding potential arching of current between the electrode and metallic guidewire. Incision of the UPJO is performed in a similar manner to laser endopyelotomy. After orienting the scope laterally, a full thickness incision into periureteral fat, 1 cm proximal and distal to the obstructing segment is created while withdrawing the ureteroscope. Retrograde pyelography confirming a complete UPJ incision and internal stent placement are then performed.

Acucise

The Acucise cutting balloon catheter incorporates radio-opaque markers surrounding a low-pressure balloon associated with a monopolar-electrocautery cutting wire *(18)*. The application of the Acucise is similar to that of ureteroscopic endopyelotomy in that the UPJ is dilated and incised. In contrast, Acucise endopyelotomy is performed under fluoroscopic guidance rather than direct visualization *(7,19)*. Dilation and incision are performed simultaneously. The Acucise cutting catheter has undergone several modifications, now resulting in a 5-Fr circumference as well as an electrically active cutting surface 2.8 cm in length and 150 µm in diameter.

Use of the Acucise catheter does not require the use of a corresponding ureteroscope. Although the Acucise may be used through a cystoscope, we prefer placement of a 35-cm, 12/14-Fr or larger, ureteral access sheath positioned several centimeters below the level of obstruction. As with direct vision endopyelotomy, a lateral incision of the UPJ is performed. Proper positioning of the Acucise balloon catheter prior to retrograde placement up the wire, avoids spiraling of the catheter (often caused by drag created by the undilated ureter). Improper positioning of the wire can result in renal vascular injury.

When performing Acucise endopyelotomy, it is important that only one working guidewire is used. Additional safety guidewires or guidewires positioned adjacent to the endopyelotomy cutting balloon wire may cause arching of current, potentially damaging adjacent tissue.

Intermittent fluoroscopy confirms correct placement of the Acucise balloon's radio-opaque markers across the predetermined marked site on the fluoroscopic monitor. One must confirm that the cutting wire is lateral to the indwelling working guidewire. At no point should the cutting wire cross the working guidewire as this would indicate spiraling of the catheter. Once aligned, the Acucise balloon is slowly insufflated with a 50/50 dilution of normal saline and radiographic contrast. The distinctive "waisting" is noted on intermittent fluoroscopy, but in contrast to ureteroscopically assisted techniques, the waist is not fully expanded until electrocautery is applied simultaneously. Seventy-five to one hundred watts of pure cutting current are applied. Under continuous fluoroscopy, the balloon is inflated with the contrast solution to its full capacity of 2.5 mL while synchronous activation of the electrocautery device is performed for 3 to 5 seconds. The waist should disappear as the balloon is fully inflated.

The balloon is desufflated and a retrograde pyelogram is performed through the Acucise catheter to confirm extravasation of contrast through the incised UPJ. If no extravasation is seen, the Acucise catheter can be withdrawn in an antegrade fashion whereupon an additional pyelogram is performed. If no extravasation is noted the catheter should be withdrawn and assessed for correct delivery of current to the cutting wire.

If successful endopyelotomy has occurred, the balloon should be maximally re-inflated for 10 minutes to tamponade the incised tissue. The balloon catheter should then be deflated and removed followed by placement of a 7- or 8-Fr internal ureteral stent. The stent is advanced under intermittent fluoroscopic guidance and confirmed in the renal pelvis. A Foley catheter is placed to prevent reflux of urine across the endopyelotomy incision. The patient is instructed to remove the catheter after 3 days. Outpatient flexible cystoscopy is performed after 6 weeks to remove the indwelling ureteral stent.

RESULTS

Currently, dismembered pyeloplasty is the gold standard approach to primary UPJO in children and secondary UPJO in adults. Success rates continue to exceed 95%, yet, the open approach involves longer duration of stay, increased morbidity and an increased need for analgesia *(20)*.

In an attempt to decrease patient morbidity, endourological techniques were employed in the treatment of UPJO. Balloon dilatation of a ureteral stricture was originally introduced in the 1980s. However, owing to lower-reported success rates and an increase in the number of attempts required to achieve a desired outcome, balloon dilatation has fallen from favor, as the simple application of dilating the diseased segment does not allow for regeneration of salubrious tissue *(21–23)*. Hence, most agree that endourological management by simple dilatation has been supplanted by the need for concomitant incision of the diseased segment *(4,24,25)*.

Wickham et al. *(26)* described the original description of endopyelotomy as an antegrade technique in 1983. However, in an attempt, to decrease the morbidity inherent with percutaneous access along with the longer hospital stay, retrograde access to perform the endopyelotomy was attempted. Unfortunately stricture rates of 21% were reported at the time when 10.8-Fr or larger ureteroscopes were used *(27)*. The re-evaluation after progress in ureteroscope design resulting in much smaller scopes has improved the iatrogenic ureteral stricture rate to less than 1% *(28)*. Furthermore, it has been shown that retrograde vs antegrade endopyelotomy is a more cost-effective procedure *(4)*. In terms of success with retrograde endopyelotomy, use of a laser or electrocautery devices appear to be equivalent and depend on availability and the surgeon's preference *(29–31)*. Prior to endourological intervention, it is important to recognize those factors that have a significant predictive value on outcomes after intervention. These factors include: the presence of crossing vessels, prior open or endourological intervention, length and degree of obstruction, and ipsilateral renal function.

Crossing Vessels

Postmortem studies of normal kidneys demonstrated that vessels that cross the UPJ are rarely located laterally *(13,14,32)*. Hence, a directly lateral incision is preferred for endopyelotomy. However, the risk of postoperative hemorrhage is still a potential problem and patients should be aware of this complication preoperatively. In those patients with UPJO, crossing vessels have been noted in 53 and 79% when evaluated using endoluminal ultrasound and computed tomography, respectfully *(33,34)*. Furthermore, several studies have shown that crossing vessels are a deterrent to successful outcomes after endopyelotomy noted by markedly decreased success rates when present *(28,35–37)*.

Therefore, if an open or laparoscopic approach is chosen, crossing vessels can be directly visualized, followed by dismembered pyeloplasty and potential translocation of the UPJ, if needed. However, if an endoscopic approach is elected, preoperative imaging may be performed so that more accurate preoperative counseling can be provided for a more realistic expectation of postoperative outcomes.

Preoperative Hydronephrosis or Renal Function

Studies have demonstrated that poor preoperative ipsilateral renal function and severe hydronephrosis, either alone or in combination, are poor prognostic factors for success *(9,38–40)*. Etiological factors thought to contribute to poor surgical outcomes are absolute urine production, decreased mitogenic factors, and decreased production of growth factors *(41)*. Potentially, the decreased production of urine may not adequately keep the incised ureter dilated enough and may result in contraction of the wound leading to failure of the intervention. Thus, while evaluating and counseling patients preoperatively, it behooves the physician to be aware of these prognostic factors when explaining realistic expectations of success.

Endopyelotomy After Prior Intervention

Open pyeloplasty continues to be the gold standard treatment for UPJO, with success rates that range from 90 to 95% *(42,43)*. The cause of failure in the 5 to 10% of patients undergoing open procedures seems to be from postoperative fibrosis as a result of urinary extravasation, suture material, or ischemia from ureteral stenting. Repeat open pyeloplasty has been laden with substantial complications and may even require nephrectomy. Yet, recent studies suggest that an endopyelotomy may provide a reasonable success rate for patients who have failed open pyeloplasty *(44)*.

Although success rates average 82% with primary retrograde endopyelotomy (Tables 1 and 2) and no significant difference is noted in primary vs secondary endopyelotomy, the success rate falls significantly to less than 50% for those who undergo repeat endopyelotomy *(45)*. Thus, endourological intervention after initial endourological failure has a reduced success rate *(44,46)*. In contrast, a failed endopyelotomy does not appear to adversely affect the success rate of subsequent open pyeloplasty *(39)*.

Preoperative Stent Placement

Originally, retrograde ureteroscopic endopyelotomy was performed with large, rigid ureteroscopes, which resulted in an increased rate of postoperative iatrogenic strictures *(1)*. Therefore, many investigators recommended preoperative stenting to allow for passive dilation of the ureter, prior to endopyelotomy *(2,3,47)*. Currently, advances in ureteroscope design and the introduction of the holmium laser allow for equally efficacious outcomes during retrograde endopyelotomy without stent placement, albeit at the expense of increased operative times *(7,28,31,48)*. Thus, we currently do not routinely stent our patients preoperatively unless they have already been stented by a referring physician.

Postoperative Stent Size

Endopyelotomy is based on the Davis intubated ureterotomy, where a full-thickness incision is made along the length of the stenotic ureteral segment, followed by prolonged stenting to allow for ureteral re-epithelialization. Histological evaluations noted complete muscular regeneration after 6 weeks of stenting *(49)*.

Current debate surrounds proper postprocedural stent sizes as they have been reported to range from 5 to 16 Fr *(50)*. Discrepancies exist between those investigators who favor the use of large ureteral stents vs those who note they are more difficult to place and may jeopardize blood flow to the ureteral segment *(51–55)*. Because secondary UPJO is usually the result of an ischemic segment and primary UPJO is mainly the result of a derangement of muscle fibers, it would seem logical that one would prefer to stent the ischemic strictures with the largest possible stent because vascular compromise is no longer an issue, and with primary UPJO, placement of a less-restrictive stent may avoid any vascular compromise to the healing segment. However, recent reports have suggested that stenting with a 7- or 8-Fr ureteral stent produces similar results to those with the 7/14-Fr endopyelotomy stent *(56–58)*. In addition, it remains uncertain whether a certain stent size is more beneficial for either primary or secondary UPJO. Recently, a porcine model was

Table 1
Results of Ureteroscopic Endopyelotomy for UPJO

Investigator	*Etiology (primary/secondary)*	*Mean operative time (minute)*	*Success rate (%)*	*Mean length of (month) follow-up*
Meretyk et al. *(1)*	16/3	179	79	17
Thomas et al. *(3)*	40/9	90	84	15
Biyani et al. *(69)*	5/3	38	88	12
Tawfiek et al. *(35)*	24/8	95	88	10
Renner et al. *(9)*	27/7	NR	85	18
Gerber et al. *(30)*	18/4	63	82	29
Conlin et al. *(28)*	15/6	120[a]	81	23[a]
Giddens et al. *(29)*	20/8	NR	79	10
Matin et al. *(31,38)*	40/5	65	73	23

[a]Represents median.
NR, not recorded.

Table 2
Results of Acucise Endopyelotomy for UPJO

Investigator	*Etiology (primary/secondary)*	*Mean operative time (minute)*	*Success rate (%)*	*Mean length of follow-up (month)*
Preminger et al. *(18)*	52/14	48	72	8
Nadler et al. *(46)*	25/3	63	81	33
Gill et al. *(70)*	13/0	33	69	18
Lechevallier et al. *(64)*	23/13	30	75	24
Shalhav et al. *(4)*	52/14	81	71	20
Faerber et al. *(71)*	27/5	35	88	14
Gelet et al. *(38)*	21/23	53	76	12
Biyani et al. *(72)*	34/8	45	64	27

used to reassess Davis' original studies of ureteral healing after ureterotomy. It was noted that wound healing at the site of endopyelotomy is more likely the result of myofibroblast recruitment rather than smooth muscle regeneration. Hence, wound healing may be more a result of contraction, suggesting that a larger stent size may serve more as a mold than as a scaffold for healing *(41)*. Further animal and prospective clinical trials will be needed to determine optimal stent size following endopyelotomy.

Stent Duration

In general, most studies suggest that stents should remain in place for 4 to 6 weeks following endopyelotomy. However, some authors report similar success rates with shorter stenting duration, as prolonged stenting may initiate an inflammatory response leading to late fibrosis *(57,59,60)*. Further clinical trials are warranted to better assess the optimal length of stenting following ureteroscopic endopyelotomy.

Follow-Up

Durability of endopyelotomy has recently been scrutinized, as most contemporary studies average follow-up is only 17 months (Tables 1 and 2). Prior studies have shown that most failures occur within 1 year of intervention *(39,61)*. As recent studies have looked at long-term results of endopyelotomy, the durability of all endourological intervention may not be as good as initially believed. Long-term assessment of the postoperative durability in those who underwent endourological intervention for UPJO demonstrated that the majority of failures occurred within 12 months but that a significant number of failures occurred thereafter. Using statistical methods with their data this recent retrospective review determined that no further failures were expected after 36 months and recommend 3 years minimum follow-up following endopyelotomy *(62)*. Of note, there does not appear to be a difference in the failure rates between patients with primary or secondary UPJO treated with endopyelotomy *(63,64)*. Based on this information, we perform routine follow-up on our patients using either intravenous pyelogram or nuclear renal scans every 6 months for 5 years.

Comparison of Approaches

In an attempt to duplicate success rates and at the same time decrease perioperative morbidity, endourological techniques using antegrade, retrograde, and Acucise endopyelotomy techniques were devised. On average, success rates range from 73 to 88% and 64 to 88% for retrograde ureteroscopic and Acucise endopyelotomy with a mean follow-up of 17 and 20 months, respectively *(19,31,48,65)*.

However, success rates have not compared with open reconstructive or laparoscopic techniques. In the early 1990s the first laparoscopic pyeloplasty was performed as another attempt to decrease perioperative morbidity associated with the open technique *(66,67)*. In several studies comparing laparoscopic pyeloplasty to open and endourological intervention, laparoscopic techniques had equivalent success rates to open surgery and superior outcomes when compared with endourological techniques. Laparoscopic pyeloplasty has also demonstrated equivalent hospital stay and analgesic use when compared with endourological techniques and were significantly less than those patients who underwent an open surgical approach *(68)*. Along with recent familiarization of intracorporeal suturing techniques and with the further developments of robotic laparoscopic procedures, some now consider laparoscopic pyeloplasty as the primary technique for initial intervention of UPJO with endourological techniques reserved for those who fail the laparoscopic approach.

In conclusion, retrograde endopyelotomy provides a safe, less invasive, and cost-effective means to treatment of primary or secondary UPJO *(65)*. Although endourological techniques initially appeared promising, the gold standard of therapy continues to be a formal repair via laparoscopic or open pyeloplasty. If patients do decide to undergo endourological management, there appears to be no difference in the success rates of subsequent pyeloplasty. Furthermore, in the minority of cases that fail primary plastic procedures, endopyelotomy continues to play a successful role in those cases refractory to open or laparoscopic repair. Further prospective trials evaluating optimal size and duration of ureteral stent placement must be performed.

TIPS AND TRICKS

General Tips

1. After performing retrograde pyelography, the site of the UPJO is confirmed and marked

on the fluoroscopic image screen using a marking pen. This maneuver will aid in identifying the area of interest as the endoscope is advance proximally.
2. The radio-opaque markers incorporated into the design of the dilating balloon allow precise placement of this device across the stenotic UPJ indicated by the marked area on the saved fluoroscopic image.
3. Semirigid ureteroscopy is preferred for the initial attempt of direct vision endopyelotomy. However, anatomical constraints in most men and some women may not allow passage of the semirigid device.
4. Pressurized irrigation from an automated pressure device will allow better visualization during ureteroscopic endopyelotomy.
5. While performing ureteroscopy, if blood clots obscure the lumen of the ureter or collecting system, it is best to pass the ureteroscope along the wall of the ureter and attempt to bypass the clot.
6. Once the UPJO is visualized ureteroscopically, the area is inspected for pulsations, which may be transmitted by a crossing vessel.

Tips for Laser Endopyelotomy

1. Incision of the UPJ is easier to perform as the ureteroscope is withdrawn from the renal pelvis, across the UPJ. The optimal holmium laser settings to incise the UPJ are either 1 J at 15 Hz or 1 J at 20 Hz.
2. The ureteroscope and laser are withdrawn in unison, at a slow rate during endopyelotomy, to ensure a through-and-through incision to approx 1 cm distal to the initial radiographic "waisting" of the ureteral dilating balloon. Although repeat incisions may be performed to insure a full-thickness incision, a single pass of the ureteroscope and laser will always result in the "cleanest" UPJ incision.
3. If bleeding is encountered at the incision site, the laser may be "defocused," by moving the fiber 2 to 3 mm away from the site of bleeding, fired, and the ureter reinspected for hemostasis.

Electrocautery Tips

1. Cover the indwelling safety guidewire with a 5-Fr open-ended ureteral stent to avoid potential arching of current between the electrohydraulic lithotriptor electrode and metallic guidewire.

Acucise Tips

1. Place a 35-cm, 12/14-Fr or larger ureteral access sheath several centimeters below the level of obstruction. This helps decrease the potential drag that the Acucise device may encounter during retrograde placement into the ureter.
2. Only use one working guidewire. Additional guidewires positioned adjacent to the endopyelotomy-cutting balloon wire may cause arching of current, potentially damaging adjacent tissue.
3. At no point should the cutting wire cross the working guidewire on the fluoroscopic image, as this would indicate spiraling of the catheter.
4. If no extravasation is noted, the catheter should be withdrawn and assessed for correct delivery of current to the cutting wire.

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12 Percutaneous Endopyeloplasty

David S. Sharp, MD, *Mihir M. Desai,* MD, *Mahesh R. Desai,* MS, FRCS, *and Inderbir S. Gill,* MD, Mch

Contents

SUMMARY

Percutaneous endopyeloplasty is a minimally invasive endourological approach to the treatment of ureteropelvic juction obstruction (UPJO). This proceedure incorporates endoscopic suturing through a nephroscope to provide a mucosa-to-mucosa closure of a traditional endopyelotomy incision. Closing the logitudinal endopyelotomy incision in a Heineke-Mikulicz fashion opens the UPJ while limiting urinary extravasation that may decrease the success rate of endopyelotomy alone. Experimental and clinical studies have supported the safety and efficacy of percutaneous endopyeloplasty. Comparatively, in similar patients, percutaneous endopyeloplasty requires a shorter operative time than laparoscopic dismembered pyeloplasty and is relatively simple to perform. Functional results appeal very promising at 1–2 years. Further experience and clinical trials will help determine where this procedure fits into the treatment algorithm for UPJO. We offer percutaneous endopyeloplasty as a primary treatment modality for many patients with UPJO.

Key Words: Ureteropelvic junction; UPJ; UPJ obstruction; UPJO; pyeloplasty; endopyeloplasty; percutaneous surgery; percutaneous endopyeloplasty; endourology.

INTRODUCTION

Percutaneous endopyeloplasty is a recently described endourological technique designed in an attempt to retain the advantages of a minimally invasive endourologi-

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cal approach to the treatment of ureteropelvic junction obstruction (UPJO) while also improving results. The introduction of traditional endopyelotomy (either antegrade or retrograde) has revolutionized the treatment paradigms for UPJO. It has largely replaced open pyeloplasty as the initial treatment of choice for most adults with primary UPJO. Similarly, with the advent of laparoscopic dismembered pyeloplasty, the indications for traditional open pyeloplasty are diminishing. Despite the significantly reduced morbidity compared to open pyeloplasty, endopyelotomy (even in a favorable group of patients with a short UPJO, good renal function, only mild to moderate hydronephrosis, and absence of a crossing vessel) is associated with a 10 to 15% failure rate *(1–3)*. The success rates of laparoscopic dismembered pyeloplasty may exceed 95%; however, this technique employs advanced intracorporeal suturing skills, which may limit its applicability to a minority of practicing urologists *(4)*.

Oshinsky et al. *(5)* initially explored the concept of intrarenal suturing through the nephroscope. A single absorbable suture was placed after standard endopyelotomy either through the nephroscope using a J-shaped needle and a conventional laparoscopic needle driver ($N = 5$), or through a separate retroperitoneal tract. However, no further reports of this technique were forthcoming, probably owing to the technical difficulty and unreliability because of suture cut through.

In 2000, we developed a novel technique of percutaneous endopyeloplasty using a modified laparoscopic suturing device (Sew-Right SR·5, LSI Solutions, Victor, NY) in a porcine survival model *(6)*. Percutaneous endopyeloplasty consists of horizontal suturing of a conventional vertical endopyelotomy incision performed through a solitary percutaneous renal tract via a nephroscope, essentially creating a Fengerplasty. Our detailed animal study demonstrated that endopyeloplasty is technically straightforward and reproducible, heals by primary intention full-thickness healing, and creates a wider caliber UPJ as compared to conventional endopyelotomy. Also, in contrast to endopyelotomy, the meticulously sutured endopyeloplasty was associated with absent or minimal contrast extravasation on antegrade contrast study performed intraoperatively immediately after suturing. Given the known detrimental effect of urinary extravasation on ureteral healing *(7)*, these findings suggest that endopyeloplasty may provide an optimal environment for full-thickness primary intention healing of the reconstructed UPJ. Thus, our animal experiment provided evidence for a possible functional advantage of endopyeloplasty over endopyelotomy in the surgical treatment of UPJO.

In this chapter, we will focus on our technique of percutaneous endopyeloplasty. We will discuss our indications and contraindications, the instruments used, the technique itself, our laboratory and clinical results, and some “tips and tricks” to performing the procedure. Additionally, we will discuss our preliminary laboratory work with percutaneous dismembered pyeloplasty, where an Anderson-Hynes type dismembered pyeloplasty is performed via a transrenal tract. We believe these procedures hold promise in the treatment of UPJO, and may continue to evolve along with the changing algorithms in the treatment of this common urological disorder.

INDICATIONS

Essentially, any patient that is a candidate for primary antegrade or retrograde endopyelotomy is a candidate for percutaneous endopyeloplasty. The indications to intervene for any patient with UPJO include the presence of symptoms, progressive or overall impairment of renal function, development of upper tract stones or infection, or, rarely, causal hypertension *(8)*. Percutaneous endopyeloplasty has been utilized as the primary therapy in an increasing number of patients. To date, in part because of the extrarenal dissection needed to appropriately mobilize the tissues prior to suture placement, percutaneous endopyeloplasty is not advocated for use as a secondary treatment modality. Percutaneous stone removal during the same setting is advocated for percutaneous endopyelotomy. Five of fifty patients to date have undergone percutaneous stone at the same time for small calyceal or renal pelvic stones. As a result of concerns over tissue dissection and healing, large or infectious calculi have been excluded from the endopyeloplasty to this point.

Contraindications to a percutaneous endopyeloplasty include active infection, a long segment of stricture/obstruction (generally greater than 1–2 cm), and uncorrected bleeding disorders. The issue of a crossing vessel and its relationship to the etiology of UPJO remains controversial. We consider the presence of a crossing vessel to be a contraindication at this time. In one patient who had negative preoperative imaging for crossing vessels, a pulsating vessel was identified upon periureteral dissection after completing the endopyelotomy incision. The significance of this vessel is uncertain, but the procedure was completed uneventfully and the patient has done well with more than 6 months follow-up. Another early patient did have a crossing vessel on preoperative imaging and still desired a percutaneous endopyeloplasty. Unfortunately, this patient failed and had persistent UPJO. We advocate routine dedicated helical computed tomography of the kidneys with three-dimensional rendering to detect the presence of a crossing vessel. In patients noted to have a crossing vessel, currently laparoscopic or open dismembered pyeloplasty is offered.

INSTRUMENT LIST

Standard setup and equipment utilized for percutaneous renal access and nephroscopy are used. This equipment includes: access needles, a dilator set for the percutaneous renal tract, nephroscopy sheath, light source, video equipment, fluoroscopy table and unit, and irrigation sets. In addition, the following supplies are needed:

1. *Nephroscope*: A 26-Fr Storz Nephroscope is used. (Karl Storz, Germany). The size of the working channel on this scope permits the passage of the suturing device.
2. *Suturing Device*: Sew-Right® SR·5™ Suturing device (LSI Solutions® Rochester, NY). The Sew-Right SR·5 is a 5-mm laparoscopic suturing instrument used for placing interrupted sutures (Fig. 1). The original laparoscopic version of the suturing device was reduced in outer diameter and lengthened to enable its use through the nephroscope.
3. *Sutures*: Specialized sutures with attached ferrules are necessary to load the suturing device (LSI Solutions). We have utilized 2.0 polyglysorb suture with good results. The development of finer suture for the device is underway and 3.0 suture is now available commercially.
4. *Knot pushers*: Standard knot pushers, either with closed loop or open loop, used for extra-corporeal laparoscopic suture tying are utilized.
5. *Endopyelotomy device*: We use a bugbee electrode on cutting current to initiate the endopyelotomy incision. Other devices depending on surgeon preference could be utilized including cold knife, holmium laser, or laparoscopic hook dissector.

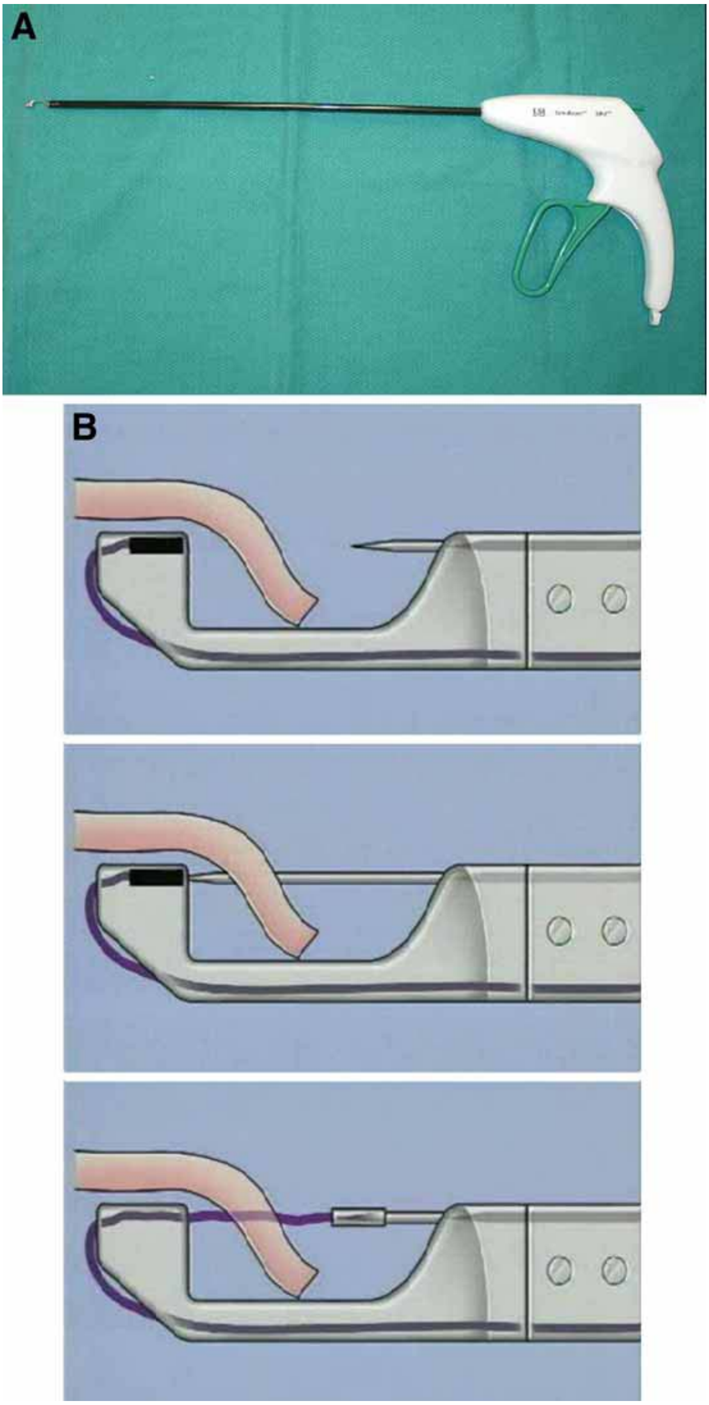

Fig. 1. (A) Photograph of the Sew-Right SR·5 used for the endopyeloplasty suturing. Each end of the suture used with the Sew-Right SR·5 has a metal ferrule and comes pre-packed in a cartridge. The tip of the suturing device fits on a groove on the suture cartridge and the loop of the main body of suture is threaded through the length of the shaft and exits through an opening on the handle. Tugging on the loop, loads the metal ferrules onto two grooves present on the distal part of the tip. A lever, present on

6. *Laparoscopic Endoshears*: Both 3- and 5-mm Endoshears are useful (USSC, Norwalk, CT). A 5-mm Endoshear with curved blades is used to undermine and dissect out the endopyelotomy mucosal edges prior to suturing. The 3-mm MicroEndoshear has straight blades and can be maneuvered to reach areas that the 5-mm device is too bulky to reach. The 3-mm MicroEndoshear is also useful for completing the endopyelotomy incision.

TECHNIQUE

Step 1: Retrograde Ureteral Access

Retrograde ureteral access is obtained cystoscopically by placing a 6-Fr open-ended ureteral catheter into the pelvicalyceal system.

Step 2: Percutaneous Renal Access

Percutaneous renal access is obtained in a standard fashion through an upper or mid-pole calyx, which provides direct access to the UPJ (Fig. 2). A 30-Fr Amplatz sheath is positioned within the renal pelvis.

Step 3: Conventional Endopyelotomy

A conventional, laterally placed, full-thickness endopyelotomy incision is made using 3-mm MicroEndoshears and a bugbee electrode on cutting current (Fig. 3). The bugbee electrode is used to make the initial perforation in the mucosa, and then the incision is completed with the 3-mm MicroEndoshears that have a linear cutting profile. The incision is made across the stricture segment and extends for approx 1 cm into the normal ureter distally and normal pelvis proximally. Care is taken to ensure a clean and sharp cut and to avoid ragged edges to facilitate subsequent endopyeloplasty suturing.

Step 4: Mobilizing the Distal Ureteral Lip

A crucial step in preparation for endopyeloplasty suturing is the mobilization of the distal ureteral lip (Fig. 4). The periureteral fibroareolar tissue is carefully dissected away from the incised ureteral margin and the adjacent unincised ureter. This maneuver is performed carefully under vision using a 5-mm laparoscopic Endoshears. The 3 mm MicroEndoshears enables even more precise dissection. Care is taken not to excessively thin out the ureteral wall during this step. The entire dissection is performed “cold,” without cautery. Only specific spot coagulation of bleeding points is carried out as required. Occasionally one can encounter a significant-sized vessel, which can be gently

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Fig. 1. (*Continued*) the proximal end of the suturing device, switches between the two needles present at the proximal end of the tip. **(B)** The instrument is positioned such that the edge of the tissue to be sutured is brought into the trough on the instrument tip (top). Squeezing the handle pushes the needle, which pierces the tissue and locks into the metal ferrule (middle). When the handle is released, the needle retracts into its resting position thereby pulling one end of the suture through the tissue (bottom). The lever is switched to activate the other needle and the suture is passed through the other tissue edge to be sutured.

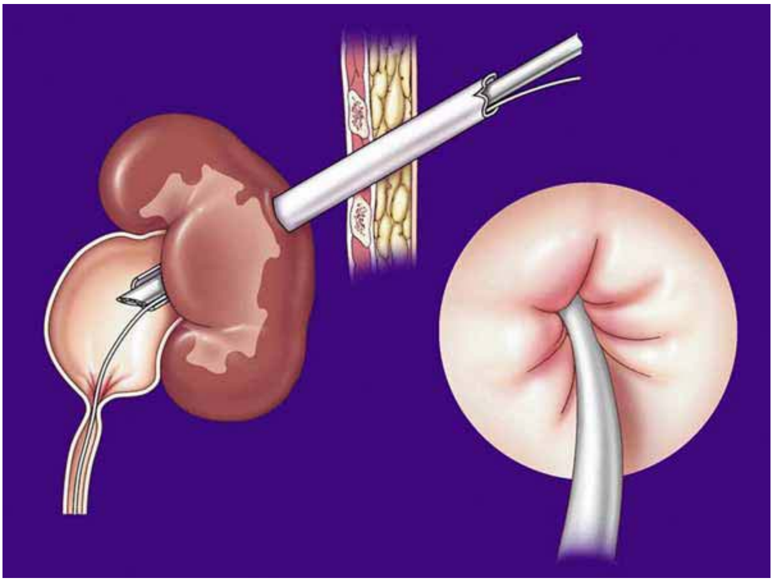

Fig. 2. Percutaneous renal access is obtained through a suitable upper or middle calyx.

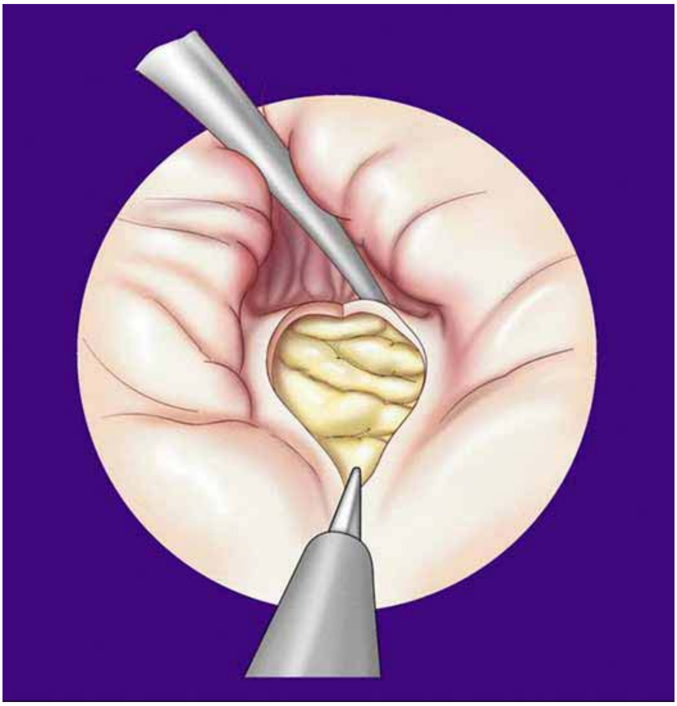

Fig. 3. A laterally oriented full-thickness endopyelotomy incision is made using a Bugbee electrode and cutting current.

dissected away from the ureteral wall. This critical step serves three important purposes. First, it provides space for the suturing device while placing the distal bites. Second, it defines the distal ureteral lip enabling precise full-thickness suturing. Third, it releases tension on the horizontal suture line.

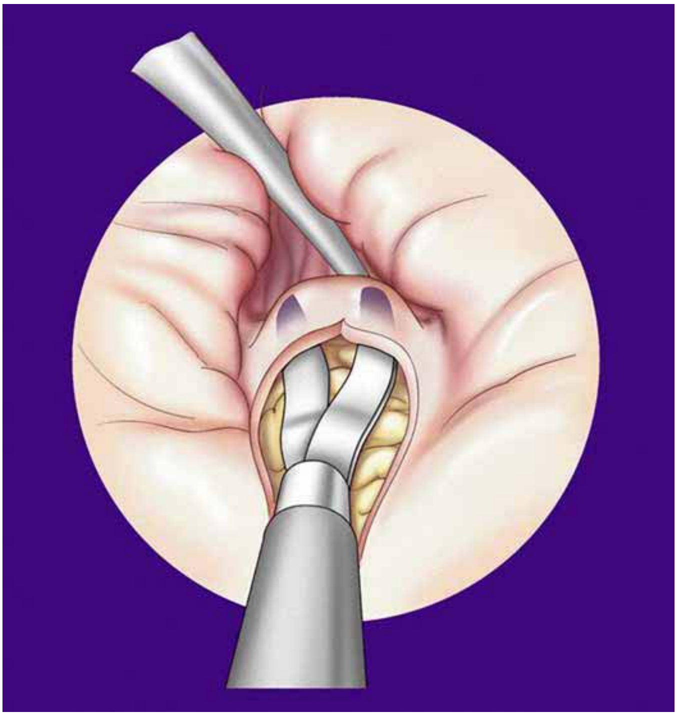

Fig. 4. Mobilization of the distal ureteral margin is performed using a 5-mm MicroEndoshears. The extraluminal aspect of the ureter is dissected by a combination of sharp and blunt dissection with minimal use of electrocautery and preserving a reasonable amount of periureteral tissue. This is important in order to prevent excessive thinning of the ureter and thereby risk cutting through of the sutures. This crucial step serves three purposes. First, it creates adequate space for passage of the suturing device. Second, it defines the edge to enable full-thickness suturing. Third, it releases tension on the suture-line.

Step 5: Endopyeloplasty Suturing

The loaded Sew-Right SR·5 is passed through the working channel of the 26-Fr nephroscope. The initial suture approximates the distal and proximal angles of the endopyelotomy incision, thereby dividing the horizontal suture-line into two equal halves (Fig. 5). Additional sutures are placed on either side of the initial stitch to complete the procedure (Fig. 6). The number of sutures depends upon the length of the endopyelotomy incision. Typically, three sutures are required, one on either side of the initial stitch. However, anywhere from one to four sutures may be placed in the individual case.

Step 6: Placement of a Double-J Stent and Nephrostomy Tube

After obtaining precise mucosa-to-mucosa coaptation, a double-J ureteral stent is placed in an antegrade fashion. A 20-Fr nephrostomy tube is also placed.

RESULTS

Because percutaneous pyeloplasty is a relatively new procedure, there is much more limited experience compared with other minimally invasive treatments for UPJO.

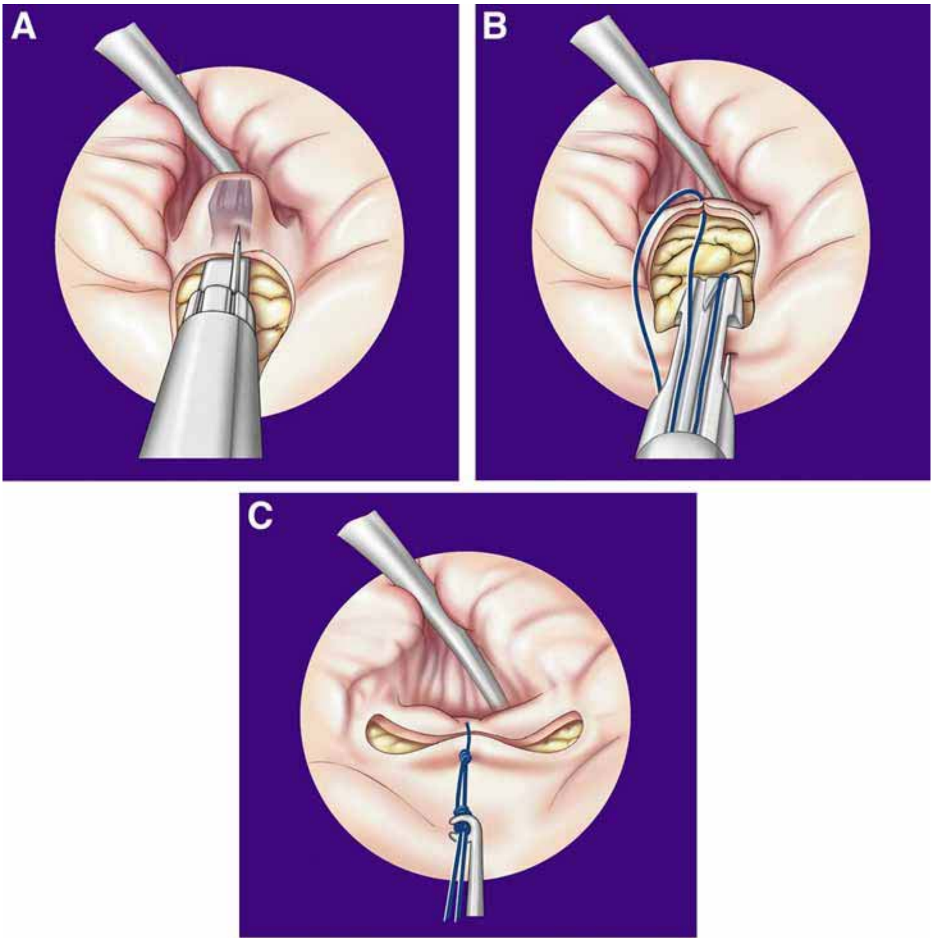

Fig. 5. Placement of the first suture during an endopyeloplasty. The initial suture approximates the proximal and distal angle of the endopyelotomy incision, thereby dividing the incision into two equal halves. **(A)** First needle-pass through distal angle. **(B)** Second ferrule grasped with opposite needle through mucosa of proximal angle. **(C)** Resultant interrupted stitch is tied down with extracoporeal knot pusher.

Despite its novelty, the success of the technique is well-supported in the preliminary studies performed in both experimental and clinical settings. The encouraging data for the technique is outlined herein.

Experimental Data

Our initial studies used to develop the technique were performed in a porcine model. In 2002, we reported on the feasibility and efficacy of percutaneous endopyeloplasty in a chronic porcine bilateral UPJO model and compared outcome data with conventional endopyelotomy and laparoscopic pyeloplasty *(6)*. This study used multiple outcome measures to prove the efficacy of the procedure and critically assess the technique. Partial UPJO was successfully created in 20 kidneys (11 pigs) by laparoscopic ligation of the upper ureter over a 5-Fr ureteral catheter. Subsequently, after interval development of hydronephrosis over a period of 4 to 6 weeks, animals

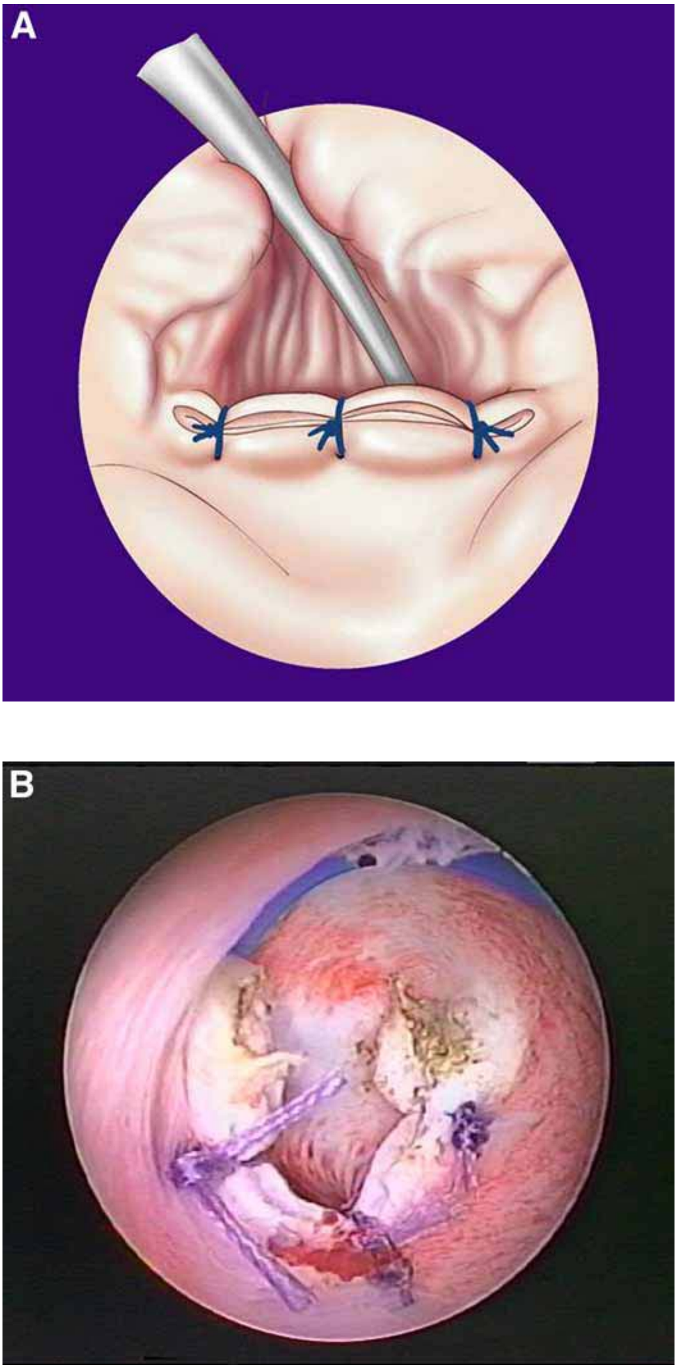

Fig. 6. (A) Diagrammatic and **(B)** nephroscopic view of a completed endopyeloplasty. Typically, two additional sutures are placed on either side of the initial suture providing precise mucosa-to-mucosa approximation.

received either percutaneous endopyeloplasty ($n = 10$), conventional percutaneous endopyelotomy ($n = 5$) or laparoscopic pyeloplasty ($n = 5$). Percutaneous endopyeloplasty was technically successful in all 10 kidneys with a mean total operative time of

81.4 minutes (51–117 minutes). The mean time to complete the suturing step of the procedure was 29.4 minutes (20–64 minutes). The solitary complication was a lower pole infundibular stenosis. Over a mean follow-up of 7.7 weeks, all renal units showed relief of obstruction as evidenced by regression of hydronephrosis, improvement in T1/2 and glomercular filtration rate on renogram and a low intrapelvic pressure on Whitaker test. At autopsy, the endopyeloplasty site showed a fine, well-healed transverse scar with no evidence of residual suture on the mucosal surface. Mean caliber of the UPJ following endopyeloplasty (13.8 ± 2.2 Fr) was significantly greater ($p = 0.01$) than that following conventional endopyelotomy (7.5 ± 1.9 Fr). Intraoperative extravasation upon completion of endopyeloplasty was absent ($n = 6$) or mild ($n = 4$) as compared to significant extravasation in all five kidneys following conventional endopyelotomy. Thus, our detailed animal study demonstrated that endopyeloplasty is technically straightforward and reproducible, heals by primary intention full-thickness healing, and creates a wider caliber UPJ as compared to conventional endopyelotomy. Also, in contrast to endopyelotomy, the meticulously sutured endopyeloplasty was associated with absent or minimal contrast extravasation on antegrade contrast study performed intraoperatively immediately after suturing. As previously mentioned, it is felt that decreasing or eliminating urinary extravasation may improve uretereal healing and thus improve functional results over endopyelotomy. The technique is optimized to allow for full-thickness primary intention healing of the reconstructed UPJ.

Clinical Data

Since our initial clinical report *(9)*, we have now performed percutaneous endopyeloplasty in more than 50 patients with primary UPJO. Data on the first 32 patients was recently compiled *(10)*. Inclusion criteria for this cohort included short (<1 cm) segment stenosis, absence of crossing vessel on preoperative imaging, and absence of prior surgery on the UPJ. Mean age for the group was 27.5 years. Hydronephrosis was mild in 3, moderate in 19, and severe in 10 patients. High insertion of the UPJ was present in 11 patients. The criteria for success was strictly defined, importantly including both symptomatic and radiographic improvement. Success was defined as the absence of pain and improvement of drainage on intravenous pyelogram and/or diuretic renal scan. Percutaneous endopyeloplasty was technically successful in all 32 patients. Mean operative time was 106.3 minutes and mean time for suturing was 29.7 minutes. Endopyeloplasty involved placement of 1 suture in 2 cases, 2 sutures in 3 cases, 3 sutures in 22 cases, 4 sutures in 4 cases, and 5 sutures in 1 case. Intraoperative complications included irrigation fluid extravasation ($n = 1$), and suture cut-through ($n = 1$). Postoperative complications included pyrexia requiring prolonged double-J ureteral stenting ($n = 3$). Follow-up was greater than 2 years in 9, 1–2 years in 7, greater than 6 months in 5, and less than 6 months in 11 patients (Mean 14.1 months; range, 1–27 months). All 32 patients remain symptom free and show improved drainage on intravenous pyelogram (IVP) (Fig. 7) and/or diuretic renal scan (mean postop T1/2 9.6 minutes, mean improvement in renal function 12%). This data confirms that percutaneous pyeloplasty is feasible, well-tolerated, and efficacious.

To evaluate percutaneous endopyeloplasty vs other minimally-invasive techniques for the correction of UPJO, a comparative study was then performed. We reported our intermediate term (1 year) data on endopyeloplasty and retrospectively compared it with endopyelotomy and laparoscopic pyeloplasty in 44 patients with primary UPJO *(11)*. At two institutions, 44 consecutive, nonrandomized patients with primary UPJO

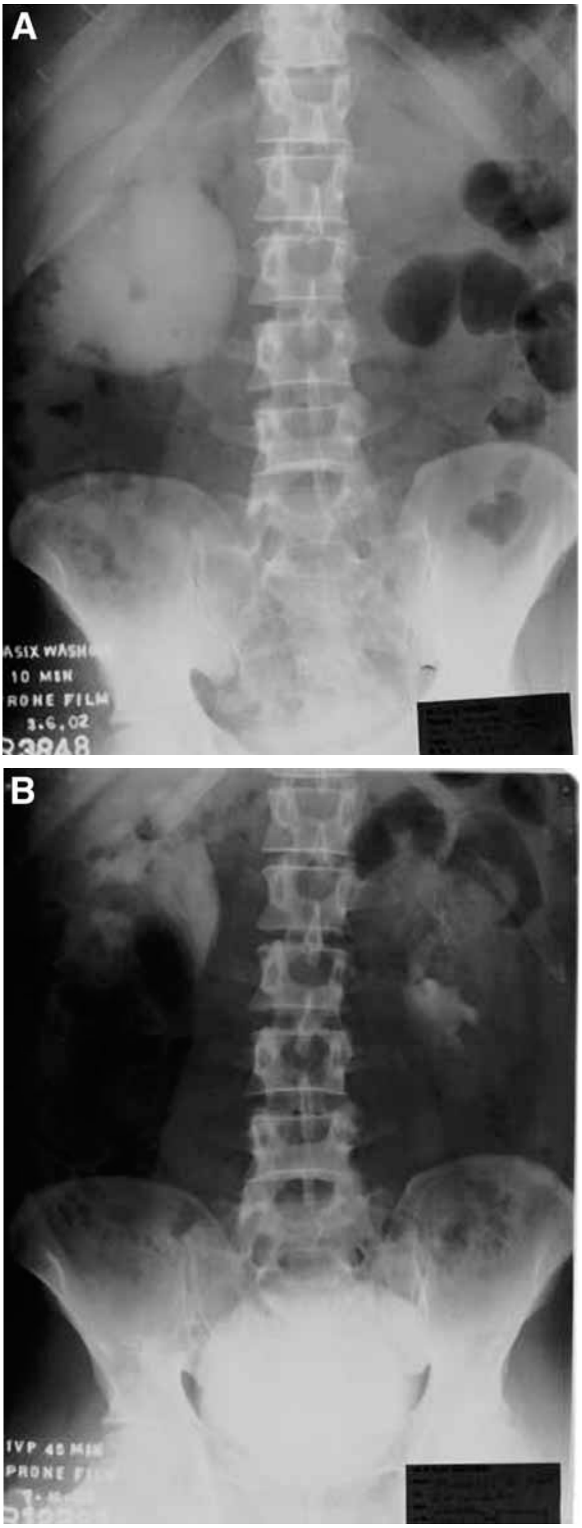

Fig. 7. (A) Preoperative intravenous pyelogram (IVP) shows right ureteropelvic junction (UPJ) obstruction. **(B)** Followup IVP performed 1 year after endopyeloplasty. On the right side, there is significant reduction in hydronephrosis, funneling and wider caliber of the UPJ, and prompt drainage of contrast.

underwent either percutaneous endopyeloplasty ($n = 15$; group I), percutaneous endopyelotomy ($n = 15$; group II), or laparoscopic dismembered pyeloplasty ($n = 14$; group III). Study inclusion criteria were short segment (<1 cm) stenosis, no prior surgery for UPJO, and no crossing vessel in group I. Mean age was 30.3 vs 38.6 vs 38.9 years, and duration of symptoms was 5.5 vs 6 vs 6.6 months in group I, II, and III, respectively. Postoperative success was evaluated on symptoms, intravenous urogram (IVU), and/or diuretic renogram. Mean operative time was 119 minutes in group I, 52 minutes in group II, and 243 minutes in group III ($p < 0.001$). Complications occurred in three patients in group I (fever two, fluid extravasation one), two patients in group II (bleeding one, urinoma one), and no patients in group III. Duration of double-J stent placement was 2, 4 and 6 weeks in groups I, II, and III, respectively. Resolution of symptoms and unobstructed drainage on IVP and/or diuretic renogram was noted in 100 and 100% of patients in group I (mean follow-up 11.6 months), 93 and 88% of patients in group II (mean follow-up 31.4 months), and 93 and 100% in group III (mean follow-up 20 months).

Though retrospective in nature, again this report supports percutaneous endopyeloplasty as efficacious and comparible to endopyelotomy and laparoscopic pyeloplasty. There is shorter operative time in percutaneous endopyeloplasty compared to laparoscopic dismembered pyeloplasty and complications were not clinically significant among the three groups. Though follow-up time was shorter in the percutaneous endopyeloplasty group, success rates are at least as good if not better than the other treatment modalities. There is no reason to speculate that durability of the success will be significantly different for percutaneous endopyeloplasty than the durability observed with both endopyelotomy and laparoscopic pyeloplasty, though this remains to be definitively proven. A prospective, multicenter trial of the technique would be useful to not only test this durability, but also ensure reproducibility among other institutions.

Future Directions

We recently demonstrated the initial technical feasibility of dismembered percutaneous endopyeloplasty in the animal model *(12)*; which may further increase the role of percutaneous intrarenal reconstructive surgery. With this technique, an Anderson-Hynes type completely dismembered pyeloplasty is performed via a single transrenal tract utilizing similar instrumentation as the percutaneous (Fengerplasty) endopyeloplasty described in this chapter. The procedure utilized small hook electrocautery for dissection in addition to 3-mm MicroEndoshears and evolved during its development to be performed under intrarenal CO_2 insufflation. In five pigs with unilateral UPJO created 3–6 weeks prior, percutaneous dismembered endopyeloplasty was performed. Percutaneous transrenal access to the UPJ was obtained, and the UPJ was completely dismembered in all cases from within the renal pelvis through the solitary percutaneous tract. The dismembered proximal ureter was circumferentially mobilized, and in two animals, the UPJ segment was completely excised and removed. A spatulated end-to-end endopyeloplasty anastomosis (Anderson-Hynes) was created transrenally with 5 to 10 interrupted sutures using the Sew-Right device (Fig. 8). The technique was developed in three acute pigs. Subsequently, two survival pigs were sacrificed at 2 and 5 weeks, respectively. All cases were successfully dismembered and a precisely sutured mucosa-to-mucosa anastomosis was created. Intraoperative bleeding was negligible and operative time ranged from 3 to 5 hours, with the majority of time dedicated to transrenal retroperitoneal dissection of the scarred, fibrotic UPJ. CO_2 insufflation was

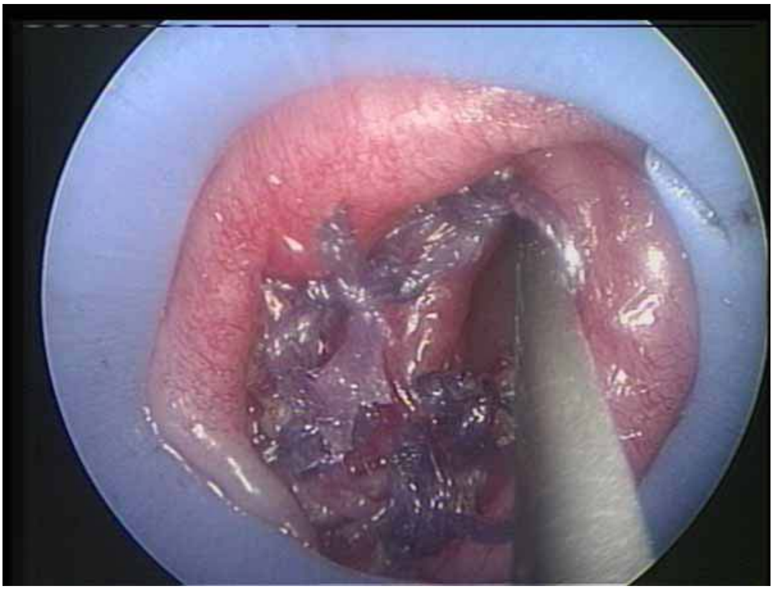

Fig. 8. Completed dismembered percutaneous endopyeloplasty. Nephroscopic view under CO_2 insufflation of sutured anastomosis. Eight interrupted sutures have reconstructed the ureteropelvic junction (UPJ) around a guide wire and one may visualize the lumen of the distal ureter. A dependent, funneled, watertight UPJ is constructed.

efficacious because it minimized fluid extravasation and tissue edema, and additionally, enhanced visualization. Postoperative pyelograms revealed an adequately funneled UPJ, with good flow into the distal ureter. The two survival animals had minimal apparent morbidity from the procedure and retrograde pyelogram at euthanasia revealed a patent anastomosis without extravasation. A 6-Fr catheter easily crossed the reconstructed UPJ at autopsy in all animals and a Whitaker test in the survival animals confirmed a nonobstructed anastomosis.

We feel that dismembered percutaneous endopyeloplasty (Anderson-Hynes type) is technically feasible and promising. Theoretically, the technique may incorporate pelvic reduction in the case of significant hydronephrosis and may be also useful for cases with intrarenal pelvices. We feel it is conceivable and likely that the technique could be utilized in the setting of a crossing vessel. Follow-up studies to determine its utility in the case of a crossing vessel are necessary. Certainly, further technical experience and additional functional outcome analysis in the survival model are needed prior to moving the dismembered procedure from the laboratory into clinical practice.

TIPS AND TRICKS

Percutaneous endopyeloplasty is attractive not only because of its efficacy but also because of its simplicity. A majority of urologists are comfortable with endopyelotomy and percutaneous renal surgery because of their experience with stone disease. These skills are all helpful in performing percutaneous endopyeloplasty. There are two key tips that should be reiterated: (1) Creating a nice linear endopyelotomy without ragged edges facilitates the subsequent suturing. We have found the bugbee electrode on cutting current helpful in making the initial opening in the renal pelvis. The 3-mm MicroEndoshears may then be utilized to complete the endopyelotomy until healthy ureteral tissue is reached and opened for an additional centimeter. (2) Adequate mobilization of the distal ureteral lip is critical. We have utilized both the 3- and 5-mm MicroEndoshears for this step. This step is important to allow for adequate space for precise full-thickness suturing and releases tension on the horizontal suture line.

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13 Endoureterotomy

Khaled S. Hafez, MD *and J. Stuart Wolf, Jr.*, MD

CONTENTS

SUMMARY

Although not as widely reported as the endoscopic treatment of ureteropelvic junction obstruction, endoureteromy for ureteral obstruction at other sites is nonetheless an effective minimally invasive procedure. Most ureteral strictures other than at the ureteropelvic junction are acquired, and are very often iatrogenic. Endoureterotomy for distal and upper ureteral strictures less than 2 cm and not associated with radiation or other ischemic injury is highly successful and results in minimal morbidity. Strictures longer than 2 cm, those associated with radiation or ischemic injury, and some in a middle ureteral location may be managed more appropriately by open reconstruction because of the increased failure rate of endoureterotomy in these patients. Importantly, failure to establish patency with endoureterotomy does not preclude a successful open surgical reconstruction.

Key Words: Endoureterotomy; ureteral obstruction; ureteral stricture; urinary tract obstruction; laser; balloon dilation catheter.

INTRODUCTION

Treatment of ureteral stricture has changed dramatically with the widespread use of upper urinary tract endoscopy. This minimally invasive technology has greatly improved outcomes and the quality of life of many patients. Strictures of the upper urinary tract are

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either congenital or acquired. Congenital ureteral strictures are most commonly located at the ureteropelvic junction (UPJ). Aside from primary UPJ obstruction (UPJO), most other ureteral strictures are acquired and typically iatrogenic *(1)*. The most common etiology of iatrogenic ureteral stricture disease is injury during endoscopic, open, or laparoscopic surgical procedures. The advent of ureteroscopic manipulation has led to an increased incidence of ureteral strictures *(2,3)*. A 1 to 11% incidence of stricture formation has been reported after upper tract endoscopy *(2–8)*. In addition, gynecologic procedures, most commonly radical hysterectomy, carry a higher risk of ureteral injury. Ureteral injury has also been described during various general and vascular surgical procedures. Ureteroileal strictures arising after urinary diversion and post-kidney transplant represent special subsets. Noniatrogenic acquired causes of ureteral stricture include those that develop after spontaneous passage of calculi and after chronic inflammatory ureteral involvement as in tuberculosis and schistosomiasis *(9–12)*.

INDICATIONS

Benign Ureteral Strictures

Benign ureteral strictures are either ischemic or nonischemic in nature. A stricture resulting from surgical injury or radiation therapy is ischemic. Ischemic strictures heal with fibrosis and scar formation, and have diminished success rates after endoureterotomy *(1,13)*. Alternatively, a stricture is nonischemic if it is the result of stone passage or congenital abnormality *(1)*. Postendoscopy ureteral strictures may be either ischemic or nonischemic depending on the mechanism of injury (i.e., mechanical or thermal trauma) *(14,15)*.

Malignant Ureteral Strictures

Ureteral strictures owing to the recurrence of a primary malignancy or as the result of extrinsic mechanical compression (usually from a malignancy) are best managed with formal resection and anastomosis, or catheter bypass (indwelling ureteral stents or percutaneous nephrostomy tubes).

SURGICAL TECHNIQUES

The success rate of endourological techniques in the management of ureteral strictures is generally less than that of formal resection and anastomosis. Nonetheless, these minimally invasive approaches are preferred given their decreased morbidity, reduced operative time, shorter hospitalization, and decreased cost as compared to formal reconstruction. Importantly, successful open operative repair is not precluded by failure of a minimally invasive endourologic technique.

Endoureterotomy for upper urinary tract strictures can be performed in an antegrade fashion using percutaneous access, an exclusively retrograde method, or by means of a combined antegrade and retrograde approach. The combined technique is usually reserved for complex strictures, as is the case of ureteroenteric strictures in patients with urinary diversion.

General Technique of Endoureterotomy

Endoureterotomy begins with the passage of a guidewire across the stenotic segment. Guidewire placement can be accomplished cystoscopically or percutaneously with the patient in the prone position. A balloon dilation catheter is guided over the wire across the stricture. With only partial inflation of the balloon, the stricture creates a “waist” in the balloon that characterizes the stricture and helps to formulate the proper approach. If the stricture is particularly tight, then complete balloon dilation of the stricture (i.e., full rather than partial inflation of the balloon) may be needed to provide adequate access to the distal end of the stricture. At the University of Michigan, we routinely dilate strictures in this manner prior to endoscopic incision, as it greatly improves access and visualization in most strictures. After the balloon is removed, a flexible or semirigid endoscope is advanced beyond the previously dilated stenotic segment to the level of the normal ureteral mucosa. A full-thickness incision is performed, into the retroperitoneal fat, extending approx 1 cm above and below the lesion. For extreme proximal or distal strictures, carrying the incision all the way into the renal pelvis or bladder marsupializes the site into the larger cavity. A variety of cutting devices can be used to create the incision.

The site of the incision varies according to the location of the stricture: proximal and midureteral strictures are incised laterally, distal strictures (i.e., below the iliac vessels) are incised medially, and strictures over the iliac vessels are incised anteriorly. After the initial incision, the dilating balloon should be placed over the guidewire and slowly inflated. The balloon should expand with minimal pressure and without any evidence of residual stricture. If a ureteral narrowing or waisting of the balloon is noted, the stenotic site should be re-incised under direct vision. Typically an 18- or 24-Fr balloon is used, but some urologists use up to a 30-Fr balloon. Following incision, a ureteral stent is placed to facilitate regeneration of urothelial and muscle layers with an adequate caliber lumen. After placement of the ureteral stent and according to the route employed for access, a Foley catheter and/or a nephrostomy tube is left in place for 2 to 3 days to prevent urinary extravasation through the incision.

INSTRUMENT LIST

1. Endoscopes: cystoscopes, ureteroscopes, nephroscopes (rigid and flexible).
2. Access wires.
3. Access catheters.
4. Balloon catheter (18–24 Fr).
5. Cutting devices: cold knife, electrocautery, lasers, Acucise endoureterotomy.
6. Stents and catheters.

Antegrade Endoureterotomy

A percutaneous endoureterotomy is typically the recommend treatment for proximal or midureteral strictures when there is co-existent pathology in the kidney (e.g., renal calculi). Antegrade endoureterotomy should employ an upper or mid-calyceal approach to provide straight access to the ureter. The incision in the ureteral stricture is full thickness until retroperitoneal fat is seen. The extent of the incision should be 1 cm beyond the area of the stricture on either side, including extension of the cephalic portion of the incision into the renal pelvis for extreme proximal strictures.

Midureteral strictures may be approached antegrade or retrograde. In cases of midureteral stricture using the antegrade approach, a flexible ureteroscope is recommended to minimize trauma to the intervening ureter. The flexible ureteroscope necessitates the use of a 2- or 3-Fr electrosurgical probe or a laser fiber. Using visual orientation along with fluoroscopy in two planes, a full-thickness incision is made laterally in the ureter above the iliac crossing, anteriorly in the ureter overlying the iliac vessels, or anteromedially in the ureter below the iliac vessels. Retroperitoneal or periureteral fat should be exposed by the incision, which extends 1 cm proximal and 1 cm distal to the ureteral stricture. Tissue injury from use of electrosurgical devices with a greater than 400-µm tip is similar to that of a cold-knife incision *(16)*.

Retrograde Endoureterotomy

The decision of whether to use a retrograde rather than an antegrade endoureterotomy approach to manage a ureteral stricture depends on the individual case and the surgeon's preference. Decreased morbidity, hospitalization, and ease of access to the upper urinary tract, make the retrograde approach attractive for many patients with ureteral strictures.

The retrograde approach is easiest for distal ureteral strictures. Usually these strictures occur at the ureteral orifice, in the intramural portion, or just at or slightly above the ureterovesical junction. If the orifice or intramural ureter is involved, these strictures are incised cystoscopically such that the lower limb of the incision extends through the ureteral orifice to open the site into the larger cavity *(17)*. A right-angle electrocautery attachment is placed through the resectoscope sheath. Using a 50-W pure cut, the surgeon begins the incision at the 12 o'clock position of the ureteral orifice and extends it cephalad through the ureteral orifice, ureteral tunnel, and for a distance of 1 cm cephalad to the area of stricturing. The incision is performed over an inflated ureteral dilating balloon placed in the intramural ureter, with care taken not to puncture the balloon with electrocautery. For more proximal strictures, a ureteroscope can be used (Fig. 1).

The Acucise cutting balloon device has also been used in the management of proximal and distal ureteral strictures *(18)*. Under fluoroscopic control, the balloon catheter is positioned in the strictured region of the ureter. In the proximal ureter above the iliac vessels, the cutting wire is oriented posterolateral. Below the iliac vessels the cutting wire is directed anteromedially to avoid the branches of the internal iliac artery and vein. For strictures lying directly over the iliac vessels, direct ureteroscopic visualization would be a more appropriate approach.

Antegrade/Retrograde Endoureterotomy

For complex ureteral strictures, such as those located at ureteroenteric anastomosis or occurring in the ureter of a transplanted kidney, an approach with both antegrade and retrograde control affords optimal access to and control of the stenotic site. Through-and-through access facilitates identification and manipulation of the stenotic area, which is often difficult when approached from only one direction.

Complete ureteral obstruction is a great technical challenge. When this situation occurs, the extent of the stricture can be estimated through a combined antegrade nephrostogram and retrograde ureterogram. A well-described technique for these cases is the "cut-to-the-light" procedure performed using a small electrocautery probe through one endoscope with the light turned off, cutting towards the light at the tip of another endoscope on the other side of the stricture. A short (<1 cm) occlusion can be approached effectively in this manner. Bagley *(19,20)* has reported successful recanalization of complete ureteral obstructions up to 5 cm in length. However, in general, ureteral strictures longer than 2 cm are more successfully managed with an open surgical procedure. Alternative endoscopic techniques for complete ureteral occlusion have been described, including a "cut-to-the-light" procedure that uses a laser (with railroading of a catheter over the laser fiber) and entrapment snares to pull a wire through the ureter.

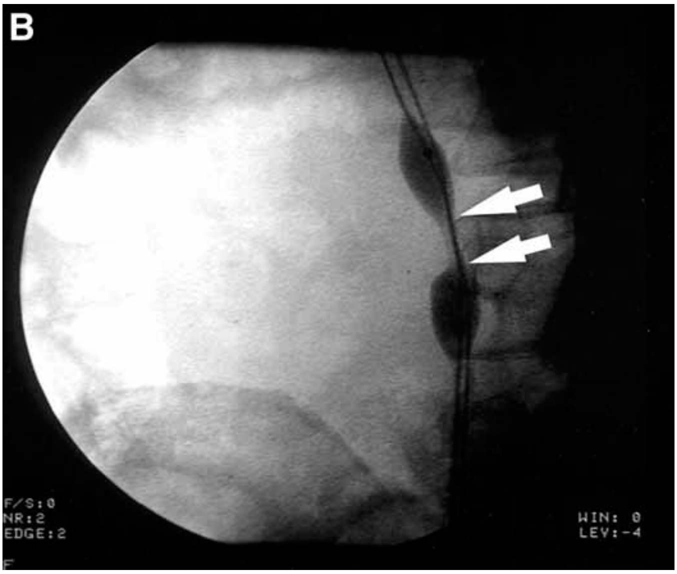

Fig. 1. (A) Intravenous urogram demonstrating high-grade proximal right ureteral stricture (white arrowhead). **(B)** Prior to retrograde ureteroscopic incision, the stricture is defined with low-pressure inflation of a ureteral dilating balloon (white arrowheads indicate stricture). **(C)** Ureteroscope proximal to stricture following incision laterally. **(D)** 10-mm balloon fully inflated at the stricture site. **(E)** Contrast material injected through the distal balloon port after deflating the balloon reveals the desired wide extravasation (white arrowhead). (Reprinted from ref. *17a*, with permission.)

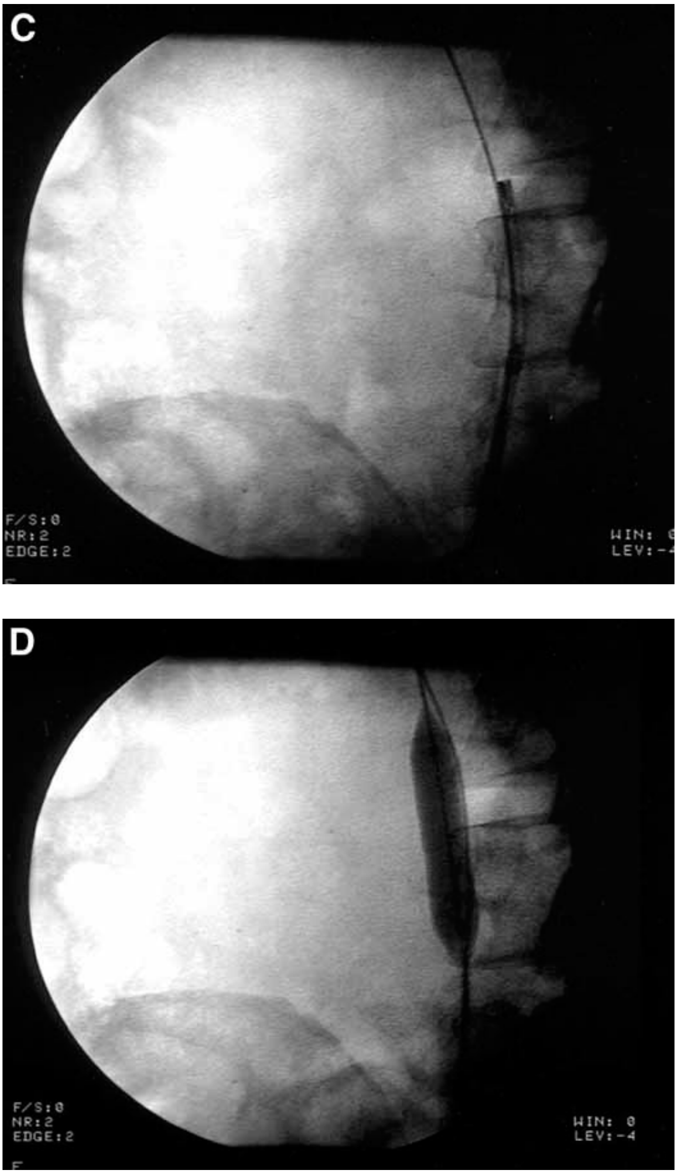

Fig. 1. (*Continued*)

TYPES OF CUTTING DEVICES

Cold Knife

A rigid ureteroscope is employed when making a cold-knife incision to relieve ureteral strictures. Knife blades come in variety of configurations: straight, half-moon, and hook shape. Owing to the large size of the endoscopic instrument needed to perform the incision, their use is limited to the distal ureter where a retrograde approach employs a semirigid ureteroscope, or to the proximal ureter, where an antegrade approaches employs a nephroscope. For additional control under direct endoscopic vision, knife blades can be mounted over a guidewire running through a resectoscope *(20)*.

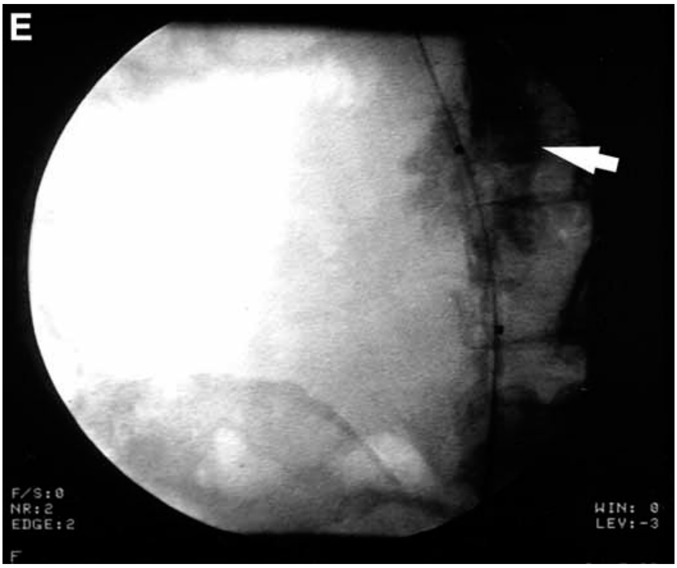

Fig. 1. (*Continued*)

Electrocautery

The electroincision technique for ureteral strictures usually uses 2- to 3-Fr electrodes, which are available in various configurations. Electroincision is favored over the cold-knife incision because the lower caliber probes can be placed through smaller semirigid and flexible ureteroscopes, therefore enabling the incision to be made anywhere along the ureter *(20)*.

Lasers

The small and flexible laser fibers provide the main advantage this modality for ureteral strictures. Currently available lasers include the Nd:YAG (neodynium:yttrium-aluminum-garnet), diode lasers with contact fibers, the KTP Nd:YAG (potassium-titanyl-phosphate Nd:YAG), and the Ho: YAG (holmium:YAG). The Ho:YAG laser provides the finest incisions and the least peripheral damage. Of these lasers, only the Ho:YAG laser also permits stone fragmentation, and as such it is the most versatile for endourological purposes. The preferred power setting for performing endoureterotomy is 10 W *(21,22)*.

Acucise Endoureterotomy

The Acucise endoureterotomy incorporates both a monopolar electrocautery cutting wire and a low-pressure balloon *(18,23)*. The catheter is passed to the strictured segment over a working guidewire either in a retrograde or antegrade fashion *(24)*. The balloon is utilized to define the area of stenosis and to carry the cutting wire. The electrically active surface on the cutting wire is 2.8 cm in length and 150 µm in diameter. The cutting wire should be activated for 5 seconds at 75 W. The catheter body has radio-opaque markers that help locate the balloon and cutting wire during positioning. Fluoroscopy must be employed to visualize the orientation of the cutting wire within the ureter.

ENDOURETEROTOMY RESULTS

Endoureterotomy success rates vary between 55 and 85% for benign ureteral strictures *(17–25)* (Table 1). Comparisons among the studies are difficult because of the different

Table 1
Endoureterotomy for Benign Ureteral Strictures (Review of Literature)

References	*Location*	*% Success*	*Follow-up months*
Lopatkin et al. *(68)*	Proximal (3)	67%	22
	Middle (0)	N/A	
	Distal (4)	100%	
	Total (7)	86%	
Eshghi et al. *(69)*	Total (20)	88%	N/A
Schneider et al. (28)	Proximal (0)	N/A	15
	Middle (0)	N/A	
	Distal (12)	83%	
	Total (12)	83%	
Chandhoke et al. *(18)*	Proximal & middle (3)	67%	4
	Distal (5)	80%	
	Total (8)	75%	
Cohen et al. *(24)*	Proximal (3)	67%	29
	Middle (0)	N/A	
	Distal (5)	80%	
	Total (8)	75%	
Preminger et al. *(26)*	Total (40)	71%	9
Wolf et al. *(1)*	Proximal (4)	75%	28
	Middle (5)	100%	
	Distal (29)	78%	
	Total (38)	82%	
Singal et al. *(21)*	Proximal & middle (2)	50%	11
	Distal (10)	70%	
	Total (12)	67%	
Total	Proximal (10)	70%	4–29
	Proximal & middle (5)	60%	
	Middle (7)	86%	
	Distal (65)	78%	
	Total (145)	78%	

cutting modalities, variable length of follow-up, etiology, stricture location, and length, as well as variable duration of stenting and size of stents used.

Endoureterotomy for middle and distal ureteral stricture disease appears to have good clinical results with success rates ranging from 66 to 88%. The overall success rate for 156 patients undergoing endoureterotomy is 78%, which appears to be better than the overall success rate of 67% noted for balloon dilation *(1,18,24–28)*.

The largest reported series of endoureterotomy consisted of 38 benign ureteral and 30 benign ureteroenteric strictures in renal units with greater than 25% of residual renal function *(1)*. Various cutting modalities were employed. Median follow-up for benign ureteral strictures was 28.4 months, and all failures occurred within 11 months of the procedure, with a 3-years success rate of 80% *(1)*. Preminger et al. *(26)* reported the results of a multicenter trial involving the use of the Acucise balloon catheter for the management of 40 ureteral and 9 ureteroenteric strictures. Patients were followed for an average of 8.7 months (range 1.2 to 17 months). Acucise incision of the distal ureter had a success rate of 58%, while incision of the proximal and midureter had success rates of 50% each. The overall success rate for Acucise incision of benign ureteral strictures was 55%.

TIPS AND TRICKS

Several studies have suggested that better outcomes are achieved when endoureterotomy is applied to strictures in the terminal portions of the ureter (i.e., distal or proximal), in nonischemic strictures and in short strictures. Ipsilateral renal function has also been identified as an important predictor of outcome *(13,14,25,29–32)*.

Stricture Location

Endoureterotomy for proximal and distal ureteral strictures has a greater success rate than that for midureteral strictures *(25,31)*. Opening the stricture widely by marsupialization into a larger cavity such as the renal pelvis or bladder may account for the difference. Other authors have suggested that distal reflux after stricture marsupialization into the bladder could provide additional distention of the incised ureter that could contribute to higher success rates (25).

Smith (30) showed that in a series of 28 patients with ureteral stricture disease, all 4 patients with a midureteral stricture failed balloon dilation. Similarly, Meretyk et al. *(25)* noted a 25% success rate for endourologic incision of midureteral strictures compared with an 80% success rate for distal and proximal ureteral strictures.

Stricture Type

The causes of ureteral strictures have also had a significant impact on the success of a procedure. The most common cause (23%) of ureteral stricture in one series was postoperative fibrosis following open pelvic surgery or ureteroscopic procedures. These relatively nonischemic strictures respond better to endoscopic treatments than do poorly vascularized strictures *(25,33,34)*.

Ureteral strictures secondary to radiation therapy, or resulting from extraluminal malignancies causing periureteral compression, respond poorly to endoureterotomy *(33)*. In contrast, patients with a concomitant ureteral calculus and an apparent ureteral stricture usually have resolution of the stricture following removal of the obstruction and alleviation of the inflammatory response.

Stricture Length

Longer strictures tend to be associated with poorer success rates. Netto et al. *(33)* and Chang et al. *(34)* concluded that strictures longer than 1 cm rarely respond well to balloon dilation. Meretyk et al. (25) found that the best results following endoureterotomy were in those patients with strictures less than 2 cm. Schneider et al. *(28)* reported that the longest stricture they treated by cold-knife incision was 2.5 cm in length, and this patient re-obstructed 24 hours after removal of the ureteral stent. It is most appropriate to apply endosurgical management only to strictures less than 2 cm in length.

Stricture Duration

The duration of a ureteral stricture before treatment has no significant effect on the success rate of the therapy. When the factors of stricture length, location, and type are controlled, the duration of the stricture does not alter the outcome. Successful endosurgical therapy has been reported in strictures ranging from 8 weeks to 18 months duration *(33)*.

Renal Function

Renal units contributing less than 25% of overall renal function are more likely to fail endoureterotomy. This may be the result of inadequate urine flow through the ureter, which may contribute to preventing the incised stricture from re-stenosing. Moreover, a poorly functioning kidney produces less epidermal growth factors. Production of various growth factors appears to correlate well with glomerular filtration rate, irrespective of the cause of decreased renal function. Poor stricture healing may be caused by lack of sufficient mitogenic stimulation *(35)*.

Stent Size

Stents from 5 to 16 Fr in size have been utilized following endoureterotomy *(25)*. It is not clear whether the stent should act as a mold, around which the ureter reforms, or as a scaffold that guides ureteral healing. Some like to use the a large stent, whereas others argue that large stents might compromise vascularization of the ureteral segment *(36–40)*. A retrospective report suggests that benign ureteral strictures benefited from the use of a 12 Fr or larger stent *(1)*, but other studies of endopyelotomy suggest that smaller stents (6–8 Fr) provide equal results, as compared to patients who received a 7/14-Fr endopyelotomy stent *(41–43)*.

Duration of Stenting

The rationale of placing stents following ureteral dilation or incision is to promote ureteral healing, prevent extravasation of urine, and avoid restricturing. Most authors agree that stents are useful for successful healing following endoureterotomy. Although there have been experimental studies of “stentless” endoureterotomy, this has not been applied clinically. Excessively long duration of indwelling stents can cause inflammation that may prevent adequate healing or promote the formation of hyperplastic muscle or scar tissue. In one animal study, there was no difference in ureteral healing among incisions managed with a 1-, 3-, or 6-weeks period of stenting *(44)*. The duration of stenting, as long as it is not less than 1 week or more than 6 week, likely is not a major factor.

Choice of Cutting Modality

Cold-knife incision of ureteral strictures is as effective as electrosurgery and Ho:YAG laser *(18,21,26,28)*. Figenshau et al. *(45)* investigated the acute tissue changes that occur in the pig ureter following balloon dilation, cutting balloon, and endoscopic incision with a cold knife, Nd:YAG laser, or electrocautery (250- and 660-μm electrocautery probes). There was no significant difference in the degree of tissue injury among the various cutting modalities except for the larger 660-μm electrosurgical probe. Unlike a ureteral incision balloon, dilation resulted in injury to the lamina propria but did not appear to split the muscularis and adventitial layers *(45,46)*. The Ho:YAG laser is currently the cutting modality of choice for many urologists since it provides a well-controlled, hemostatic incision *(21,47)*.

Adjunctive Steroids

Triamcinolone at a dose of 120 to 200 mg (3–5 mL at 40 mg/mL) has been endoscopically injected with a 3-Fr Greenwald needle into the incised stricture bed in selected patients with long and or ischemic strictures in whom endoureterotomy alone is less likely to be effective. These patients often have complex medical issues that prompt the selection of endoureterotomy over open surgical correction. Schmeller et al. *(48)* demonstrated that histologically the area of the ureterotomy consisted of collagen-rich connective tissue with few fibroblasts and a scarcity of smooth muscle fibers. Thus, the application of triamcinolone into the incised bed of the ureteral stricture may inhibit collagen formation and improve the success of endoureterotomy. However, the long-term utility of triamcinolone in the management of stricture disease is unknown *(1,25)*.

Adjunctive Urothelial Graft and Metal Stents

Urothelial graft in association with endoureterotomy has been reported in a few patients. Experimental results with free tissue grafts (i.e., tunica vaginalis) to repair the ureter have been inconsistent and complicated by hydronephrosis and graft sloughing *(49,50)*. However, a free graft of bladder urothelium has worked well for urethral stricture disease and could possibly be of value for ureteral replacement *(51,52)*. In Urban's series *(53)*, six patients underwent a free urothelial graft for ureteral strictures. Mean follow-up at 30 months revealed a patency rate of 83%.

The use of metallic ureteral stents is another controversial issue. Cussenot et al. *(54)* reported on the use of a flexible, expandable, tantalum wire stent in the management of ureteral stricture disease. All patients had complicated pathology including periureteral malignancy; several failed endourological balloon dilation attempts. Follow-up showed that 75% had recurrent obstruction. In contrast, Pauer *(55)* used a 7-mm self-expanding stainless steel alloy stent to treat ureteral obstruction secondary to metastatic retroperitoneal tumor. With a mean follow-up of 27 weeks, 87% of the stents remained patent.

ENDOURETEROTOMY IN SPECIAL CIRCUMSTANCES

Ureteroenteric Anastomotic Strictures

Ureteroenteric strictures are a late complication of urinary diversion. The rate of stenosis at the ureteroenteric anastomosis ranges from 4 to 8% *(56,57)*. The cause is thought to be ischemia in most cases. Recurrent tumor or inflammation secondary to radiation therapy is a less common cause of late stricture formation.

Treatment for ureteroenteric strictures may take an antegrade, retrograde or combined antegrade and retrograde approach (Fig. 2). The largest single-center series of balloon dilation reported the treatment of 37 ureteroenteric anastomotic strictures in 29 patients *(58)*. Most of these patients had undergone cystectomy and diversion for bladder or uterine/cervical carcinoma and had received adjuvant radiation therapy before cystectomy. All of the ureteroenteric strictures were dilated in an antegrade fashion. Most of the ureters were stented with an 8.3- or 10-Fr stent and were maintained for 1 to 6 weeks. In short-term follow-up, only 30% of the cases were considered to be clinical successes. At 1 year of follow-up, only 16% of strictures were patent.

Endosurgical incision of the ureterointestinal anastomotic stricture may be performed in an antegrade or a retrograde manner, although most investigators have used the antegrade technique or a combined antegrade/retrograde approach *(1,21,59–62)*. The largest single-center study was reported by Poulakis et al. *(70)*. In this report, the authors describe a success rate of 86, 68, and 61%, respectively at 1, 2, and 3 years in 40 patients with 43 ureterointestinal anastomotic strictures. The authors' technique is

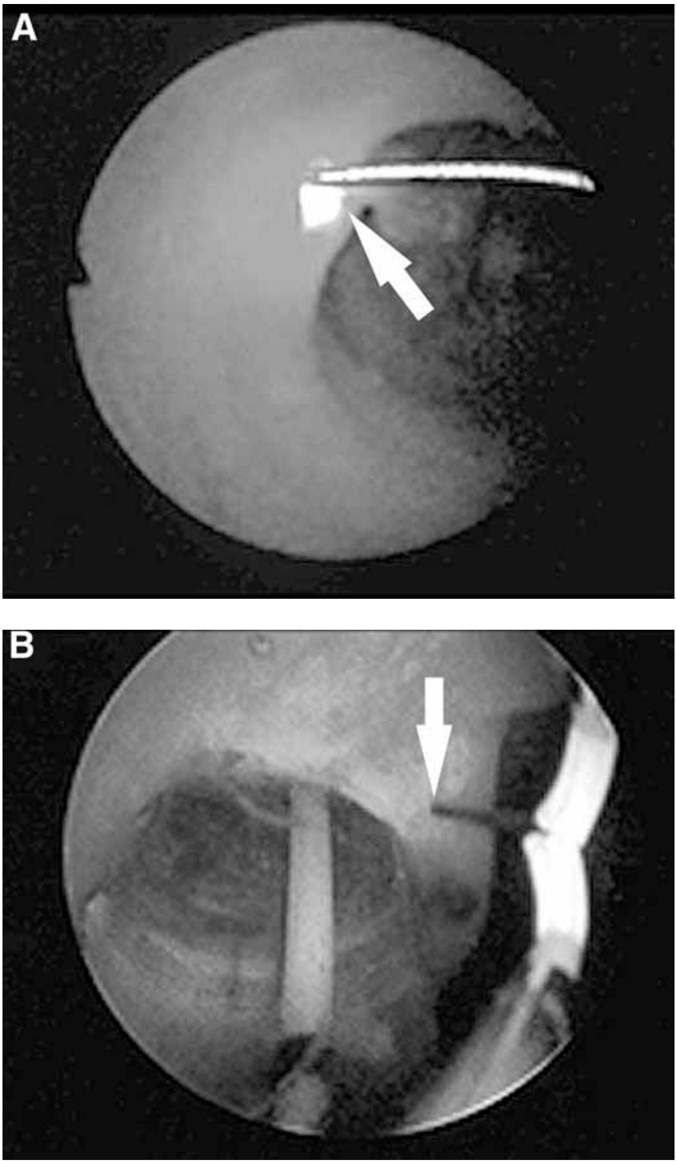

Fig. 2. (A) Endoscopic view from the ileal conduit aspect of a ureteroenteric anastomotic stricture at a wire that has been placed through the stricture using an antegrade ureteroscope (white arrowhead indicates light from antegrade ureteroscope). **(B)** A ureteral dilating balloon has been placed over the wire and a resectoscope with Colling's knife (white arrowhead) is used to incise the stricture over the balloon. **(C)** Appearance of stricture after incision, which was marsupialized ureter proximal to the stricture into the ileal conduit. (Reprinted from ref. *17a.*).

notable for the use of a cold-knife, which may minimize thermal damage to the surrounding tissue. In addition, the authors used multiple shallow cuts rather than a single deep incision. This technique differs from the more commonly performed single incision through the entire scar depth. The excellent results of these authors may suggest that this type of incision may be a better way to manage ureteroenteric strictures. These authors found that many factors (renal function, length of stricture, interval to stricture

Fig. 2. (*Continued*)

formation, degree of stricture, etc.) were cumulative in their impact on their results. Wolf et al. *(1)* reported their series of 30 ureterointestinal anastomotic strictures in 25 patients. The success rates of endoureterotomy for ureteroenteric strictures at 1, 2, and 3 years were 72, 51, and 32%, respectively. There was an improved outcome for right rather than left strictures (68 vs 17% 3-years success rates, respectively) and for strictures treated less than 24 months after the etiological insult. More favorable outcome was noted with the use of 12 Fr or larger stents and stenting longer than 4 weeks. The three most important factors in the minimally invasive management of ureteroenteric strictures probably are renal function, stricture length, and completeness of the stricture.

Ureteral Strictures Postrenal Transplantation

Following renal transplant, the frequency of a ureteral complication is closely associated with the type of reimplant performed at the time of transplantation. With Leadbetter–Politano reimplantation, urinary tract complications occur in 5 to 11% of patients *(63)*. However, with the adaptation of extravesical ureteroneocystostomy, the incidence of urological complications has fallen to below 4% *(63)*. However, up to two-thirds of these urological complications are still owing to ureteral obstruction. The obstruction may be either intrinsic (i.e., ureteral stricture) or extrinsic (i.e., perirenal fluid collection, such as lymphocele, urinoma, abscess, or hematoma). The development of strictures usually occurs early in the postoperative course, but in some cases formation may occur as late as 5 years postoperatively *(63–65)*.

Endoureterotomy has been successfully used in posttransplant ureteric strictures. Conrad et al. *(66)* used cold-knife endoureterotomy to treat 11 transplant patients with ureteral strictures; all but two of the strictures were in the distal ureter. An indwelling 14-Fr stent was placed for a period of 4 to 6 weeks. Success was achieved in 82% of patients with a mean follow-up of 28 months. Using the Acucise balloon device, Youssef et al. *(67)* reported a high rate of success in postrenal transplant ureteral strictures. Overall, it would appear that an endourological approach with balloon dilation or endoureterotomy is a reasonable first step when dealing with posttransplant ureteral strictures.

CONCLUSION

Endoureterotomy is the procedure of choice for the initial management of benign ureteral strictures. Endoureterotomy for benign ureteral strictures has consistently reported higher success rates than endoureterotomy for ureteroenteric strictures, and in the former, failures appear within the first year. In addition, repeat endoureterotomy has a better likelihood of success if radiological improvement was noted after the initial procedure. In contrast, endoscopic or fluoroscopic incision of ureteroenteric strictures appears to do less well, with failures continuing for the first three years. Repeat incisions are more likely to fail and open repair or chronic long-term stenting is often a better management if open surgery is to be avoided *(68)*.

The success of endosurgical treatment depends to a large extent on the characteristics of the stricture: cause, length, and location *(69)*. Unfortunately, rarely do study reports subdivide the patient groups according to their stricture characteristics. This factor, when combined with the inconsistencies of the technique of incision and the variability in posttreatment stent size and duration of stenting, results in a significant amount of clinical confusion such that cumulative data on the endosurgical management of ureteral stricture can only be judged in a broad manner.

In conclusion, endourological management of ureteral strictures has not acquired the same degree of acceptance as endourological management of UPJO. Overall, the endosurgical management of distal and upper ureteral strictures less than 2 cm and not associated with radiation or other ischemic injury is highly successful and results in minimal morbidity. Also, failure to establish patency does not preclude a subsequent open reconstructive repair. Strictures longer than 2 cm and those associated with radiation or ischemic injury or a middle ureteral location may be managed more appropriately by open reconstruction because of the high failure rate associated with this group of patients treated endosurgically. Further clinical studies are necessary to determine the long-term feasibility and success of adjuvant therapy, such as triamcinolone injection and free urothelial grafting.

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14 Treatment of Caliceal Diverticula

Edward D. Matsumoto, MD, FRCSC,
and Margaret S. Pearle, MD, PhD

CONTENTS

SUMMARY

Caliceal diverticula represent a therapeutic challenge for the endourologist. Treatment options for symptomatic, stone-bearing, caliceal diverticula include shockwave lithotripsy (SWL), ureteroscopy, percutaneous nephrostolithotomy/ablation, and laparoscopic unroofing. A surprising number of patients achieve symptomatic relief despite poor stone-free rates with SWL, although this approach is best reserved for patients with a small stone burden in a diverticulum with a widely patent neck. Ureteroscopic management (consisting of laser endoinfundibulotomy or balloon dilation of the infundibular neck and fragmentation/removal of the stones) is a good option for relatively small, upper or middle caliceal diverticula with stones less than 15 mm in size. The percutaneous approach is associated with the highest stone-, symptom-, and diverticulum-free rates and is the optimal treatment for all but anteriorly located diverticula. Lastly, laparoscopy is reserved for large, anteriorly positioned diverticula or diverticula that fail endourological management.

Key Words: Caliceal diverticulum; hydrocalyx; renal calculus; endoinfundibulotomy; infundibular stenosis.

INTRODUCTION

Caliceal diverticula are eventrations of the upper collecting system that are lined by transitional epithelium and communicate with the collecting system via narrow

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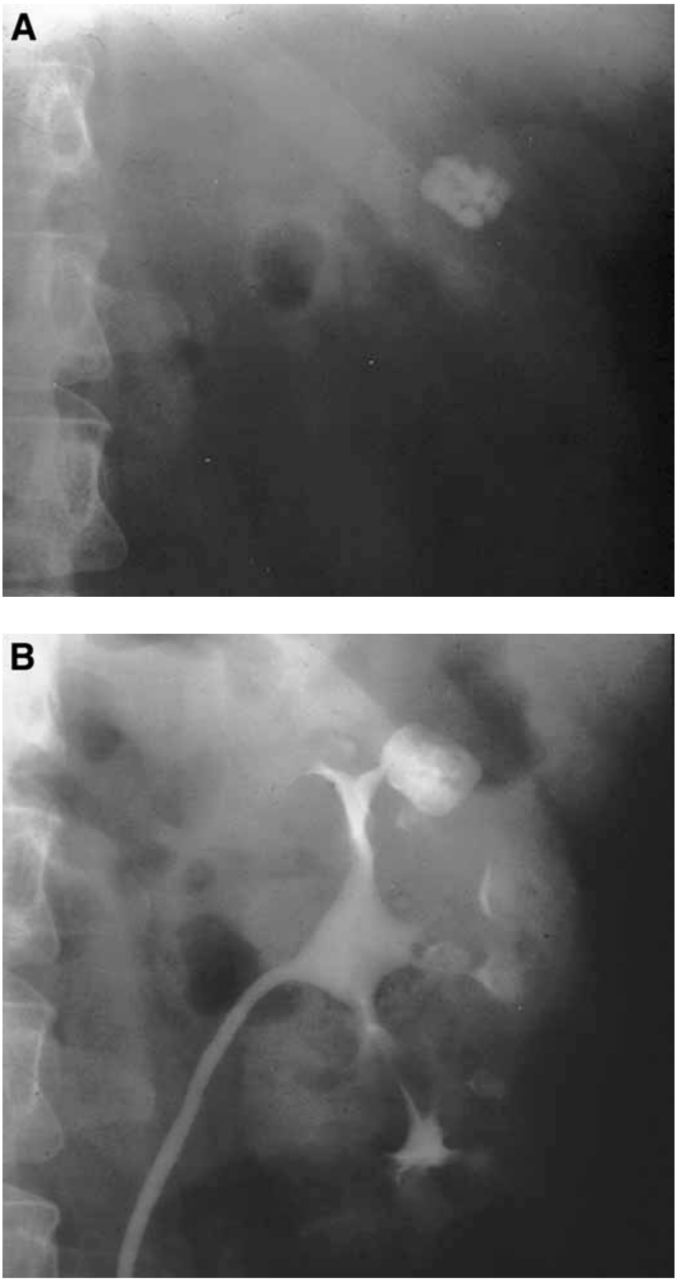

Fig. 1. (A) Scout film demonstrating cluster of stones. **(B)** Intravenous pyelogram demonstrating stones within upper pole caliceal diverticulum.

infundibula *(1)*. The radiographic incidence of caliceal diverticula is 0.2 to 0.5% *(2,3)*. In 25 to 50% of cases, stones are identified within the diverticulum *(4,5)*.

Although caliceal diverticula are often asymptomatic, they may also be associated with flank pain, urinary tract infection or hematuria. Asymptomatic patients require no treatment; however, intervention may be necessary in symptomatic patients.

Historically, symptomatic caliceal diverticula were managed surgically by (1) obliterating the diverticular cavity and enlarging or closing the infundibulum; (2) excising the thin overlying parenchyma and marsupializing the diverticulum; or (3) partial nephrectomy *(1,2,6)*. Currently, minimally-invasive alternatives are available for management of symptomatic caliceal diverticula with or without stones, including shockwave lithotripsy (SWL), ureteroscopy, percutaneous nephrostolithotomy, or laparoscopic ablation. Likewise, hydrocalices associated with stenotic infundibula can be treated by the same endoscopic approaches, while leaving the secretory epithelium intact. The objective of this chapter is to review the endourological approaches to treatment of caliceal diverticula.

INDICATIONS AND PREPARATION FOR SURGICAL INTERVENTION

Indications for the treatment of caliceal diverticula include flank pain, hematuria, or urinary tract infections that cannot be attributed to other causes. Microscopic or gross hematuria is most commonly associated with stone-bearing caliceal diverticula.

All patients should undergo preoperative imaging with a computed tomography (CT) scan and intravenous urogram to determine the size and location of the diverticula and stones, to assess the overlying renal parenchyma and the diverticular neck and to delineate the relational anatomy of the diverticula. Careful inspection of intravenous urogram images may allow identification of the calyx with which the diverticulum is associated; retrograde pyelography may further delineate the diverticular neck (Fig. 1).

Active urinary tract infections should be treated in advance of the procedure and the selection of preoperative antibiotics should take into account organisms cultured from previous urine specimens.

RETROGRADE URETEROSCOPIC APPROACH

Instrument List

1. Flexible or rigid cystoscope.
2. Flexible ureteroscope.
3. 0.035-in. Bentson guidewire.
4. 0.038-in. double flexible tip, extra-stiff guidewire.
5. 5-Fr open-ended angiographic catheter.
6. 8-Fr cone-tip catheter.
7. 8/10-Fr coaxial dilator or 10-Fr dual lumen catheter.
8. Single action syringe-assist pressure irrigating device or pressurized irrigation bags.
9. Holmium:YAG laser and 200-µm laser fiber.
10. 7-Fr double pigtail ureteral stent.
11. Optional:
    a. 0.035-in. angled and/or straight hydrophilic guidewire.
    b. 12/14-Fr ureteral access sheath.
    c. 4-mm, 4-cm dilating balloon mounted on a 3-Fr shaft for passage through the ureteroscope (Passport™ Balloon on a Wire, Boston Scientific, Natick, MA) or 4-mm, 4-cm high pressure dilating balloon (7-Fr shaft).

Indications for Retrograde Approach

Patients with upper- or midpole caliceal diverticula with or without stones 15 mm or less in size are amenable to a retrograde ureteroscopic approach.

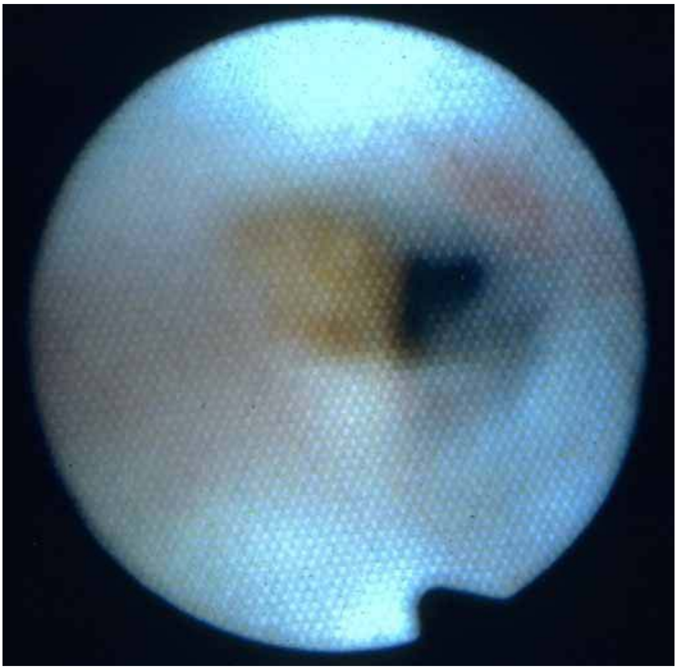

Fig. 2. Ureteroscopic view of diverticular ostium with stone evident.

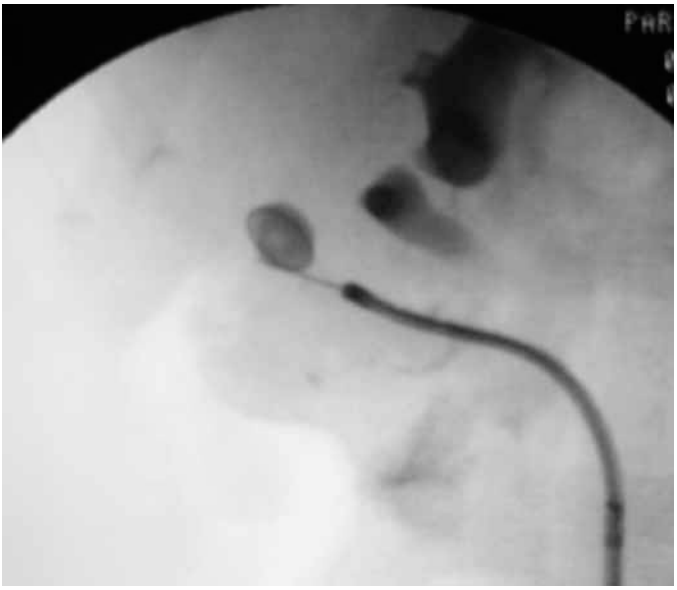

Fig. 3. Guidewire advanced into diverticulum.

Technique

Broad-spectrum or culture-specific antibiotics are administered preoperatively. After induction of general anesthesia, the patient is placed in the dorsal lithotomy position then prepared and draped. Rigid or flexible cystoscopy is performed to inspect the bladder and a retrograde pyelogram is performed via a 8-Fr cone tip catheter to delineate the caliceal anatomy and identify the diverticulum. A 0.035-in. Bentson guidewire is passed cystoscopically into the appropriate ureteral orifice and coiled in the collecting system using fluoroscopic guidance. After removal of the cystoscope, a second 0.038-in. double flexible tip, extra-stiff guidewire is introduced via an 8/10-Fr coaxial dilating system or a 10-Fr duel lumen catheter. The flexible ureteroscope is passed over the extra-stiff guidewire into the collecting system. Use of a ureteral access sheath is optional and may be placed at the discretion of the surgeon at this point in the operation.

Using pressurized saline irrigation as needed, the collecting system is inspected in order to identify the ostium of the diverticulum, which appears as a thin membrane or pinhole opening in the fornix or papilla (Fig. 2). If the ostium is not readily apparent, injection of dilute contrast through the ureteroscope may opacify the diverticulum fluoroscopically and allow identification of the calyx with which the diverticulum is associated. The "blue spritz" test has also been described, whereby methylene blue-stained saline is instilled through the flexible ureteroscope into the collecting system, then aspirated back out through the working channel *(7)*. A stream of blue dye effluxing from the ostium of the diverticulum directs attention to the diverticular neck. A guidewire is passed through the ureteroscope into the ostium and then coiled within the diverticulum to confirm proper position (Fig. 3).

The infundibulum is then dilated or incised. Dilation can be performed using a 4-mm, 4-cm dilating balloon mounted on a 3-F catheter that can be passed directly through the ureteroscope into the diverticulum; alternatively, the ureteroscope is removed and a 4-mm, 4-cm dilating balloon (7-Fr shaft) is passed over the guidewire under fluoroscopic guidance until the radio-opaque marks straddle the diverticular neck. The balloon is dilated under fluoroscopic guidance until a waist, representing the narrowed infundibulum, is no longer identified. If the infundibular neck is short, incision can be carried out under direct vision using a 200-µ Holmium:YAG laser fiber or a 2- or 3-Fr electrosurgical probe (Fig. 4). Optimal settings for incision are 1 J at 10–15 Hz for the Holmium:YAG laser and 50 W pure cutting current for an electrosurgical probe. The guidewire should be removed from the diverticulum before incision to avoid lasing or electrifying the guidewire. The infundibulum is incised by way of several shallow, radial cuts to avoid bleeding from a single deep incision. Dilation of the diverticular neck after incision is optional, but assures separation of the edges of the incised tissue.

Once access to the diverticulum is established, the diverticulum is entered and the stone is removed intact or fragmented with the laser. With the ureteroscope in the diverticulum, pressurized irrigation should be used judiciously to avoid perforating the thin parenchyma overlying the diverticula. A 3-Fr pronged-wire grasper or tipless nitinol basket is used to remove small stones or fragments. Larger stones require fragmentation into pieces small enough to pass through the diverticular opening. Simultaneous SWL has been described to accomplish stone fragmentation after ureteroscopic treatment of the diverticular neck *(7,8)*. Finally, gentle irrigation through the ureteroscope assures clearance of all fragments from the diverticulum. Although ablation of the diverticular wall is desirable, it is often impractical from a ureteroscopic approach because of the large surface area that needs to be ablated by the small laser fiber or electrosurgical probe.

A double pigtail ureteral stent is placed with the proximal coil optimally positioned within the diverticulum. However, for small diverticula with insufficient room to accommodate the coil, the stent is simply placed with the proximal coil in

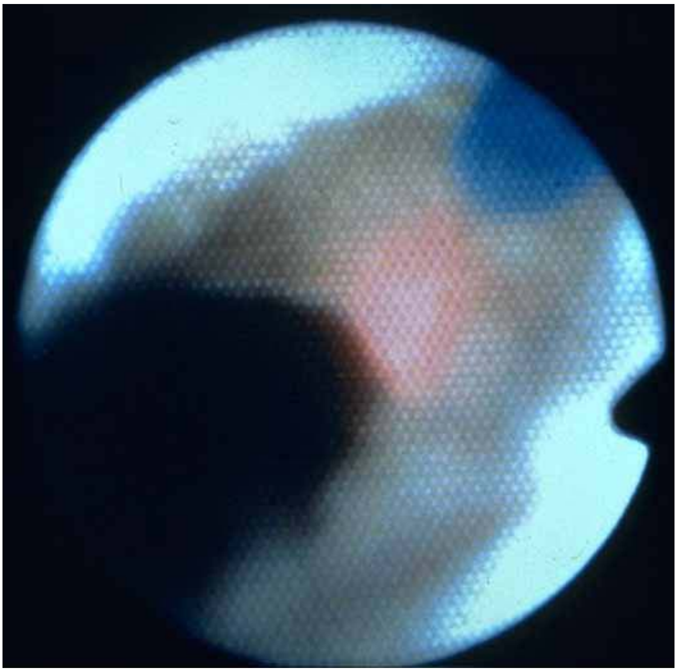

Fig. 4. Holmium:YAG laser infundibulotomy.

the collecting system. The stent may be removed in 7 days if it is placed in the diverticulum and potentially sooner if it is not. Antibiotic coverage is continued until stent removal.

PERCUTANEOUS APPROACH

Instrument List

1. Radiolucent endourology table, with adequate clearance for a C-arm, fitted with split-leg spreader bars.
2. Portable C-arm and fluoroscope.
3. 0.035-in., 260-cm Exchange Bentson guidewire.
4. 7-Fr, 11.5-mm Occlusion balloon catheter.
5. Touhy-Borst adapter (side arm fitting) (Cook, Inc., Spencer, IN).
6. 60% Iodinated contrast, diluted 50:50 with normal saline.
7. 20-Fr Councill catheter.
8. 22- or 18-gage, 15-cm Chiba needle.
9. 0.018-in. Platinum-tip Cope Mandril guidewire (Cook, Inc., Spencer, IN).
10. Jeffrey introducer (Cook, Inc., Spencer IN).
11. 0.035-in. Bentson guidewire.
12. 0.035-in. Angled hydrophilic guidewire.
13. 30-Fr Nephrostomy tract dilating balloon with 30-Fr Amplatz working sheath.
14. 7.1-Fr Single pigtail catheter.
15. 22-Fr Councill catheter.
16. 8-mm, 4-cm Dilating balloon.

17. 24-Fr Rigid nephroscope.
18. Resectoscope fitted with a rollerball electrode.
19. Flexible nephroscope.
20. Ultrasonic lithotriptor.
21. Optional:
    a. Flexible ureteroscope.
    b. Holmium:YAG laser.

Indications for Percutaneous Approach

Peripherally located caliceal diverticula containing large stones (>15 mm cumulative size) are best treated from a percutaneous approach. Direct percutaneous access is optimal for posterior diverticula, whereas anterior caliceal diverticula are most safely accessed indirectly to avoid traversing a large segment of renal parenchyma and risking renal hemorrhage.

Technique

Broad-spectrum parenteral antibiotics are administered preoperatively and intermittent compression devices are applied to the patient's lower extremities prior to induction of anesthesia. After intubation, the patient is positioned prone, with legs secured to spreader bars and bolsters placed lengthwise from shoulders to iliac spine to facilitate chest excursion. In female patients, the breasts are placed inside the rolls. A foam face cushion prevents pressure on the face and eyes. The arms are flexed at the elbows and placed at an angle less than 90° with the shoulders to prevent brachial plexus injury. The knees are padded and flexed and hyperextension of the hips should be avoided.

The perineum and the ipsilateral flank are prepared and sterilely draped. A 0.035-in., 260-cm exchange Bentson guidewire is introduced into the collecting system via flexible cystoscopy. A 7-Fr, 11.5-mm occlusion balloon catheter passed through a 20-Fr Councill catheter fitted with a Touhy-Borst adapter is passed over the guidewire until the tip of the occlusion balloon catheter is visualized fluoroscopically within the renal pelvis. The Councill catheter is passed into the bladder and the balloon is inflated with 10 cc of sterile water. The occlusion balloon is inflated with 1 cc of dilute contrast and withdrawn until it is resting at the ureteropelvic junction. The occlusion balloon is secured to the Councill catheter using the Touhy-Borst adapter.

DIRECT APPROACH

A stone-bearing caliceal diverticulum is targeted directly, or the diverticulum is opacified with dilute contrast via the occlusion balloon catheter. Under fluoroscopic guidance, a 22-gage Chiba needle is used to directly puncture the diverticulum (Fig. 5). Proper position of the needle within the diverticulum is confirmed by aspirating fluid and then gently injecting contrast to opacify the diverticulum. A 0.018-in. platinum-tipped Cope Mandril guidewire (Cook Urological, Spencer, IN) is introduced through the Chiba needle and coiled within the diverticulum (Fig. 6). Although an attempt is made to negotiate the guidewire through the diverticular neck into the collecting system, in most cases the diverticular neck is unable to be cannulated fluoroscopically preventing access to the collecting system. An introducer set (Jeffery sheath, Cook, Inc., Spencer, IN) is passed over the 0.018-in. guidewire into the diverticulum and the inner dilator and stiffener are removed leaving the outer sheath in place, through which a

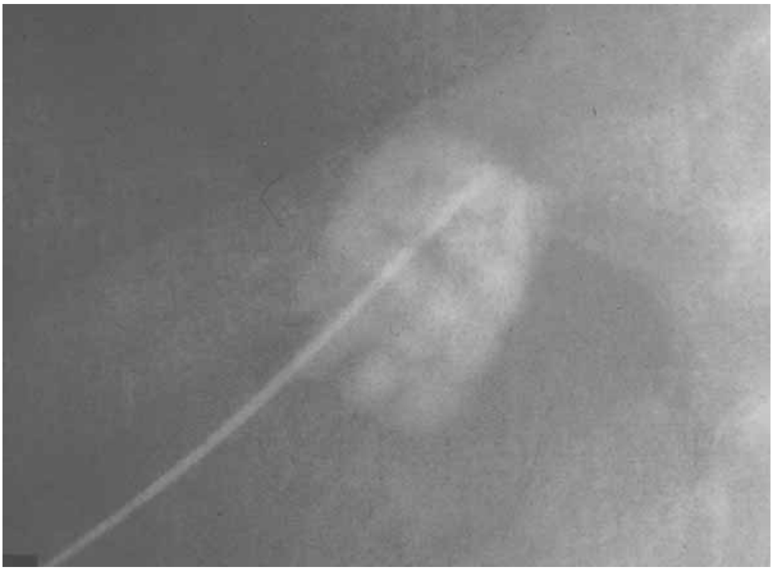

Fig. 5. Percutaneous puncture directly into caliceal diverticulum.

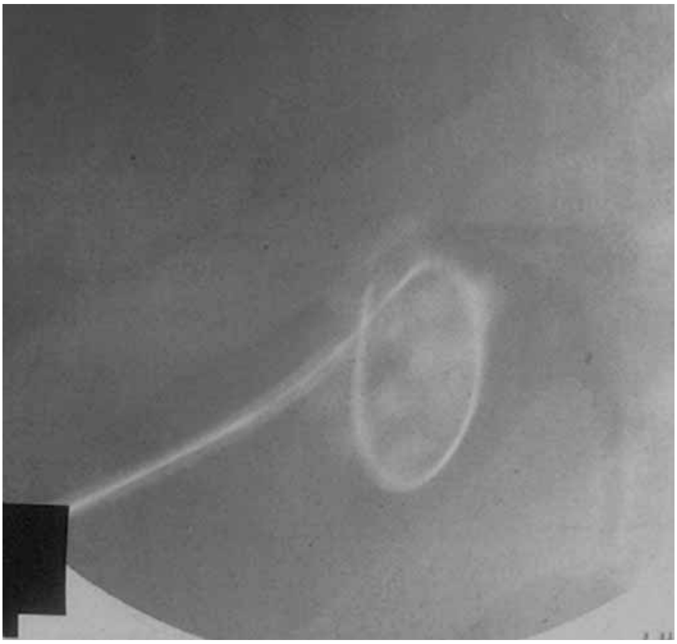

Fig. 6. Guidewire coiled within caliceal diverticulum.

standard 0.035-in. Bentson or Terumo guidewire is introduced. A moveable core guidewire provides variable flexibility or rigidity as needed and may be preferred to a standard Bentson guidewire. Alternatively, an 18-gage Chiba needle may be used to puncture the diverticulum, and a standard size guidewire used directly. The percutaneous tract is dilated using a 30-Fr nephrostomy tract dilating balloon with a back-loaded 30-Fr Amplatz working sheath. Care is taken not to perforate the diverticulum as the balloon is passed over the guidewire. Because the dilating balloon has a long tapered tip and the guidewire is typically coiled within the diverticulum, the working sheath is often left short of the diverticulum, necessitating careful maneuvering of the nephroscope into the diverticulum with subsequent further passage of the sheath into the diverticular cavity.

When the neck of the diverticulum cannot be identified or intubated with a guidewire, creation of a neoinfundibulum may provide secure access to the collecting system and allow internal drainage of the diverticulum *(9–11)*. In this case, an 18-gage Chiba needle is used to directly puncture the diverticulum through and through until the needle enters the collecting system. A guidewire can then be directed down the ureter into the bladder, thereby securing access. The neoinfundibulum is then dilated after removal of the diverticular stones.

For caliceal diverticula that are too small to allow secure percutaneous access but for which percutaneous ablation is desirable (small diverticulum with no stone), a combined retrograde/antegrade approach may be advantageous. With the patient positioned prone as for a percutaneous approach, a flexible ureteroscope is advanced into the collecting system and an attempt is made to identify the ostium of the diverticulum. If the ostium can be seen, the diverticular neck is incision or dilated as previously described and the diverticulum is entered. Percutaneous puncture directly into the diverticulum is performed under both fluoroscopic and endoscopic guidance and the guidewire is passed antegrade through the Chiba needle and retrieved ureteroscopically to obtain secure through and through access. The nephrostomy tract can then be safely dilated and the diverticulum entered and fulgurated from an antegrade approach as previously described. In this case, ureteroscopic assistance facilitates safe access to the collecting system, and greatly facilitates treatment of the diverticulum.

Small stones (≤1 cm) can be removed from the diverticulum with either a grasper or basket. Larger stones (>1 cm) require fragmentation using ultrasonic, pneumatic, or electrohydraulic lithotripsy (Fig. 7). After clearance of stones from the diverticulum, an attempt is made to identify the diverticular neck, which often appears as a pinpoint ostium. Injection of air or indigo-carmine stained saline via the occlusion balloon forces a stream of bubbles (Fig. 8) or blue dye (Fig. 9) into the diverticulum, thereby facilitating identification of the diverticular neck. A guidewire can then be passed through the diverticular neck into the collecting system and ideally down the ureter. The wall of the diverticulum is ablated using a resectoscope fitted with a rollerball electrode (Fig. 10). The guidewire leading into the collecting system should be covered with an angiographic catheter during electrocoagulation to prevent electrifying the guidewire and potentially injuring the collecting system or ureter. The diverticular neck is then dilated with an 8-mm, 4-cm high-pressure dilating balloon or incised with the holmium:YAG (Ho:YAG) laser in shallow, radially oriented incisions. The diverticulum is fulgurated *prior* to dilation or incision of the diverticular neck to prevent loss of orientation and inadvertent fulguration of the collecting system.

Passage of a 7.1-Fr single pigtail catheter over the guidewire into the bladder provides a secure tract over which a large bore nephrostomy tube (22-Fr Councill catheter) is advanced into the collecting system, traversing the dilated/incised diverticular neck. Drainage holes should be cut proximal to the balloon, taking care not to incise the balloon port, to allow drainage of the diverticulum. If the diverticular neck cannot be identified, the balloon catheter alone is passed over the guidewire into the ablated diverticulum to serve as a drain. Placement of a large nephrostomy tube without active fulguration has

Fig. 7. Stones in a caliceal diverticulum viewed percutaneously.

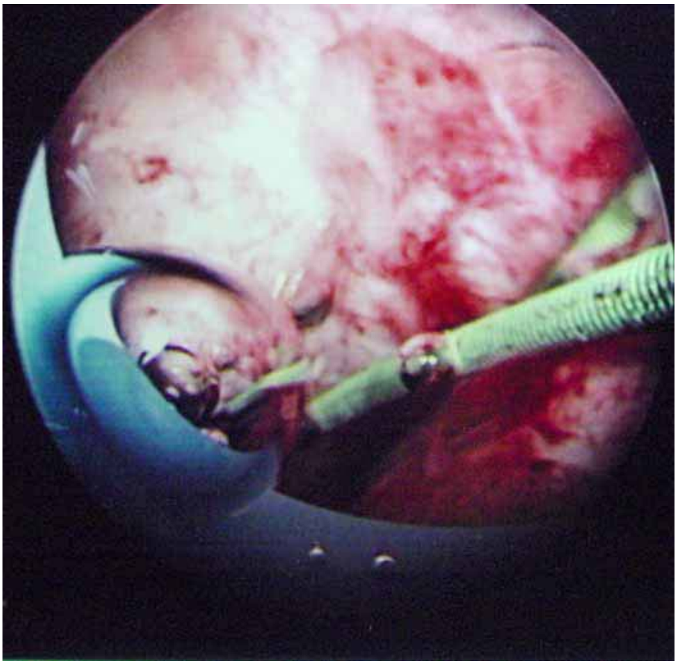

Fig. 8. Air bubbles emanating from diverticular neck after injection of air through occlusion balloon catheter.

been thought by some to be sufficient to stimulate a granulomatous response that results in obliteration of the diverticulum *(12,13)*. The nephrostomy tube is secured to the skin and connected to a drainage bag. Finally, the chest is examined fluoroscopically to iden-

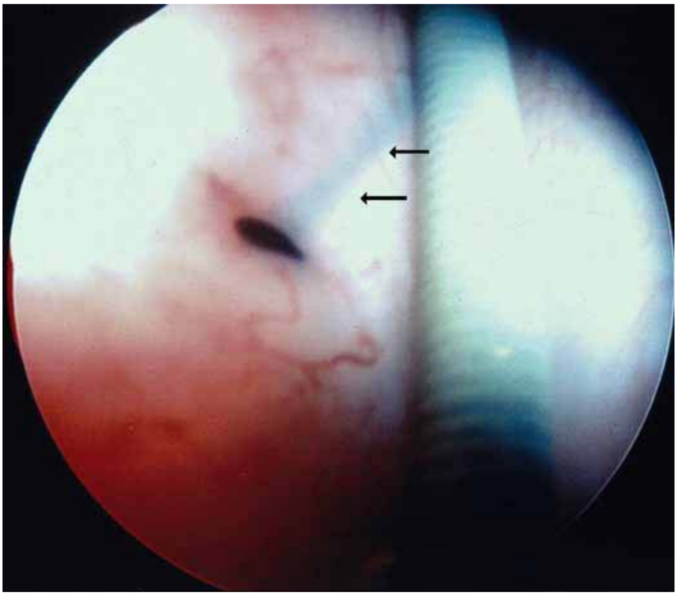

Fig. 9. Stream of blue dye emanating from diverticular neck after injection of indigo carmine-stained saline through retrograde occlusion balloon catheter.

Fig. 10. Rollerball fulguration of caliceal diverticulum through percutaneous access sheath.

tify a hydrothorax. The nephrostomy tube is left in place for 2 to 7 days to allow the diverticular walls to coalesce and the diverticular neck to heal with a larger caliber lumen.

INDIRECT APPROACH

Fig. 11. Ostium of caliceal diverticulum viewed via indirect percutaneous approach.

For the anteriorly located diverticulum, or a diverticulum that lies above the 11th rib, an indirect percutaneous approach is safer than a direct approach, which risks bleeding or injury to the pleura. With an indirect approach, percutaneous access is obtained via a posterior calyx remote from the diverticulum and the diverticulum is accessed indirectly with a flexible or rigid nephroscope. Preoperative preparation and positioning are identical to the direct percutaneous approach. Based on preoperative contrast studies, a posterior calyx likely to provide easy access to the diverticulum is identified and punctured as described in the direct approach. For a diverticulum lying above the 11th rib, a convenient posterior lower pole calyx is chosen; for an anterior diverticulum, a posterior calyx either in the same polar region or opposite is used. Once percutaneous access is obtained, a rigid or flexible nephroscope is used to inspect the collecting system and identify the ostium of the diverticulum, similar to a ureteroscopic approach (Fig. 11). A 0.035-in. Bentson guidewire is passed through the ostium and coiled in the diverticulum. The nephroscope is removed and an 8-mm, 4-cm high pressure dilating balloon is passed over the guidewire under fluoroscopic guidance until the radio-opaque marks straddle the diverticular neck, and the infundibulum is dilated until the waist disappears. Alternatively, endoinfundibulotomy can be performed using either a 2- or 3-Fr electrosurgical probe or the Ho:YAG laser as described previously. If an electrosurgical probe is used, a 5-Fr angiographic catheter should be passed over the guidewire to prevent cautery transmission and inadvertent urothelial injury.

Once the neck of the diverticulum is dilated/incised, the rigid or flexible nephroscope is advanced into the diverticulum and the stones are fragmented and/or removed using ultrasonic, pneumatic, electrohydraulic, or laser lithotripsy (Fig. 12). After stone removal, the urothelial lining of the diverticulum is ablated using electrocautery via a 5-Fr Bugbee electrode (with a flexible nephroscope) or via a resectoscope fitted with a rollerball electrode (with a rigid nephroscope). Irrigation pressure should be minimized

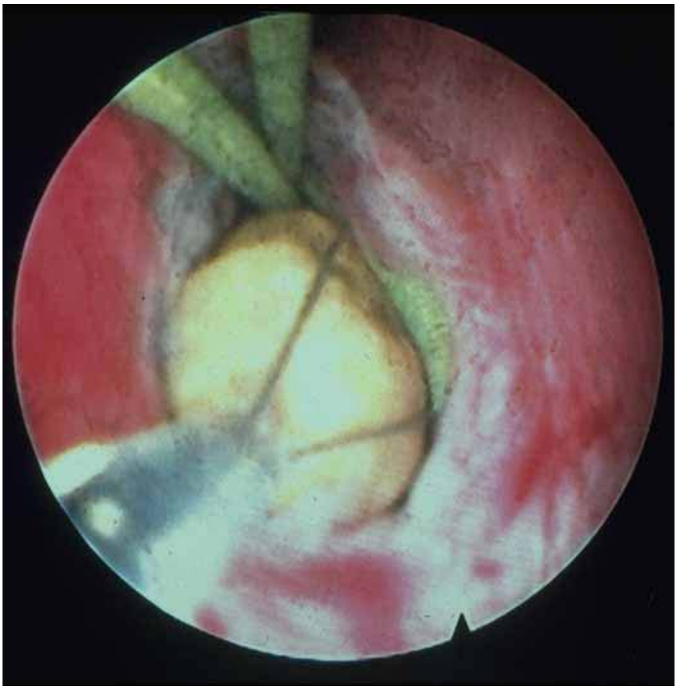

Fig. 12. Basket extraction of a stone from a caliceal diverticulum approached indirectly.

while working in the diverticulum to avoid perforation of the diverticulum, particularly when the overlying parenchyma is thin.

A large bore nephrostomy tube as previously described is placed into the diverticulum and secured to the skin. Extra drainage holes proximal to the balloon are necessary to provide adequate drainage of the collecting system. Alternatively, an 8 to 12 Fr locking loop nephrostomy tube is positioned with the loop in the diverticulum. The nephroscopy tube is left in place for 2 to 7 days.

HYDROCALYX

A hydrocalyx associated with a stenotic infundibulum can be approached in a manner similar to a calyceal diverticulum. However, because the hydrocalyx is associated with secretory epithelium, only the stenotic infundibulum should be addressed and the calyx should not be fulgurated. It can be difficult to distinguish a hydrocalyx from a caliceal diverticula radiographically. However, inspection of a hydrocalyx will reveal a renal papilla whereas inspection of a caliceal diverticular cavity will not.

RESULTS

Outcomes for endourological modalities (ureteroscopy and percutaneous approaches) for the treatment of caliceal diverticula are reviewed in this section. However, for the purposes of comparison, a brief review of outcomes for SWL and laparoscopic approaches are included as well in order to guide treatment selection.

Shockwave Lithotripsy

SWL has been used for treatment of stones in caliceal diverticula with limited success. The mean stone-free rate for SWL from published series is only 21% (range 13 to 58%); however, relief of symptoms surprisingly has been achieved in 68% of patients (range 56 to 86%) *(14–19)*. In the most successful series reported, Streem and Yost *(19)* selected patients with caliceal diverticula associated with short, radiographically patent diverticular necks and stones less than 15 mm in diameter. A stone-free state was achieved in 58% of 19 stone-bearing diverticula; furthermore, in 86% of 14 symptomatic patients, treatment resulted in resolution of symptoms postoperatively.

In general, SWL is indicated only for patients with small stones in caliceal diverticula with a short, radiographically patient diverticular neck. Endoscopic approaches, both ureteroscopic and percutaneous, allow for treatment of both the stone and diverticulum, and as such, are preferred treatment over SWL.

Ureteroscopic Approach

In 1989, Fuchs and David *(8)* ureteroscopically treated 15 patients with stone-bearing caliceal diverticula, additionally applying simultaneous SWL to fragment the stones after dilating or incising diverticular neck. A stone-free state was achieved in 73% of patients and 87% of patients were rendered symptom free. Only one patient (7%) required salvage percutaneous nephrolithotomy. Although in most cases, the diverticula was reduced in size, only one patient demonstrated complete obliteration of the diverticulum on follow-up imaging studies.

Expanding their earlier series (previous paragraph), Pang and associates reported on 36 patients with symptomatic stone-bearing caliceal diverticula in whom ureteroscopic management was initially attempted *(8,20)*. In four patients with lower pole caliceal diverticula, percutaneous treatment was ultimately required. Among the remaining 32 patients, 75% were rendered stone free with combined SWL/ureteroscopy and 87.5% of patients were rendered free of symptoms. Although four patients with residual stones had resolution of their symptoms at early follow-up, two subsequently became symptomatic and were successfully retreated ureteroscopically.

Grasso and associates *(21)* treated four patients with five caliceal diverticula via an endoscopic approach. Although ureteroscopy was attempted in all patients, a completely ureteroscopic approach was utilized in only two cases: the remaining three cases required a combined retrograde ureteroscopic/percutaneous approach. Only one of the two patients treated completely ureteroscopically was rendered stone free. In contrast, the three patients treated with a combined approach were successfully rendered free of both stones and symptoms.

Batter and Dretler *(22)* treated 26 patients with caliceal diverticula, with or without stones, via a ureteroscopic approach, including 18 patients who failed previous SWL treatment. The diverticula were successfully entered in 18 cases (69%) and successfully cleared of stones in 83% of the 18 cases. The three patients with residual stones required further SWL treatment. Among the patients in whom the diverticula were successfully entered and the stones cleared, all were symptom free at a mean follow-up of 45 months. Complications included pain, sepsis, and bleeding, although no patient required a blood transfusion.

In the largest series to date, Chong and co-workers *(23)* treated 96 caliceal diverticula, including 10 lower pole diverticula, using a ureteroscopic approach. The diverticular neck was dilated with a balloon or incised with a Bugbee electrode or Ho:YAG laser; a combination of Ho:YAG or electrohydraulic lithotripsy was used to fragment the stones. The diverticular neck was successfully identified in 95% of cases, with the four failures occurring in lower pole diverticula. An immediate stone-free rate of 90% was achieved and, at 8-year follow-up, only 8% of patients had recurrence of symptoms or stones.

Auge and co-workers *(24)* reviewed their series of 17 patients with symptomatic stone-bearing caliceal diverticula treated ureteroscopically. In four patients, the ostium of the diverticulum was unable to be identified, necessitating a percutaneous approach. Three other patients initially treated with ureteroscopy later underwent a percutaneous procedure because of retained stones and inadequate symptom relief. Among ten patients managed completely ureteroscopically, three patients were rendered stone free and six were symptom free. No complications were reported.

Overall, the retrograde ureteroscopic approach for treatment of caliceal diverticula has been successful in achieving a stone-free state in 78% of patients and a symptom-free state 79% of patients (Table 1). However, in 11% of cases, a secondary procedure was necessary. The complication rate was 9%, although most complications were minor, such as bleeding not requiring transfusion and infection. Caliceal diverticula associated with upper or middle calyces were more successfully accessed ureteroscopically (96% of 79 cases) than diverticula associated with lower calyces, which were successfully entered in only 23% of 13 of cases.

Percutaneous Approach

Hulbert and associates *(25)* used direct (*n* = 15) and indirect (*n* = 3) percutaneous access to manage 18 stone-bearing caliceal diverticula in one of the earliest published series on percutaneous treatment of caliceal diverticula. No attempt was made to fulgurate the diverticular cavity as the authors felt that the trauma to the wall of the diverticulum caused by the dilation process was sufficient to promote obliteration. All patients were rendered stone free and no complications were reported. Among the 15 patients available for follow-up, the diverticulum was successfully obliterated in 12 patients (all direct access); in the 3 patients who underwent an indirect approach, the diverticula persisted on follow-up imaging.

Eshghi and colleagues *(13)* also reported on 14 patients with caliceal diverticula/hydrocalyces managed percutaneously. A direct approach was used to access the diverticula/hydrocalyx in 11 cases and an indirect approach in the remaining 3. The diverticular neck was managed in one of three ways: radial cold knife incision at one or two sites under direct vision (*n* = 8); dilatation to 16 to 18 Fr with fascial dilators or a dilating balloon (*n* = 4) or by direct-vision dissection of the infundibulum using two-prong grasping forceps (*n* = 2). No attempt was made to fulgurate the diverticulum. A Malecot drain was left in the diverticulum from 3 to 14 days. At 12-months follow-up, all 14 patients were stone free and 85.7% of patients demonstrated a decrease in the size of the diverticulum/hydrocalyx. However, in no case was the diverticulum completely obliterated.

Hedelin and colleagues *(26)* percutaneously treated 13 patients with caliceal diverticula percutaneously (direct approach in seven cases, indirect in six cases) and reported a 69% stone-free and symptom-free rate despite complete obliteration of the diverticulum in only one case. No major complications occurred, and a single patient developed a new 1-mm stone in the residual diverticulum during follow-up.

Ellis and co-workers *(27)* reviewed their series of 12 patients with caliceal diverticula, among whom 10 patients had stones and 2 had associated infections. Among the 10 patients with stones, 9 were treated with direct percutaneous puncture and dilation of

Table 1
Retrograde Ureteroscopic Management of Caliceal Diverticulum

Study	*N*	*Location*	*Adjunct procedures*	*Management of diverticular neck*	*Successful entry into diverticulum*	*Stone free*	*Symptom free*	*Obliteration of diverticulum*	*Complications*	*Follow-up (mo)*
Fuchs et al. (8)	15	UP 6 MP 7 LP 2	SWL	Dilation	100% (15/15)	73% (11/15)	87% (13/15)	7% (1/15)	—	
Pang et al. (20)	32	UP/MP 32	SWL	—	—	75% (24/32)	87.5% (28/32)	—	—	—
Grasso et al. (21)	2	UP 1 MP 1	—	Dilation or Ho:YAG incision	100% (2/2)	50% (1/2)			0%	
Batter et al. (22)	26	UP 15 MP 4 LP 7	—	Dilation or electroincision	69% (18/26)	83% (15/18)	100% (18/18)		15% (4/26)	45 (15-84)
Chong et al. (23)	96	NR	SWL	Dilation or incision	96% (92/96)	90% (86/96)	—	—	—	
Auge et al. (24)	17	UP12 MP 2 LP 3	—	Dilation or Ho:YAG incision	76% (13/17)	18% (3/17)	35% (6/17)	18% (3/17)	0% (0/17)	1.4 (1-2)
Overall	191	—	—	—	88% (140/159)	78% (142/184)	79% (65/82)	13% (4/32)	9% (4/43)	—

the diverticular neck with or without fulguration of the cavity, and 1 was treated with an indirect puncture and dilation of the diverticular neck. A 100% stone-free a rate was achieved in the 10 patients with stones. Furthermore, at a mean follow-up of 16 months, 88% of patients were symptom free. In this series, the diverticular cavity was fulgurated in 7 of 12 cases (all by the direct approach) and follow-up imaging showed no residual diverticula in all cases. Interestingly, tetracycline sclerosis was additionally performed in one patient; however, this technique was discontinued because of technical difficulties in determining the correct dosage and because of the potential for extravasation or entry of tetracycline into the collecting system.

Shalhav and colleagues *(28)* reviewed their series of percutaneous treatment of caliceal diverticula and additionally stratified their outcomes by modality for treating the diverticulum and diverticular neck. Among 30 patients treated, 28 underwent a direct approach resulting in successful obliteration of the diverticulum in 79% of patients as determined by follow-up intravenous pyelogram or CT. The remaining two patients were treated by the indirect approach, which was successful in 50% of cases. Incision of the diverticular neck was associated with an 83% success rate compared with a 67% success rate in patients in whom the diverticular neck was dilated only. Fulguration of the diverticular wall resulted in successful obliteration of the cavity in 86% of cases; in contrast, resolution of the diverticulum occurred in only 50% of patients in whom the diverticulum was not fulgurated. Based on their findings, these authors concluded that a direct percutaneous approach, with incision of the diverticular neck and fulguration of the diverticular wall has the highest likelihood of complete resolution of the diverticulum and consequently alleviation of symptoms.

When the diverticular neck is not readily identifiable or cannot be cannulated, the creation of a neoinfundibulum provides direct access from the diverticulum into the collecting system. Al-Basam and associates *(11)* and Auge and colleagues *(10)* both described the creation of a neoinfundibulum after direct percutaneous access to the diverticulum when the diverticular neck was not readily apparent. In this case, a long Chiba needle is advanced directly through the diverticulum into the renal collecting system, allowing a guidewire to be negotiated into the collecting system. The transdivertcular tract is then dilated to 30-Fr using a standard nephrostomy tract dilating balloon.

Using this technique, Al-Basam and co-workers (*11*) successfully cleared all stones from 16 of 18 caliceal diverticula and left 2 diverticula with 5-mm-or-less fragments at 2 and 5 weeks postprocedure. At a mean follow-up of 126 weeks, 80% of 15 patients available for follow-up were free of symptoms. A single complication, a renal-pleural fistula, was managed with tube thoracostomy for 1 week. Among six patients who underwent imaging with an intravenous urogram at follow-up, four patients demonstrated a persistent diverticulum. In this series, the diverticula were not fulgurated; however, after reviewing their outcomes, these investigators recommended fulguration of the diverticula when the cavity exceeds the size of the 30-Fr working sheath.

Utilizing a similar technique, Auge and co-workers *(10)* treated 18 of 22 patients with caliceal diverticula and a non-negotiable diverticular neck with creation of a neoinfundibulum. At 6 weeks postprocedure, 17 of 18 patients were symptom free and 1 patient reported a significant decrease in pain. Among 15 patients imaged postoperatively, 80% were clear of stones. In one patient with a diverticulum but no stone, the diverticulum decreased in size by approximately half. Complete resolution of the diverticula was demonstrated in 63% of cases (10 of 16). Complications occurred in two patients; one asymptomatic pneumothorax and one hemopneumothorax were successfully managed

Table 2

Percutaneous Nephrostolithotomy Approach of Caliceal Diverticulum

Study	*N*	*Approach*	*Fulguration of diverticulum*	*Management of diverticular neck*	*Stone free*	*Symptom free*	*Obliteration of diverticulum*	*Complications*	*Follow-up (months)*
Eshgi et al. (13)	14	Direct 11 Indirect 3	No ablation	Incision 8 Dilatation 4 Dissection 2	100% (14/14)	—	0% (0/14)	0% (0/14)	12
Hulbert et al. (25)	18	Direct 15 Indirect 3	Ablation 1	Dilatation 18	80% (12/15)	—	80% (12/15)	6% (1/18)	4–14
Hedelin et al. (26)	13	Direct 7 Indirect 6	No ablation	Dilatation 8	69% (9/13)	69% (9/13)	8% (1/13)	0% (0/13)	24 (6–48)
Ellis et al. (27)	12	Direct 11 Indirect 1	Ablation 7 Sclerosis 1	Dilatation 9	100% (10/10)	88% (7/8)	75% (6/8)	33% (4/12)	33% (4/12)
Jones et al. (17)	24	Direct 22^a Indirect 2	Ablation 17	Dilatation 22	96% (23/24)	100% (24/24)	100% (17/17)	29% (7/24)	16 (4–72)
Lang et al. (34)	10	Direct 10	No ablation	Neoinfundibulum 10	100% (10/10)	—	20% (2/10)	10% (1/10)	35 (6–60)
Hendrikx et al. (18)	13	Direct 12 Indirect 1	Ablation 3	Dilatation 9	77%(10/13)	77% (10/13)	—	31% (4/13)	24–84
Bellman et al. (35)	20	Direct 20	Ablation 20	Dilatation 20	95% (18/19)	100% (20/20)	80% (16/20)	25% (5/20)	18 (3–36)
Shalhav et al. (28)	30	Direct 28 Indirect 2	Ablation 22^b	Incision 12 Dilatation 9	93% (21/23)	85% (23/27)	76% (16/21)	20% (6/30)	6 (3–36)
Donnellan et al. (36)	21	Direct 20 Indirect 1	No ablation	Incision 7 Dilatation 13	95% (20/21)	86% (18/21)	29% (6/20)	10% (2/21)	42 (12–88)
Monga et al. (37)	14	Direct 14	Ablation 14	Incision	100% (11/11)	100% (14/14)	100% (14/14)	7% (1/14)	74 (6–144)
Al-Basam et al. (11)	18	Direct 18	No ablation	Neoinfundibulum 18	89% (16/18)	80% (12/15)	33% (2/6)	6% (1/18)	38 (8–74)
Auge et al. (10) bulum 18	18	Direct 18	No ablation	Neoinfundi-	80% (12/15)	94% (17/18)	64% (10/16)	11% (2/18)	32 (3–82)
Landry et al. (38)	31	Direct 31	Ablation 24	Incision 31	84% (26/31)	88% (27/31)	64% (20/31)	13% (4/31)	(1.5–3)
Overall	256	—	—	—	89% (212/237)	89% (181/204)	60% (122/205)	15% (38/256)	24.6 (18–96)

[a] Includes 10 patients ESWL + PCNL.

[b] only includes patients with follow-up.

with tube thoracostomy. The average hospital stay was 2.8 days, and all patients were discharged home with a 22-Fr nephrostomy tube that was removed 1 week later.

In published series, overall stone-free and symptom-free rates of 89 and 89%, respectively, have been achieved (Table 2). Furthermore, in 60% of cases, the diverticula were successfully obliterated. For caliceal diverticula approached directly the overall success rate (obliteration of diverticulum) was 63% (88/139) vs indirectly which was 9% (2/22). Complication rates are slightly higher with a percutaneous approach (15%) compared with a retrograde ureteroscopic approach (9%) (Tables 1 and 2).

Laparoscopic Approach

A total of 13 cases of laparoscopic unroofing of caliceal diverticula have been reported in the literature, including a transperitoneal approach in 1 case and a retroperitoneal approach in 12 cases *(29–33)*. Operative times ranged from 60 to 215 minutes, and the overall complication rate was 7.7%, with the only reported complication consisting of bleeding requiring transfusion. Radiographic studies demonstrated obliteration of the diverticula in all 13 cases and all patients were rendered symptom free at a mean follow-up of 6 months. The laparoscopic approach is generally reserved for large diverticula (>5 cm) or anteriorly located diverticula with thin overlying parenchyma.

TIPS AND TRICKS

Ureteroscopic Approach

- Contrast injected through the ureteroscope helps to identify the calyx with which the diverticulum is associated.
- Passage of a guidewire into the diverticula confirms proper identification of the ostium and opens up the diverticular neck sufficiently to position a laser fiber for incision.
- Dilation of the diverticular neck after incision separates the incised edges and facilitates clearance of stones fragments from the diverticulum.

Percutaneous Approach

- After percutaneous puncture, a moveable core guidewire or J-wire coiled within the diverticulum provides moderately secure guidewire access over which a dilating balloon can be passed.
- Injection of indigo carmine-stained saline or air via the occlusion balloon catheter facilitates identification of the diverticular neck, which can then be cannulated with a guidewire.
- Fulguration of the diverticulum prior to dilation or incision of the diverticular neck prevents inadvertent fulguration of the collecting system urothelium.
- The transdiverticular approach is an alternative method of treating the diverticulum that provides secure access into the collecting system.

CONCLUSIONS

Therapeutic options for treatment of symptomatic caliceal diverticula include SWL, ureteroscopy, percutaneous nephrostolithotomy/ablation, and laparoscopic unroofing. SWL is associated with the lowest stone-free rates, although in a surprising number of patients symptoms resolve despite persistence of the diverticulum and stone fragments.

SWL therapy is best reserved for patients with a small stone burden (≤15 mm) in a mid- or upper pole caliceal diverticulum with a radiographically patient diverticular neck.

Retrograde ureteroscopy should be considered for upper- and midcaliceal diverticula associated with a stone burden of 15 mm or less, when the infundibulopelvic angle is favorable for ureteroscopic access *(7)*. Likewise, anteriorly located diverticula with a modest stone burden are effectively accessed via a ureteroscopic approach, which is safer than a percutaneous approach and less invasive than a laparoscopic approach. Although the diverticulum is rarely successfully obliterated, high stone-free rates can be achieved and improved drainage of the diverticulum attained.

A percutaneous approach offers the best chance of achieving a stone-free and symptom-free state and is the only endoscopic option in which the diverticulum can be directly treated. A direct percutaneous approach is preferable to the indirect approach, and if direct access cannot be safely performed, a ureteroscopic approach should be considered if the diverticulum and/or stone burden is small. An indirect approach is still favored over ureteroscopy for a large stone burden or a large diverticulum (>2 cm), particularly if a rigid nephroscope can be used to access the diverticulum and fulgurate the urothelium.

Management of the diverticular neck is controversial. Whether it is necessary or preferable to dilate or incise the neck vs simply fulgurate the diverticulum has not been firmly established. Likewise, if treatment of the diverticular neck proves superior to simple fulguration, the advantage of one modality over another (incision vs dilation) will remain to be proven. Until further information is available, it is advisable to dilate or incise the diverticular neck if the ostium can be identified after fulguration of the diverticulum. If the diverticular neck cannot be identified, fulguration of the urothelial lining may be sufficient.

For large diverticula (>5 cm) or for anteriorly located diverticula with thin overlying parenchyma and large stones, laparoscopic unroofing offers the most expeditious treatment, resulting in successful stone removal and resolution of the diverticula.

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IV

ABLATIVE THERAPY

15

Percutaneous Approach to Upper Urinary Tract Tumors

Ioannis M. Varkarakis MD, PhD
and Thomas W. Jarrett, MD

CONTENTS

SUMMARY

The “gold standard” for treatment of upper tract urothelial carcinoma is nephrourterectomy. In some cases, however, organ-sparing endoscopic therapy via percutaneous or ureteroscopic approaches should be considered. The percutaneous approach is generally used for cases of larger volume renal disease and those not accessible by ureteroscopic techniques. This chapter will review the indications, technique, complications, and results of this technique.

Key Words: TCC; percutaneous; management.

NATURAL HISTORY OF UPPER URINARY TRACT TRANSITIONAL CELL CARCINOMAS AND INDICATIONS FOR CONSERVATIVE THERAPY

Upper urinary tract (UUT) urothelial tumors are rare accounting for 1 to 2% of all genitourinary tumors *(1)*. The vast majority are transitional cell carcinomas (TCC) (90%), whereas only 10% are squamous cell carcinomas and 1% adenocarcinomas *(2)*.

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Urothelial tumors of the renal pelvis are three to four times more frequent than those located in the ureter *(3)*.

The incidence of UUT TCC increases with age in both genders and appears most frequently during the sixth and seventh decades of life. Males present with this disease three times more frequently than women *(4)*.

Like that of the bladder, upper TCC most likely represents a field change disease with multiple recurrences in both time and space. This polychronotopism is generally confined to the ipsilateral renal unit or to the bladder. Although recurrence at an additional site in the genitourinary system will occur in 30 to 50% of patients *(5)*, recurrence in the controlateral renal unit will develop only in 1 to 5.8% *(6,7)*. This natural history makes nephroureterectomy with resection of a bladder cuff safe and effective for therapy of an UUT TCC. Rates of local or ipsilateral recurrence after nephron preserving surgery are high and therefore conservative management with renal sparing procedures has been implemented only when preservation of renal function is necessary. This includes patients with an anatomically or functionally solitary kidney, those with bilateral disease, and patients who refuse or are unable to tolerate open surgery because of medical comorbidities.

Recent advances in endoscopic technology with the development of better optics, actively deflecting telescopes, and adjunctive instrumentation made it possible for us to diagnose and stage more accurately patients with upper urinary TCC. In fact direct visualization of the tumor allows obtaining a tumor biopsy and selective urine cytology. Tumor grading in this setting is very accurate and is 90% in agreement with the grade of the final pathological specimen. Unfortunately ureteroscopic biopsy is unreliable in determining stage *(8)*. However several studies have suggested a good correlation between the grade of TCC and the stage of the tumor *(9,10)* and high accuracy of the Computed tomography (CT) scan in detecting evidence of tumor extending beyond the wall of the ureter or renal pelvis *(11)*. Therefore the combination of low grade on biopsy and absence of frank extension outside of the urinary tract by CT scan strongly suggests the disease is superficial *(12,13)*. These criteria create a new subset of patients with small and low-grade tumors that can potentially be managed by endoscopic management only, even in the presence of a healthy controlateral kidney *(14)*. Although the cancer-related risks are greater for any treatment short of the gold standard nephroureterectomy, some patients are better treated by parenchymal sparing surgery, provided they know the risks and are committed to vigilant follow-up.

Both ureteroscopic and percutaneous tumor resection are possible and are used in selected centers for up to 15% of patients with upper urinary TCC *(15)*.

The percutaneous access is preferred for larger tumors located proximally in the renal pelvis and or upper ureter. The main advantage of the percutaneous approach is the ability to remove a larger tumor volume from any portion of the collecting system owing to the use of instruments with larger working channels, which allows better visualization and faster resection. Deeper biopsies can be obtained when compared to those taken with ureteroscopy, whereas the percutaneous approach may avoid the limitations encountered even by flexible ureteroscopy, especially in complicated caliceal systems or areas difficult to access, such as the lower pole calyx or the UUT of patients with urinary diversion. Access to any renal unit is possible irrespective of any prior operative intervention such as urinary diversion. With a percutaneous approach, the established nephrostomy tract can be maintained for immediate postoperative nephroscopy and administration of topical adjuvant therapy.

The main disadvantage with the antegrade access is the increased morbidity compared to ureteroscopy. Nephrostomy tube placement has inherent risks and therefore requires inpatient admission. In addition, loss of urothelial integrity and exposure of nonurothelial surfaces to tumor cells carries the risk for tumor seeding along the nephrostomy tract *(16)*.

INSTRUMENTATION

Imaging Guidance

- C-arm configuration fluoroscopy equipment (preferred) or
- Real-time diagnostic ultrasonography or
- CT fluoroscopy

Access Equipment

- 18 or 21-gage needle for puncture of the collecting system
- Guidewires: 0.018-, 0.035-, 0.038-in.; stiff or soft bodied; straight or angled tipped; soft or hard tipped; Teflon or hydrophilic coated
- Conversion catheter
- Fascia incising needle

Dilatation and Maintenance of the Nephrostomy Tract

- Progressive fascial dilators
- Amplatz renal dilator sets
- Metal coaxial dilators
- High-pressure balloon systems

Tumor Resection/Ablation

- Working Amplatz or plastic sheath
- Rigid or flexible nephroscope
- Resectoscope
- Ho:YAG or Nd:YAG laser
- Foley-type urinary drainage catheters
- Self-locking pigtail nephrostomy catheters

TECHNIQUE

Patient Preparation

Preoperative evaluation should include a coagulation profile with negative urine cultures. We favor a single stage approach for access, tract dilatation, and tumor resection.

Patient Positioning and Stent Placement

Anesthesia induction is usually performed in the operating room but on the patient's preoperative stretcher. After the patient is intubated and ready from an anesthesia end point the patient is flipped into the prone position on the operative table. Use of two gel-foam rolls placed under the patient allows the flank area of interest to be presented in a better manner. After patient positioning is complete, cystoscopy is performed with the patient in a prone position and an open-ended ureteral catheter is placed in the renal pelvis. The use of the flexible cystoscope allows the surgeon to evaluate the bladder and catheterize the ureter even after the patient has been moved in the prone position. Alternatively anesthesia induction on the operative table and stent placement with the patient in the supine position can be performed but we have found that changing position is less cumbersome when the patient is simply rolled off the preoperative

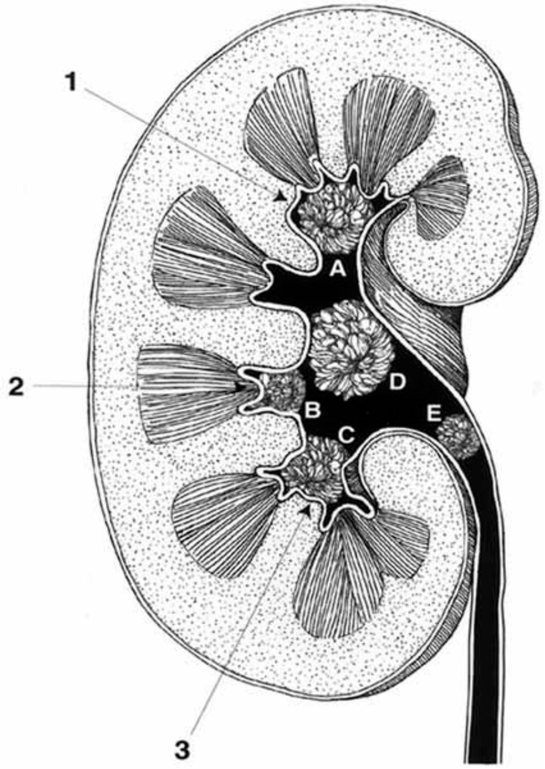

Fig. 1. Nephrostomy tract puncture site. Position of the nephrostomy is important for successful percutaneous resection of transitonal cell carcinomas of the renal collecting system and upper ureter. Tumors located in peripheral calyces **(A–C)** are best approached by direct puncture. Tumors located in the renal pelvis and upper ureter **(D,E)** are best approached by puncture to an upper or middle calyx. (Reprinted from ref. *17* with permission from Elsevier.)

stretcher. The ureteral stent is available for retrograde injection at all times during the operation. Finally the patient is prepped and draped in the standard sterile fashion.

Establishment of the Nephrostomy Tract

Contrast medium is injected through the ureteral catheter to define the caliceal anatomy and tumor location. A percutaneous nephrostomy tract is established through the desired calyx. In some cases additional percutaneous accesses are required to resect all tumor completely. Access under the 12th rib is usually preferred. Supracostal approaches may be used if necessary but at the risk of pleural injury. Tumors in peripheral calyces are best approached with direct puncture distal to the tumor (Fig. 1). Disease in the renal pelvis and upper ureter is best approached through an upper or middle pole (Fig. 1) access to allow scope maneuvering through the collecting system and down the ureteropelvic junction. After a needle is passed through the desirable calyx and a guidewire is manipulated preferably down the ureter, the tract is then dilated using either sequential (Amplatz) or balloon dilatation so as to accommodate a 30-Fr sheath. Access to the desired calyx and correct positioning of the nephrostomy tract is crucial to the success of the procedure and should be done by the urologist or by the radiologist after direct consultation with the operating surgeon.

After 30-Fr is reached, the nephroscope is inserted and the ureteral catheter is grasped, brought out of the tract, and exchanged for a stiff guidewire, thus providing

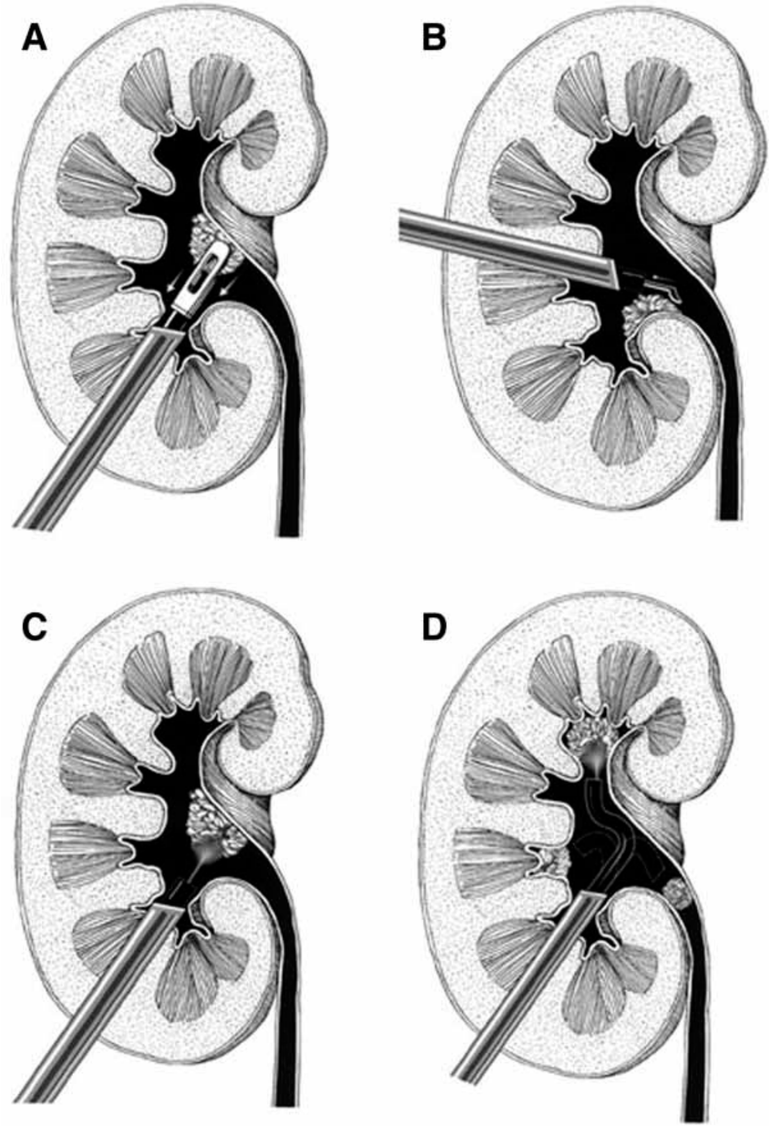

Fig. 2. Technique for percutaneous removal of transitional cell carcinomas of the renal collecting system. **(A)** The tumor is removed to its base with the big biopsy forceps and its base after being biopsied in fulgurated. **(B)** Alternatively the tumor may be resected using the standard resectoscope. **(C)** For tumors smaller in size laser ablation can be used. **(D)** Laser fibers through flexible scopes can be used to reach tumors located even in the most difficult of positions. (Reprinted from ref. *17*, with permission from Elsevier.)

both antegrade and retrograde control. This is the second safety guidewire and helps maintain access should the original wire be inadvertently removed.

Biopsy and Definitive Therapy

Through the 30-Fr inner diameter nephrostomy sheath, which is used to maintain a low-pressure system, the collecting system is evaluated thoroughly using rigid and flexible endoscopes when necessary (Fig. 2). Any suspicion of upper ureteral involvement warrants antegrade ureteroscopy. After identification, cold-cup biopsies of the tumor (if not already sampled) and surrounding mucosa are performed to evaluate the extent of the disease and to rule out the possibility of carcinoma *in situ*. If the tumor is small enough the cold-cup biopsy forceps can be used also for complete tumor removal. In such a case, the bulk of the tumor is grasped using forceps (Fig. 2) and removed in piecemeal fashion until the base is reached. A separate biopsy of the base is performed for staging purposes and the base is cauterized using a Bugbee electrode and cautery. Low-grade papillary lesions on a thin stalk are easily treated in this manner with minimal bleeding. Alternatively a cutting loop (Fig. 2) from a standard resectoscope is used to remove the tumor to its base. Because the relatively small capacity of the renal pelvis, the specimen must be removed after each loop and irrigation drained in order to keep visualization optimal and prevent migration of specimen. Once again, the base should be resected and sent separately for staging purposes. This approach is more effective for larger broad based-tumors for which simple debulking to a stalk is not possible. In addition, when resecting care must be taken not to go too deep, because the pelvicalyceal system lacks a thick muscle layer and, therefore, perforation with parenchymal and vascular injury is always possible.

Alternatively a Holmium:YAG or Ho:YAG or Neodymium:YAG (Nd:YAG) laser (at settings of 25–30 and 15–20 W respectively for three exposures) can be used to ablate the tumor after an adequate cold-cup biopsy has been obtained (Fig. 2). Some authors *(8)* prefer using a combination of both. The Nd:YAG laser can be used to coagulate the major volume of tumor because it can penetrate to several millimeters, while the coagulated tissue can then be removed with the Ho:YAG laser taking advantage of its more shallow penetration which makes its use more controllable *(19)*. The ability to control the energy settings and the fact that the thermal effect on adjacent tissues declines with distance makes laser energy safe especially for the thin pelvic/ureteral wall. In fact, the lower risk of perforation and the absence of bleeding, decrease the risk of stricture and tumor cell extravasation as well.

Other means of tumor resection have been used as well but in fewer patients. Nakada et al *(20)* reported the use of electrovaporization using high levels of pure cut energy for ablation of relatively large tumors. Electrovaporization was found to be effective, safe, fast, and simple in use, but cold-cup biopsies were necessary before the treatment in order to establish a diagnosis.

At the end of the procedure, a 24-Fr nephrostomy tube is always left in place. This access can be used for second look follow-up nephroscopy to ensure complete tumor removal.

Second-Look Nephroscopy

Follow up nephroscopy is performed 4 to 14 days later to allow for adequate healing (Fig. 3). The tumor site is identified and any residual tumor is removed. If no tumor is identified the base should be biopsied and treated using cautery or the Nd:YAG laser (15–20 W and 3-second exposures) because of its very superficial effect. The nephrostomy tube can be removed several days later if all tumors have been resected. Some authors advocate a third look with random biopsies before the nephrostomy tube is finally removed *(20)*. If the patient is being considered for adjuvant topical therapy then a small 8-Fr nephrostomy tube is left to provide access for instillations. The nephrostomy tube is removed after the patient successfully tolerates clamping of the tube for several hours. A nephrostomogram can be performed to rule out extravasation but in our institution is not routinely performed.

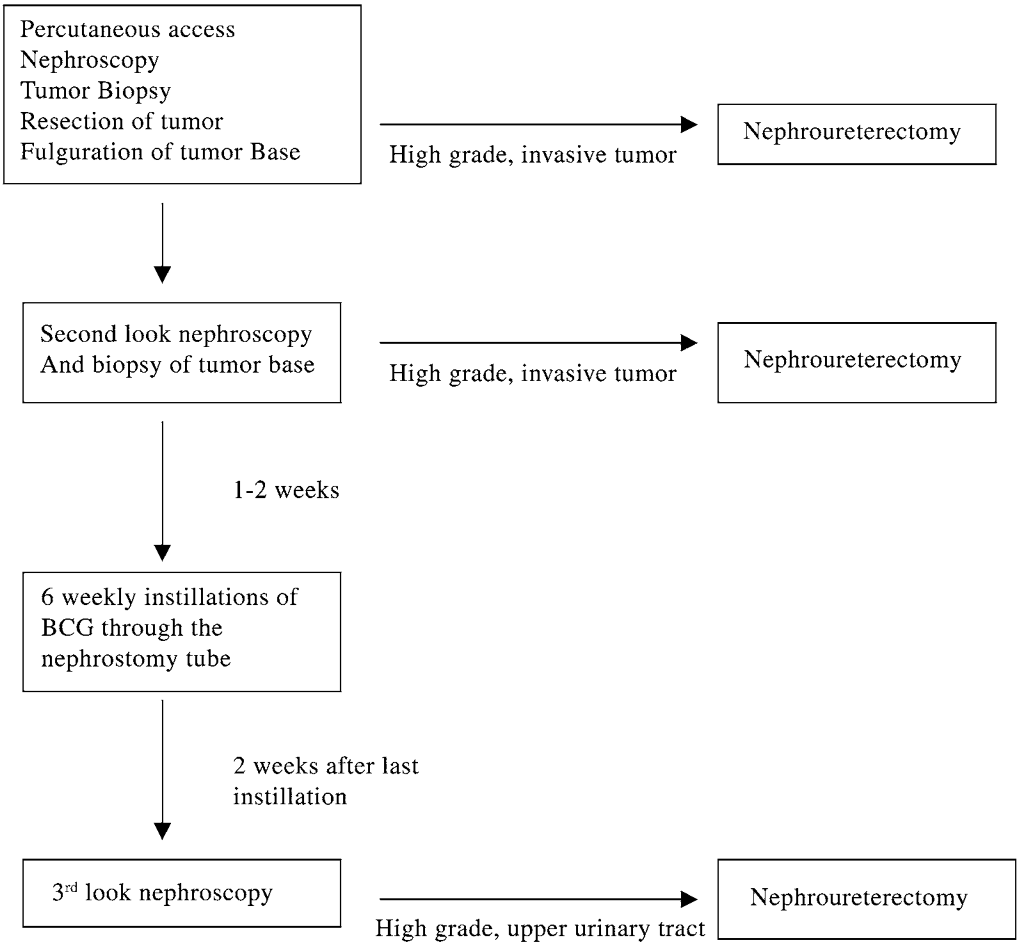

Fig. 3. Algorithm for management of upper urinary tract urothelial tumors after initial management with percutaneous resection.

Adjuvant Installation Therapy

Adjuvant therapy has been employed after percutaneous resection of urothelial tumors in an effort to decrease recurrences in these patients. Both immunotherapeutic and chemotherapeutic agents have been used.

Bacillus Calmette-Guerin (BCG) is usually administered in six weekly installations through the nephrostomy tube (Table 1), with the first dose given a week after the second look nephroscopy. Negative urine cultures, cessation of hematuria, and confirmation of nonobstructive flow are necessary before administration of any agent. For this procedure the patient is usually hospitalized overnight and placed on intravenous antibiotics. Fifty cubic centimetres of 1×10^8 colony-forming units of BCG (or 1 amp diluted in 50 cc normal saline) are administered through the nephrostomy tube. Then the tube is clamped for 1 hour. Care is taken so that installation pressures never rise above 25 cm of H_2O. The tube is unclamped, the patient voids and is discharged from the hospital the following day. The third look procedure in this setting is delayed until 2 weeks after completion of the BCG therapy.

Alternatively the agent may be administered by bladder installation in the Trendelenberg position after double-J insertion or by a simple bladder catheter if there is vesicoureteral reflux *(22)*. However the extent of urothelial exposure is variable and therefore the effectiveness questionable.

Adriamycin *(23)* and Mitomycin *(20,24)* (20 mg in 50 mL of water) are the chemotherapeutic agents most frequently used for adjuvant therapy. The same precautions and routes of administration required for BCG intracavitary instillation are employed for these agents as well.

Surveillance Protocol

Surveillance for recurrence is essential with endoscopic treatment of the UUT. Patients are evaluated every 3 months for 1 year, every 6 months for 4 years, and then yearly. Follow-up visits include always history, physical examination, and urine cytology studies. Cystoscopy is also necessary because of the high incidence of recurrent bladder tumors in these patients. Evaluation of the entire UUT can be done at 3- to 6-month intervals; either by excretory urography or by retrograde ureteropyelography. Nevertheless, radiographic studies present with high rates of false negative results *(25,26)* and, therefore, many investigators prefer ureteroscopy because direct inspection has proven to be more sensitive in detecting tumor recurrence *(18)*. Because ureteroscopy is invasive, it can be obtained yearly or when clinically indicated. Higher-grade lesions need to be followed more carefully and should include evaluation for metastatic disease with imaging of chest, abdomen, and pelvis. If the pathological results at any time reveal deeply invasive and/or high-grade carcinoma, or if there is a question of unresectable tumor, nephroureterectomy, if medically allowed, is performed.

RESULTS

Tumor Control

Conservative management of UUT urothelial tumors requires lifelong vigilant follow up for recurrence in the site of primary resection or elsewhere in the UUT. Recurrence in the bladder is seen in 30 to 50% *(5,7)* and requires cystoscopic surveillance as well.

Local control can be achieved with the percutaneous approach but long-term results vary from study to study owing to the diversity of patient characteristics, follow-up patterns, and the small number of patients used in these cohorts. Comparative studies are of limited applicability owing to selection bias because some studies treat all patients, while other treats only patients with bad prognosis and a history of highly-recurrent disease. When comparing results to the gold standard nephroureterectomy, one must keep in mind the possibility of understaging of conservatively treated patients since pathologic staging is not available in all cases.

What has been invariantly shown is that tumor grade was the strongest prognostic indicator of recurrence and cancer related deaths. Recurrence rates increased with increasing grade and the only cancer related deaths were in patients with grade III disease. In a study by Jarrett et al. *(21)* grade I, II, and III tumors recurred in 18, 33, and 50% respectively. Similarly time of recurrence depends from tumor grade as well, with high-grade tumors recurring faster than low grade ones.

Grade I tumors have generally good prognosis. Recurrence rates after percutaneous management are relatively low and comparable to those presented with nephroureterectomy.

Excellent results for grade I tumors with recurrence rates of 0 to 29% and a disease specific survival of 100% have been reported by many authors *(18,21,27–30)*.

Grade II tumors present with variable behavior and, although progression of grade II tumors does not exceed 11% according to the national bladder cancer group, ipsilateral recurrence *(31)* is frequent after open conservative surgery. This is the reason why percutaneous management of theses tumors is still the center of controversy. Local recurrence rates for grade II tumors after percutaneous management vary from 6 to 40%, whereas disease-specific survival range from 8 to 100%. Stage for this subset of tumors can further distinguish prognosis. Ta grade II tumors progress in 6 to 20% of cases whereas similar grade T1 tumors progress in 21 to 40% *(13,21,27,28,32–36)*. Similarly effected is disease specific survival, with Ta and T1 grade II tumors having a 100 and 80% rates, respectively. With Ta tumors all recurrences are superficial and easily treatable and only 5% progressed to invasive and metastatic disease. Previous history of TCC in the UUT or bladder is also an important factor and might account for higher recurrence rates *(37)*.

Grade III tumors have bad prognosis invariably of the approach followed and recurrence is high as 56% with 5-years survival rates near only 60% *(36)*. These patients are best served with nephroureterectomy unless medically contraindicated.

Tumor stage overall is not as reliable in predicting outcome since disease progression and death from metastasis was seen also in a patient with T1 grade III disease *(21)*.

Existing data show that survival can be directly related to DNA ploidy status *(38)* as well, but this is not used in everyday practice.

Resection modality does not influence success of conservative management. Nd:YAG laser success rates are comparable to those obtained after electro-resection *(21,33,39)*, although some authors had higher recurrences when lasers were used and therefore are less enthusiastic for this option *(35)*.

We conclude that percutaneous management is acceptable in patients with low-grade disease regardless the status of the contralateral kidney, provided the patient is committed to life long endoscopic follow-up. Patients with grade III disease do poorly regardless and should probably undergo nephroureterectomy in order to maximize cancer therapy. The largest area of controversy is for percutaneous management of patients with grade II disease and a normal contralateral kidney. Some studies present acceptable results for the conservative treatment of noninvasive grade II disease while others do not.

Complications

The percutaneous approach is more invasive than ureteroscopy and several complications may occur. In most cases they are similar to those induced during percutaneous surgery for benign reasons.

Bleeding was the most commonly reported complication in a series of 34 patients with upper TCC treated percutaneously *(21)*. Of the 34 patients, 52.9% required transfusion, 11.7% needed further embolization, and 5.8% finally underwent salvage nephroureterectomy after interventional radiology failed. Blood loss was seen to be directly related to tumor grade. This seems reasonable since higher grade tumors are usually of higher stage and require more extensive resection.

Usually the percutaneous approach is used for relatively large tumors making deeper resection often necessary. Deeper resection carries the risk of perforation and vascular injury, which can usually be managed conservatively by leaving the nephrostomy tube in place. However with perforation the risk for potential extraluminal seeding, particularly alongside the nephrostomy tract theoretically exists. Tomera et al *(40)* first reported local recurrence after open pyeloscopy for filling defects of unclear etiology despite the fact that nephroureterectomy was performed immediately after the diagnosis of TCC was made. The fact that recurrence occurred even for low-grade tumors suggested that pyeloscopy led to seeding of the tumor. Although several more reports of nephrostomy tract infiltration with high-grade tumors exist *(16,40)*, there was no tract seeding reported in large contemporary series *(21,30,34,42)* implying that this event is possible but very rare. Some authors use sterile water as the irrigant for its cytolytic effect *(43)* in an attempt to prevent seeding of the tract. Alternatively irradiation of the access tract with an iridium wire or a commercial high dose rate radiation delivery system has been used *(44,45)* with good results and acceptable morbidity. A potential but rare complication is the development of a urinary cutaneous fistula that can lead even to a nephroureterectomy *(29)*.

Complications such as hemothorax and hydrothorax have been reported. Avoiding intercostal punctures by using the triangulation or renal displacement technique allow us to avoid entering in the pleural space *(21,30)*. If these complications occur they can be managed as with any percutaneous procedure.

Stricture formation is a long-term complication of percutaneous management. The risk is probably greater for extensive tumors particularly if they are located near the ureteropelvic junction or the entire circumference of the ureter. The overall incidence of stricture formation with percutaneous management is lower compared to the ureteroscopic approach.

Injury of adjacent solid or hollow viscera can occur but are very rare. For example, only one case of colonic perforation exists in the literature and was managed conservatively *(34)*.

A case report *(46)* of intracavitary explosion during tumor fulguration is rather an extreme complication, which can be prevented by avoiding the introduction of air into the collecting system.

Water absorption and dilutional hyponatremia can occur and are treated as usually with furosemide and saline infusion.

Renal function preservation is the ultimate goal of endoscopic management of upper TCC. Tumor resection itself seems not to impair renal function. From 33 patients only 2 (6%) had significant deterioration of renal function leading eventually to end renal stage disease within 16 months of therapy *(21)*.

Overall complications increase in number and severity with higher-tumor grade. This finding is likely the result of the more extensive pathology and treatments necessary to eradicate the tumor. However when compared to open or laparoscopic procedures; overall endoscopic management was superior in terms of morbidity *(16)*.

Adjuvant Therapy

Intravesical agent administration has been successfully used for the treatment of superficial TCC of the bladder and therefore some investigators believe that these agents may play a role in the treatment of UUT TCC as well. Several retrospective studies have been published, but are unable to define the exact value of adjuvant topical therapy because they are not prospective and long-term follow-up is lacking. Comparisons are difficult because dosing, administration route, and patient populations vary significantly among the various studies. Unlike intravesical instillation, delivery modalities for intracavitary infusion are unable to achieve uniform distribution and adequate dwell time, which would enable a complete clinical response. Thiotepa *(30,33)*, Mitomycin *(18,35, 47)*, and BCG *(21,48,49)* have all been used and delivery is feasible and safe.

BCG administration reduced recurrence rates in several studies both for low-*(50)* and high-grade *(35)* tumors. Recurrence rates range from 12.5 to 40% with better responses reported for lower-grade tumors. Even without previous tumor resection, negative conversion of previously positive urinary cytologies has been reported in 63% of patients after BCG therapy for presumed *cis* of the renal pelvis *(48)*. On the other hand several other studies were not able to demonstrate a survival advantage *(18,21,33)*.

Mitomycin C used for high-risk disease has achieved a 42% disease-free status *(18)*, but not many studies exist.

While the efficacy of topical chemotherapy or immunotherapy is still unproven complications are rare provided urine is sterile with no hematuria and antegrade infusion is performed under low-pressure in a nonextravasating system.

Short-term fever is a common adverse effect and usually subsides with broad-spectrum antibiotics. BCG sepsis and persistent fever (5.1%) are rare complications but require prompt and prolonged anti-tuberculous therapy. A death for BCG sepsis has been reported *(21)*. BCG instillations seem not to deteriorate renal function although anecdotal exacerbation of chronic renal insufficiency attributed to BCG has been reported. Discontinuation of therapy brought the creatinine to pretreatment levels. Granulomatous involvement of the kidney in the absence of systemic signs of BCG infection was the most common event seen in a paper by Bellman et al. *(51)* but its implication is unknown.

Toxic agranulocytosis owing to absorption of extravasated Mitomycin C has been reported *(35)*.

TIPS AND TRICKS

1. Percutaneous access tract is directed towards the demonstrated filling defect.
2. Dilation of the percutaneous tract is always done under fluoroscopic guidance.
3. Introduction and maintenance of a reserve safety guidewire within the working tract safeguards our access.
4. Clear visualization at all times during tumor resection is essential. If at some point of the procedure clear visualization cannot be achieved it is better to place a nephrostomy tube and stage the procedure for another time.
5. The likelihood of access tract seeding can be lowered by:
    a. Single-stage percutaneous access, tract dilatation, and tumor resection should be preferred.
    b. Use of a large 30-Fr working sheath provides good visualization and lowers intrarenal pelvic pressures.
    c. Maintenance of a low intrarenal pelvic pressure can also be obtained by maintaining the irrigation solution less than 40 cm above the level of the patient.
    d. Use of sterile water as the irrigant for its cytolitic effect.

CONCLUSION

Percutaneous resection can be a feasible and safe alternative to nephroureterectomy. Acceptable candidates include those with low grade and stage disease, those at risk for renal failure with removal of the entire renal unit, and those with major medical comorbidities and contraindications to a major surgical procedure. More recently, well-informed patients with low grade and stage disease have been considered for conservative management providing they are committed to lifelong follow-up. Ureteroscopic therapy should be considered for those patients with small volume disease, whereas percutaneous management should be considered for those with high-volume disease.

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16 Ureteroscopic Treatment of Upper Tract Neoplasms

Demetrius H. Bagley, MD

CONTENTS

SUMMARY

Ureteroscopy is an esential step in the diagnosis and treatment of upper tract neoplasms. Most filling defects in the upper tract require endoscopic visualization and biopsy to direct treatment. Ureteroscopic treatment has had excellent success and a high recurrence rate and persistence of good renal function. Endoscopic surveillance is necessary to detect recurrences when they are small. Ureteroscopic tumor treatment includes mechanical removal, fulguration, and laser coagulation and resection. Large, extensive, and high-grade neoplasms may not be amenable to ureteroscopic treatment and can require percutaneous treatment or nephroureterectomy.

Key Words: Ureteroscopy; neoplasms; ureter; intrarenal neoplasms; lasers; biopsy; endoscopy.

INTRODUCTION

The ureteroscopic treatment of upper tract neoplasms has become possible only with the development of adequate endoscopes and instruments for tissue sampling and destruction. Initial ureteroscopic procedures for the diagnosis of upper tract neoplasms

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Table 1
Indications for Endoscopic Treatment of Upper Tract Neoplasms

Relative	
	Mild renal insufficiency (including diabetes)
	Patient's preference
Strong	
	Solitary kidney
	Compromised contralateral kidney
	Medical condition precluding nephroureterectomy

expanded into ablative procedures for the actual treatment of the neoplasms *(1)*. The concept of endoscopic treatment of transitional cell carcinoma (TCC) of the urothelium of the upper tract has a ready audience among urologists whose standard treatment of many bladder tumors has been endoscopic.

There are several limitations to the techniques of ureteroscopic treatment of upper tract tumors. With the instruments available, it is difficult to obtain adequate samples for accurate pathological evaluation and staging. The approach to diagnosis must be altered to include cytopathological techniques. Similarly, there are limitations to an extensive wide treatment of the lesion, particularly in the ureter where there is little room to avoid damage to the normal tissue. Endoscopic surveillance, which plays a crucial role in the management of bladder tumors is also an essential component in testing upper tract lesions.

As success has been observed with endoscopic treatment, the indications have expanded to include potentially more patients. Not only are patients with a solitary low-grade lesion in a solitary kidney eligible but also those with larger lesions, a normal contralateral kidney and even high grade lesions may be considered.

As experience grows with endoscopic techniques, we can expect to see more successful techniques and procedures and also to see refinement of patient selection to optimize treatment. As with bladder tumors, we expect to see the application and refinement of adjuvant therapy.

INDICATIONS

The ureteroscopic treatment of upper urinary tract neoplasms has expanded as the appropriate instruments have become available and experience with the techniques and the results have accumulated. In general, the aim of these procedures is to treat for cure or to manage upper tract neoplasms while preserving renal function. Thus, there are relative indications in different patients (*see* Table 1).

The strongest indication for minimally invasive endoscopic therapy is in patients suspected to have or proven to have a benign lesion. For example, large (>2 cm), smooth masses with a solitary base and no obstruction may be suspicious for a large fibroepithelial polyp. These lesions can be thoroughly biopsied and often removed at the base.

The ideal patient for ureteroscopic treatment of an upper tract neoplasm is a poor surgical risk with a solitary kidney or compromised renal function with a relatively small low-grade TCC. Initial experience and series with these patients demonstrated the feasibility of such treatment and also the development of treatment plans.

Other indications are patients with a larger tumor which cannot be resected in a single setting, but with compromised renal function or some other relative contraindication to surgical therapy which would render the patient anephric. Thus, an older patient with a solitary kidney and a larger (2 to 3 cm) low-grade tumor may be treated satisfactorily with a staged ureteroscopic resection.

It is also an acceptable alternative to treat some patients with normal kidney function and two kidneys. Thus, smaller low-grade tumors may be appropriate for planned initial endoscopic treatment. The patient should be well informed and should understand that surveillance is necessary and that other more extensive treatment may be necessary in the future.

High-grade TCC in general are not amenable to endoscopic treatment. Although there have been some reports of successful ureteroscopic management of small higher grade tumors, there is a high rate of recurrence with a significant risk of distant spread.

Some upper tract neoplasms cannot possibly be treated endoscopically. These include tumors that are too large, too extensive, or endoscopically inaccessible. Some of the lesions inappropriate for ureteroscopic treatment may be amenable to a percutaneous approach, although most will require extirpative therapy (*see* Contraindications below).

Contraindications
Large tumor
High-grade TCC
Inaccessible lesion

INSTRUMENTS

Appropriately sized ureteral endoscopes are the first requirement for diagnostic or therapeutic intervention for upper tract neoplasms. Biopsy devices are essential to be able to sample the neoplasm for pathologic evaluation. Other instruments for ablation or coagulation are needed in order to treat the lesion.

Access to the upper tract for tumor, diagnosis, treatment, and surveillance must include the entire upper urinary tract from the ureteral orifice to each calyx. A combination of rigid and flexible ureteroscopes can most reliably provide this access. The smallest size available with a working channel greater than 3 Fr should be available.

Small rigid endoscopes, not greater than 7.5 Fr, can reach the distal ureter reliably in a vast majority of patients *(2,3)*. This instrument can be directed through the orifice with direct visual control in most patients. They can also be used as a mechanical dilator in some patients with a relatively small diameter ureteral orifice and intramural ureter. Any additional dilation of the orifice is rarely needed. It is usually easy to pass this instrument through the distal ureter to the level of the iliac vessels, but it then may become more difficult to progress proximally, especially in males. The preferred endoscopes have a channel greater than 3 Fr to accommodate working devices and wires. A larger channel or second channel provides a lumen for irrigation with a working instrument in place.

Each endoscope consists of the housing or mechanical or skeletal components including the channels, the illuminating system and the optical mechanism. In small, diameter rigid endoscopes, the size itself confers a certain fragility to the instrument and also results in some bending in use. Therefore, these have been called semirigid endoscopes. Glass or plastic optical fibers are used to direct illumination from an external source through the ureteroscope. The imaging optical system is also routinely fiberoptic. A very acceptable image with good resolution can be achieved with these systems and there is no loss of image with deflection of the endoscope. The earlier, larger diameter ureteroscopes had a rod lens system which lost a portion of the visual field with the resultant change in the apparent image from a disk to an oval or “cat’s eye” appearance.

Flexible ureteroscopes with active deflection can be passed throughout the upper urinary tract. Active deflection in at least one direction of a full 175° is necessary to reach all lower infundibula. In the series measured from radiographs, the average angle of deflection to reach the lower infundibulum was 140° and the maximum in that series was 175°. Extension of the tip is necessary to reach into the depth of the lower infundibulum to be able to access a lower pole calyx *(4,5)*. This was first achieved by use of secondary deflection which was a more flexible portion of the shaft of the endoscope located proximal to the active deflection. The point of deflection could then be passed from the primary to secondary deflecting point to pass the tip of the endoscope into the lower infundibulum.

Two new flexible ureteroscopes have been introduced which achieve the same goal with an active mechanism *(6,7)*. One design uses an active primary and secondary deflecting segment and the other uses extended deflection which can achieve more than 200° of deflection in each direction with a single deflecting segment. Thus, both endoscopes can reach the lower pole without the instability incurred with the passively deflecting segment.

In general, the smallest diameter flexible ureteroscope available will be easier to place in more patients with minimal trauma. For example, it is much less likely that it will be necessary to dilate the ureter to place a 7.5-Fr instrument than is necessary for a 9-Fr device. Therefore, in order to minimize ureteral trauma, the smallest endoscope available should be used, especially for the initial diagnostic procedure.

Several devices are available for sampling tissue through the ureteroscope. Baskets, graspers, and forceps have all been used with some success. In a study of a yield of diagnostic samples with different instruments, the flatwire or Segura basket was shown to be the most successful in retrieving diagnostic tissue *(8)*. The largest sample from a papillary tumor can generally be retrieved with these devices. Other baskets and graspers can be used if deflection of the tip of the flexible endoscope is limited by the stainless steel flatwire basket. Deflection is effected less with a 2.4-Fr device than with the 3-Fr designs.

Cup forceps can take a fragment of tissue approx 1 mm in diameter. However, these devices limit the deflection of all of the flexible ureteroscopes.

Brushes have been used for the cystoscopic biopsy of upper tract tumors. However, when used under direct vision, it can be seen that they are relatively ineffective in obtaining samples of tissue. They can be more effective in sampling flat lesions, especially in areas that cannot be reached with the biopsy forceps.

The most effective resection and ablation devices are the Holmium:YAG (Ho:YAG) and the Neodymium:YAG (Nd:YAG) lasers and 2- and 3-Fr electrode *(9,10)*. The holmium laser can both coagulate and ablate tissue. Lower energy levels tend to have more coagulative effect while the higher energies are more ablative. In comparison, the Nd:YAG laser can only coagulate tissue. It penetrates more deeply through water, saline or tissue and thus can coagulate more deeply. Small electrodes of 2- or 3-Fr can also be used for coagulation of neoplasms ureteroscopically. A disadvantage for electrocoagulation is the need to use a nonconductive irrigant such as water or glycine.

Ureteral resectoscopes have been available. However, these are a larger diameter rigid design which are therefore usually limited to the distal ureter. These are more difficult to use and are presently not an important device or technique.

TECHNIQUES

Many techniques are involved in treating upper tract tumors ureteroscopically. There are several different steps and instruments (discussed previously) that can be employed.

Biopsy of the lesion is important to provide tissue for a pathological diagnosis and possibly for the grading of transitional cell carcinoma. Occasionally with smaller tumors, the biopsy procedure may remove the major volume of the lesion. The choice of instrument and the technique used depend on the location and configuration of the tumor. In each case, however, we always obtain a fluid sample from the site of the tumor: either a wash or subsequent aspiration of the saline with a ureteral lesion. When the tumor is in a larger space, such as the renal pelvis, then just an aspiration of the fluid present can give adequate volume. Aspiration is accomplished most efficiently by using a 50- to 60-mL syringe attached directly to the working channel of the ureteroscope. Care must be taken to keep the tip of the ureteroscope off the mucosa because it will obstruct the channel and cause bleeding. The irrigating fluid in the operative field is also aspirated initially and at other times during the procedure. The field is cleared by aspirating the fluid during and after resection of any tumors, especially in the renal pelvis. We also obtain a sample by aspiration after biopsy and after laser resection. All aspirate samples are taken fresh to the cytopathology laboratory.

The tumor is then biopsied by one of several techniques. If there are multiple tumors present, then each is biopsied separately to confirm the diagnosis. The most common type of lesion encountered endoscopically for treatment is a relatively small papillary tumor. The best technique for sampling these lesions is to use a flatwire basket. The basket is placed under direct endoscopic vision and opened at the level of the tumor. The widest opening of the basket should be at the tumor. It is then manipulated and pressed toward the tumor to allow the fronds to enter the basket which is then closed, keeping it centered on the tumor. It is closed snugly but not completely. If it were closed completely, then the tissue would be sheared from the basket and lost. If the basket is closed snugly, it will hold the tumor which is then pulled from the stalk or base. In this way, a relatively larger sample of as much as 3 to 4 mm can be removed. The entire unit of tumor basket and ureteroscope are then removed from the urinary tract. If there is only a very small sample of tissue within the basket, it can be removed through the channel of the ureteroscope without loss of sample. If the sample cannot be avulsed from the tumor easily, then the basket should be opened and a smaller sample grasped or another technique used.

There are many advantages of this basket technique. The major benefit is that it provides a larger sample than other techniques. It also can be used throughout the upper urinary tract because the small baskets do not severely limit the deflection of the flexible ureteroscope. Thus, it can be used in the mid- and lower calyces. This technique can also be effective in removing surprisingly large volumes of tumor tissue.

The major limitation of the basket biopsy technique is that it cannot be used effectively for very small papillary lesions or for nodular or flat lesions. Other baskets have also been used to sample tissue. However, we have found that they are not as effective as the flatwire basket where the tissue can be caught between the wires. A helical basket or a nitinol tipless style is less effective in collecting and holding tissue.

Cup biopsy forceps can be used to sample any type of tumor. It is quite effective for sessile or flat lesions, but it can also be used for papillary lesions. The device should be placed through the ureteroscope into the endoscopic field and then opened to be applied to the lesion to be sampled. With the larger sessile lesions, multiple samples, including those from the depths of the tumor, should be obtained. With smaller papillary lesions, the forceps is applied to the base and occasionally the entire lesion can be removed. If the tissue is located entirely within the cup, the forceps is removed through the channel of the ureteroscope. However, if there is tissue protruding outside the cup, then the entire unit of tumor, forceps and ureteroscope should be removed to avoid losing any tissue as the forceps is drawn into the channel.

The major limitation of these biopsy forceps is the stiffness. They all are approx 1 mm in diameter and made at least in part of metal. Therefore, they severely limit the deflection of all flexible ureteroscopes. They usually cannot be used to sample tissue in the lower pole.

Brushing of upper tract tumors was initially reported as a very effective technique for obtaining samples when used cystoscopically from the level of the bladder. However, when used ureteroscopically under direct vision, it can be seen that the brush tends to move the tumor. It does not sample the tumor as effectively as the other instruments. However, it can be effective in releasing cells from the surface of the urothelium or flat neoplasms. The entire brush should be submitted as a sample and a post-brushing washing and aspirate also obtained.

Possibly, the most important step in the biopsy process is the handling of the specimens. All of the samples should be handled as cytopathology specimens *(11)*. The tissue samples can be placed in saline and the aspirates in individually labeled containers and immediately taken to the cytology laboratory. The appropriate preservative is added to samples when there is any delay in transport to the pathology department. As the biopsy specimens are processed, any macroscopic sample is prepared as a cell block and then read as a histology specimen while the others are processed and read as a pure cytological preparation.

TUMOR TREATMENT

Mechanical removal of small tumors can be a very effective technique in treatment. As demonstrated by the biopsy procedures, significant volumes of tumor can be removed in the biopsy process. For example, a 6- to 8-mm tumor may be almost completely removed with a single-basket biopsy. A small stump or stalk of tumor is left. This is then removed further with a cup forceps or electrocoagulated or ablated with a laser.

Some papillary lesions can be removed with a cup forceps. If the tumor has a small base, it may be encompassed in the biopsy forceps. Other tiny single papillary lesions can be fully encompassed with the biopsy forceps and multiple tumors can be removed by repetitive biopsy.

Small lesions can be treated effectively with electrocoagulation. A biopsy may not be necessary if the diagnosis is known. In that circumstance, small defined neoplasms can be treated by electrocoagulation alone. Other lesions that have been biopsied leaving only a small stalk are similarly fulgurated effectively. The most frequently used device is a 2- or 3-Fr round tip electrode. The device is passed through the ureteroscope and then, under direct vision, applied to the tumor as it is activated. The shortest effective exposure should be used to avoid deeper coagulation of the normal ureter or renal pelvis. It is important to use a nonconductive irrigant, such as water or glycine, during the electrosurgical procedure. Use a small volume in order to minimize the risk of absorption. A defined amount of fluid such as that contained within a 30- or 50-mL syringe, is used as the irrigant during the electrosurgical activity. A much smaller amount of this irrigant is actually used to clear the field for visualization for fulguration.

An earlier technique for tumor removal is ureteroscopic resection with a ureteroscopic resectoscope. This device, which is similar to a long pediatric resectoscope, is rigid and placed into the distal ureter after adequate dilation of the ureterovesical junction. The loop is then extended and withdrawn while activated to coagulate and resect tissue. Care must be taken not to damage the ureter during the resection. This is a risky procedure because of the size of the loop because it may touch much of the area of the ureteral lumen and coagulate it during the resection. This technique has been largely replaced by the safer, more effective laser techniques.

The Nd:YAG laser is an effective instrument for coagulation of tissue. It has been used extensively for the treatment of bladder tumors and was the first laser employed ureteroscopically. The laser light of 1064 nm wavelength is carried from the laser unit along quartz fibers through the endoscope to the visual field. This laser light penetrates through a few mm of water or tissue and therefore can achieve deep coagulation.

The laser is used by aiming the fiber with the help of a helium neon aiming beam toward the involved tissue. The laser is then activated, usually at 30 to 35 W. The tissue effect is seen as blanching of the pink fronds. It is impossible to determine the depth of penetration or the resultant coagulation, which increases with increasing time. Thus, the laser energy is applied in a sweeping or painting fashion across the target tissue. In practice within the ureter, the target is usually a papillary tumor, partially or completely filling the lumen of the ureter. Because the tissue is not removed during the process of laser coagulation and it is impossible to determine the depth of coagulation, the tissue should be removed mechanically, either with a basket, grasper, or even a Ho:YAG laser. The process is then repeated until the tumor has been removed. Great care should be taken in coagulating the base beacuse the penetration of the Nd:YAG laser light can coagulate the wall of the ureter without any obvious effect seen endoscopically.

Laser fibers available from each manufacturer usually include sizes approx 200 to 300, 400, and 550 µ in diameter. The smaller fibers are more flexible but may be somewhat less effective since they can deliver less laser light than a larger fiber at the same time.

The Ho:YAG laser has become one of the most important endoscopic tools in urology. In addition to its known capabilities for lithotripsy, it can coagulate and ablate tissue. The light of 2100 nm is carried along a low water content quartz fiber for endoscopic procedures. The light penetrates only less than 0.5 mm through water or tissue. Thus, its effect is readily apparent visually. It is also necessary to place the fiber in direct contact or very close proximity to the target tissue in order to have an effect. If it is more than 1 mm from the tissue, even when aimed directly at the target, it has no effect.

The holmium laser can both coagulate and ablate tissue. The coagulative effect is more prominent at lower energies (such as 0.5 to 0.6 J per pulse) which can be achieved by specifically lowering the energy produced per pulse. It can also be achieved by withdrawing the fiber slightly from the target tissue to diffuse the beam slightly, thus, delivering less energy to the tissue over each unit area. The ablative effect is more prominent at higher energies such as 0.8 to 1.0 J per pulse. As expected, there is some overlap of the effect at these two energy levels.

In some holmium lasers, the pulse width can be changed with a choice of two widths: 350 or 700 u/s in a single laser unit. A longer pulse appears to increase the coagulative effect. Again, as expected, there is some overlap of the effect at these two pulse widths.

RESULTS OF TREATMENT

Neoplasms throughout the upper urinary tract, including the ureter and the intrarenal collecting system, can be treated ureteroscopically. Generally, the lesion can be accessed with a flexible ureteroscope and an ablative device, either electrosurgical or laser can be applied to the tumor. As noted, volume can also be removed mechanically.

There is a good basis for the endoscopic treatment of upper tract tumors by comparison with bladder tumors. Thus, general treatment is possible with certain limitations and with frequent recurrences.

Several series have demonstrated the value of ureteroscopic treatment of upper tract neoplasms. The initial studies were in those patients with a strong indication for renal preservation. These included patients with a solitary kidney or compromised contralateral kidney and those with medical indications, contraindicating or prohibiting nephroureterectomy. More recently, these techniques have been applied to patients with two functioning kidneys. This has been feasible because of the recognition of the success achieved in the earlier groups with compromised renal function. It is also based on recognition of the risk of developing a neoplasm in the contralateral kidney.

The ureteroscopic treatment of upper tract tumors represents a rational extension of techniques based on the instruments available. Nearly any area in the upper collecting system is accessible to ureteroscopes and ablative instruments necessary for the treatment of tumors. There is a strong basis for the endoscopic treatment of transitional cell carcinoma as a result of the long extensive experience with the endoscopic treatment of bladder tumors. Early series and the wider application of these techniques have demonstrated the general feasibility of treating upper tract tumors ureteroscopically. Although there are frequent recurrences, there is also strong evidence for long-term survival with maintenance of renal function. There has also been considerable evidence developed suggesting in which tumors there may be benefits from endoscopic treatment and in which tumors endoscopic treatments should be avoided. Nevertheless, many questions remain.

Some patients have tumors or other medical factors which can form a strong indication for the ureteroscopic treatment of the upper tract neoplasm. Patients with a solitary, small low-grade lesion tend to do quite well without recurrences and with maintenance of renal function after ureteroscopic treatment. Those patients with a solitary kidney or compromised contralateral kidney or overall renal risks provide an even stronger indication for endoscopic treatment. In contrast, there are other patients who may have tumors that are less likely to respond well to endoscopic resection. These include large tumors and higher grade lesions as indicated by cytology positive for malignant cells. Lesions that cover the circumference of the ureter or infundibulum tend to develop strictures after treatment. These may require alternative treatment or staged endoscopic removal.

The results of endoscopic treatment have been seen only in relatively small groups of heterogeneous patients. These also include a wide range of treatment techniques with rigid and flexible ureteroscopes and with tumor removal accomplished with electrosurgical instruments and/or lasers (either Ho: or Nd:YAG). There is a high overall recurrence rate after ureteroscopic treatment of upper tract lesions of approx 35% with a wide range in therapeutic series. The risks of bladder tumors developing after treatment have been approx 36 to 39%.

Several parameters seem to affect the ability to render the kidney tumor free. For example, there is evidence that low-grade tumors are amenable to ureteroscopic resection with resultant better tumor-free state than higher grade tumors (40 vs 76%) *(12)*. Others have seen a similar pattern with a more favorable outcome for a low-grade neoplasm *(12–28)*. However, there are definitely some high-grade tumors which can be treated ureteroscopically. Suh et al. *(29)* have documented successful treatment with survival of patients with high grade upper tract neoplasms treated ureteroscopically.

Similarly, a negative effect on successful outcome was seen with a larger tumor (greater than 1.5 cm in diameter). Smaller tumors could be treated successfully in 91% of patients with 25% recurrence rate compared to 36 and 50% in the tumors larger than 1.5 cm. Multifocal disease was less frequently resected completely than solitary lesions (50 vs 19%). The effect of location, whether in the ureter or in the kidney, has variably been reported as significant or insignificant in terms of recurrences. A previous review demonstrated a similar recurrence rate for renal pelvic tumor (33%) and ureteral tumor (31%) *(30)*.

Long-term follow-up of patients treated ureteroscopically has indicated good survival despite the associated relatively high local recurrence rate. The 5-years survival rate was 100% for grade I tumors but decreased to 80% for grade II tumors and 60% for grade III tumors *(22)*. The common association with upper tract tumors has been well established and has been the basis for continued cystoscopic follow-up of patients after nephroureterectomy for upper tract neoplasms. The occurrence of new bladder tumors after nephroureterectomy has been as high as 36% in reported surgical series. It has been approx 50% in patients with a history of previous bladder cancer. Thus, the rate of 36 to 39% seen after ureteroscopic treatment of upper tract tumors is not far from the known range seen with surgical treatment. Again, the patients treated ureteroscopically represent a heterogeneous group, including those both with and without previous bladder cancers.

There are definitely some patients with upper tract neoplasms that cannot be treated adequately ureteroscopically. These include large tumors that cannot be treated adequately even with staged procedures. Those patients may then require a percutaneous approach for resection of the entire tumor or surgical therapy, either with partial or total nephroureterectomy. An even more common limiting factor is a widely extensive or inaccessible tumor. A low-grade neoplasm carpeting the entire collecting system with circumferential extension into each infundibulum cannot be treated adequately ureteroscopically. There may also be locations within the kidney, especially in the lower pole or the medial portion of the upper pole, which may be visualized endoscopically but cannot be reached directly with an ablative device.

SURVEILLANCE

Surveillance is essential after ureteroscopic treatment of upper tract neoplasms. Ureteroscopy is the most sensitive technique available for the diagnosis of recurrent lesions. It also offers the opportunity for treatment during the same procedure. Previous studies have shown that retrograde pyelography is inadequate to demonstrate recurrences reliably. In one earlier series, as many as 75% of recurrences found by ureteroscopic inspection were missed endoscopically *(12)*. Even extensive TCC of the upper tract confirmed by ureteroscopy and nephroureterectomy may not be seen on intravenous urography *(16)*. Comparison of other techniques for the detection of recurrences had shown the low detection rate of voided urinary cytology or urinalyses *(31)*. However, there was relatively high specificity of either abnormal cytology or microscopic hematuria. The newer immunologic diagnostic studies searching for tumor associated antigens have not been studied adequately with upper tract neoplasms.

Endoscopy has been employed extensively in the surveillance for upper tract recurrences. Our surveillance program has been outlined previously *(32)*. Initially, at 3 months after ureteroscopic resection ureteroscopy is repeated to define the tumor status or complete resection of any persistent or recurrent tumor. Ureteroscopy is continued every 3 months only until the upper tract is clear. In continued surveillance, cystoscopy is performed every 3 months and ureteroscopy of the entire tract is performed every 6 months for the first 2 years. At 2 to 5 years, cystoscopy and ureteroscopy are continued at 6-month intervals. With any recurrence, the endoscopic cycle is restarted. The contralateral collecting system is studied radiographically (usually with retrograde pyelography) at yearly intervals.

The role of adjuvant therapy has not been confirmed experimentally. There has been experience in small series with topical adjuvant therapy using bacillus Calmete-Guerin (BCG), Mitomycin C, Thiotepa, Fluorouracil and Interferon α-2B *(33–36)*. There is some evidence of a positive effect from BCG or Mitomycin C. Mitomycin C has been delivered through a ureteral catheter in the early postoperative period. BCG treatment has been delayed until the urothelial damage from resection has healed.

COMPLICATIONS

Complications can occur with any endoscopic procedure, and there appear to be some complications related to the specific endoscopic procedure. For example, ureteral perforation and ureteral stricture appear to be much more common after ureteroscopic treatment of neoplasms than with stone treatment. This may be explained by the observation that the ablative technique is being applied to the wall of the ureter itself. For calculi, the interventional technique is limited to the stone rather than the wall of the ureter. In a comparison of tumor and stone treatment, a combined series of rate of stricture formation after ureteroscopic treatment of upper tract tumors has been 13% *(37)*, whereas it is a rare occurrence after stone therapy at 0.5% *(38)*.

Perforation of the ureter or renal pelvis is less common occurring in 0 to 10% of patients. These perforations generally have been treated by drainage with an indwelling stent or a percutaneous nephrostomy.

The other potential complication is the dissemination of the tumor either through extraluminal spillage or throughout the urothelium. The initial concern regarding local recurrence was reported after intraoperative pyeloscopy during surgical exploration of the kidney for renal pelvic lesions. Two of 18 patients developed local recurrences in the renal fossa after exploration for low-grade lesions *(39)*. There was also a single case report of tumor cells, in unusual lymphatic and vascular locations, with nephroureterectomy after ureteropyeloscopy *(40)*. Thus, the question of the safety of even ureteroscopic biopsy was raised. However, in a series of 13 patients who were treated with nephroureterectomy after ureteropyeloscopy, there was no evidence of extraluminal tumor *(41)*. An excellent study examined 96 patients, half of whom had ureteroscopic biopsy before nephroureterectomy and half without ureteroscopy *(42)*. There was no difference in the recurrence rate or the disease specific survival between the two groups. Thus, the conclusion from that study was that ureteroscopic biopsy of upper tract neoplasms is safe. In our patients treated with nephroureterectomy after unsuccessful endoscopic treatments, there has been no evidence of unusual spread beyond the urothelium.

There has been no documented pattern of increased urothelial implantation or dispersion of tumor after ureteroscopic treatment. Possibly, the best indication of this lack of tumor dissemination is the similar rates of bladder tumor occurrence after upper tract tumor treatment by ureteroscopy or by nephroureterectomy. However, we have noted an anecdotal case in which there were multiple urothelial recurrences throughout the ureter and bladder after ureteroscopic treatment of an initially solitary 2-cm renal pelvic neoplasm. The patient was treated successfully with nephroureterectomy and cystoscopic bladder tumor treatment. Therefore, there is a theoretical risk of tumor dissemination and some evidence in rare isolated incidents.

TIPS AND TRICKS FOR THE URETEROSCOPIC MANAGEMENT OF UPPER TRACT NEOPLASM

There are several small alterations in technique that may be considered tips or tricks that can improve the result of ureteroscopic treatment of upper tract neoplasms. These techniques can be applied throughout the treatment process from biopsy to postoperative care.

1. In the initial approach to an upper tract neoplasm, as much tissue as possible should be removed in the biopsy process. If a flatwire basket can encompass the entire lesion, then it should be sampled intact if possible without injuring the ureter. It may be necessary to remove this tissue with multiple samples. The mantra of the pathologist remains the same whether a biopsy is being performed via an open surgical technique or a small endoscopic approach—“send more tissue.” Therefore, try to remove visible fragments of tissue. When using a cup forceps for biopsy, take multiple samples. Two samples are not enough. Small tumors can often be removed entirely with a biopsy. In this way, the next step of tumor treatment has been accomplished.
2. With a more extensive tumor located within a ureter, other treatment beyond mere biopsy removal will certainly be necessary. In this situation, it can be very helpful to treat from the proximal portion of the tumor to the distal portion. In this way, the lumen can always be defined and the laser resection will not become buried into the wall of the ureter to create a false passage. Keep returning to the normal lumen as necessary to define the ureteral wall.
3. As the tumor is resected along the ureteral wall, rotate the endoscope and, therefore, the holmium laser fiber in an arc at the base of the neoplasm conforming to the wall of the ureter. Do not allow the resection to go below the surface of the ureter into the ureteral wall. Deep resection into the wall of the ureter is one of the more certain ways to cause a ureteral stricture.
4. Within a tubular structure such as the ureter or an infundibulum, minimize the use of coagulation, either with the Nd:YAG laser or an electrode. In those locations, the holmium laser can be used more safely to minimize the depth of penetration of the laser energy and the resultant damage of the ureteral wall.
5. Within the ureteral pelvis and in some calyces, coagulation can be used more freely because there is a lower risk of stricturing. It can also be applied to a wider margin around the tumor itself. However, as previously noted, a cylindrical infundibulum should be treated as the ureter.
6. Bleeding almost always occurs with biopsy and resection of upper tract neoplasms. If the ureteroscope is sufficiently smaller than the lumen of the ureter, the irrigant will pass distally into the bladder. It may be necessary to drain the bladder, either constantly with an indwelling small catheter or intermittently.
7. When a ureteral access sheath is employed, the irrigant will pass down the sheath and beyond the bladder. A low pressure can be maintained within the pelvis using a sheath. However, it is helpful to have some positive pressure within the pelvis to distend it. If the pelvis is completely collapsed, it is difficult to define the wall of the renal pelvis and the tumor itself. Trying to resect within the renal pelvis with an extremely low pressure

in the pelvis which causes it to collapse completely is like trying to resect within the bladder when it is fully collapsed.

8. The kidney and the upper ureter move with respiration. It may be necessary to slow the respiratory movement to stabilize the kidney or at least provide predictable movement during which resection can be accomplished. With the slow predictable movement, the urologist can anticipate the position of the target tissue as it passes and treat in that period. The anesthesiologist can usually slow the respiratory rate, often with the suppressant effect of narcotics.

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V

COMPLICATIONS OF ENDOUROLOGY

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Complications of Percutaneous Approaches, Including Incisions

Brian R. Matlaga, MD, MPH,
Ojas D. Shah, MD, *and Dean G. Assimos,* MD

Contents

SUMMARY

Percutaneous endoscopic renal surgery is usually a safe and effective treatment for patients with complex renal calculi, tumors of the collecting system, and ureteropelvic junction obstruction. However, a unique set of complications can occur with this surgical approach that may involve the targeted kidney and surrounding structures. Methods of preventing these events, diagnosing their occurrence, and management strategies are reviewed in this chapter.

Key Words: Hemorrhage; sepsis; hydrothorax; pneumothorax; ureteral stricture; colonic injury; ureteral avulsion.

INTRODUCTION

A variety of complications can occur with percutaneous endorenal surgery. The targeted renal unit and perirenal structures may be injured and patients may develop systemic complications such as sepsis. These complications, measures to prevent their occurrence, and management methods are reviewed in this chapter.

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INJURY TO THE RENAL UNIT

Collecting System Perforation

Collecting system perforation can occur during all phases of endorenal surgery including access, tract dilation, working sheath placement, stone removal, tumor resection, and nephrostomy tube insertion and removal. Lee and associates *(1)* reported that this occurred in 7% of 582 subjects undergoing percutaneous nephrolithotomy. It should be suspected if perirenal or renal sinus fat is visualized. Large quantities of fluid may accumulate in the retroperitoneal space or, sometimes, in the abdominal cavity, if this is not promptly recognized. The latter may cause an ileus that usually resolves spontaneously. However, computed tomography (CT) or ultrasound-guided percutaneous fluid drainage may be necessary if the ileus does not resolve, if respiratory compromise results, or if infected fluid is suspected. Terminating the procedure should be considered when perforation of the collecting system is recognized. This limits migration of stones outside the collecting system and tumor dispersion when endoscopic tumor resection is planned. A nephrostomy tube is then inserted which typically results in sealing of the perforation within 72 hours. However, it may be prudent to wait 7 days and confirm the absence of extravasation with a nephrostogram before re-embarking on stone or tumor removal. This complication can be limited by with proper access and dilation techniques, judicious stone fragmentation and fluoroscopic monitoring of nephrostomy tube insertion and removal.

Ureteral Avulsion

Ureteral avulsion is an extremely rare complication of percutaneous renal surgery. This usually occurs following attempts at antegrade basketing of large, impacted ureteral stones, but may also occur with incision or dilation of the ureteropelvic junction (UPJ) or other ureteral areas, and tumor resection *(1,2)*. This complication mandates prompt open surgical exploration, although percutaneous nephrostomy drainage may be used as a temporizing measure to permit patient stabilization. Its occurrence can be limited by initially undertaking endoscopic lithotripsy to an extent that fragments can be safely retrieved, and utilizing proper endopyelotomy, endoureterotomy and resection techniques.

Extrarenal and Extraureteral Stone Fragment Migration

Extrarenal stone fragments are generally not of clinical significance, provided the urine and stone are not infected and the stone material is far enough away from the ureter or collecting system that it does not incite an inflammatory response. The latter could promote stricture formation *(3,4)*. Retrieval should not be attempted in most cases as this may enlarge the perforation. The occurrence of this complication can be limited through the application of proper stone removal technique.

Stricture

Stricture development following percutaneous renal surgery occurs in less than 1% of cases; the proximal ureter and the UPJ are the areas most commonly involved *(5,6)*. Although stone impaction can induce stricture formation, in many cases procedural trauma, including intracorporeal lithotripsy, has a causative role. Patients who have a urinary diversion and proximal ureteral calculi may be at increased risk for stricture formation owing to an intense inflammatory response (obliterative pyeloureteritis) that may occur *(7)*. "Silent obstruction" from postprocedural stricture formation has been described, which emphasizes the necessity of routine postoperative imaging in patients to assess for this occurrence *(8)*. The majority of patients who develop ureteral strictures can be managed successfully utilizing endourologic techniques providing the stricture is less than 1.5 cm in length and in a nonradiated field. Open surgical or laparoscopic reconstruction may be required in patients with more extensive strictures or in those who fail an endoscopic approach. Stricture formation can be limited by employing proper percutaneous and endoscopic techniques.

Infundibular Stenosis

Infundibular stenosis is a rare complication of percutaneous renal surgery *(6,9,10)*. Parsons et al. *(11)* describe a 2% incidence of infundibular stenosis following percutaneous nephrolithotomy (PCNL). This probably occurs as a result of mechanical or thermal injury of the infundibulum which could induce ischemic and inflammatory changes. Prolonged operative time, a large stone burden requiring multiple procedures, and extended postoperative nephrostomy tube drainage were reported to be independent risk factors for this occurrence by Parsons and colleagues. This complication usually manifests within 1 year of the percutaneous procedure. Initial management of these patients should be endourological, with open surgery reserved for those failing this therapy. Close observation is a reasonable consideration for those who are asymptomatic providing there is no functional deterioration of the involved kidney. Proper surgical technique is the best method of limiting the occurrence of this complication.

Retained Foreign Bodies

Any instrument employed in percutaneous renal surgery has the potential to be retained in the collecting system. The retained foreign body should be removed as it may be a nidus for infection, stone formation, or granulomatous reaction. Removal of the foreign body can be facilitated with fluoroscopic guidance if it is radio-opaque. The item usually can be extracted with rigid or flexible nephroscopy using grasping devices or a basket. A retrograde ureteroscopic extraction may be considered if the retained object is identified after the nephrostomy tube has been removed. This complication can be limited with careful manipulation of laser fibers, other lithotripsy instruments, baskets, grasping devices, guidewires, and tubes to avoid shearing them off into the collecting system. These devices should be inspected periodically during and at the end of the case to monitor for this occurrence. The tips of nephrostomy tubes, such as Malecot catheters, may become entrapped in the renal collecting system because of ingrowth of fibrous or inflammatory tissue. Removal of the restrictive tissue through another nephrostomy tract is recommended for managing patients with this problem *(12)*. This will generally free up the tube and facilitate its removal. Limiting the dwell time of catheters will limit this occurrence.

Tumor Seeding

Tumor seeding and dissemination are potential complications of percutaneous resection of transitional cell carcinoma of the renal collecting system. These risks may be minimized by appropriate working sheath positioning, low pressure irrigation, avoiding perforation during resection or ablation, and optimal postoperative drainage. Only a few reports of tract seeding have been reported with this procedure *(12–15)*. This occurred in patients with locally advanced high-grade tumors; clearly cases where local and systemic failure would be expected. However this has not been reported in properly-selected cases; subjects with low-grade, noninvasive tumors *(13–15)*.

Nephrocutaneous Fistula

The development of a nephrocutaneous fistula following percutaneous renal surgery is a rare complication *(16)*. This is usually caused by distal obstruction owing to ureteral edema, an obstructing stone, blood clot, or stricture. This usually resolves with removal of the stone or ureteral stent placement.

Intraoperative Hemorrhage

Patients undergoing percutaneous renal surgery may develop high volume intraoperative bleeding and require blood transfusion. While this occurrence is reported to be less than 5% in a number of contemporary series, others have noted that transfusion may be required in approximately one-third of patients *(5,6,17,18)*. Surgical experience, technique, preoperative anemia, and advanced patient age are factors that may influence transfusion requirements. Several technical steps may reduce this occurrence. The collecting system should be accessed through a posterior calyx along the direction of the infundibulum, thereby avoiding blood vessels that are adjacent to the infundibulum *(19)*. Additionally, the posterior calyx that provides the most direct access to the targeted stone should be chosen. Once created, the tract should only be dilated up to the peripheral aspect of the collecting system. If dilation proceeds too far medially, perforation of the renal pelvis can occur, with concomitant laceration of the hilar vessels. Stoller and colleagues have reported that renal pelvic perforation is a risk factor for excessive blood loss during PCNL *(17)*. The method of dilation has been reported to influence bleeding by some investigators. Davidoff and Bellman reported that balloon dilation, as compared to coaxial dilation, of the tract is associated with a significantly lower risk of bleeding. However, others have not demonstrated this association *(20,21)*. Working sheaths are utilized in the majority of initial percutaneous interventions and they must be kept in the collecting system to limit parenchymal bleeding. Excessive torquing of rigid instruments may injure renal parenchyma and vasculature and, thus, should be avoided. Alternatively, flexible nephroscopy or placement of an additional nephrostomy track should be performed if access to the targeted pathology is not easily obtained with a rigid nephroscope. The validity of this philosophy is supported by the study of Lam and associates *(20)* who reported that multiple access tracts and flexible endoscopy decreased transfusion requirements in patients with staghorn calculi undergoing PCNL.

There is typically some degree of ongoing blood loss with these procedures. However, if this is to the point that visibility is limited, certain measures should be taken. Intraoperative hemorrhage may simply be because of the end of the working sheath being in the parenchyma and not the collecting system. If this is the case, repositioning the sheath will usually rectify this problem. However, if this maneuver does not significantly attenuate bleeding, certain measures should be undertaken. Inflation of a 30-Fr dilating balloon in the tract for 10 to 20 minutes with subsequent placement of a large nephrostomy (24–28 Fr) will usually control hemorrhage. The nephrostomy tube should be clamped if bleeding persists. This allows blood to clot and hopefully tamponade the injured vessel(s). The tube is unclamped 2 to 3 hours later and left open if there is no evidence of significant bleeding. If this is unsuccessful, a specialized nephrostomy tamponade catheter may be inserted (Kaye, Cook Urological, Spencer, IN) *(22)*. The peripheral balloon is inflated in the tract while urine drains through the inner core of this device, and it is typically left inflated for 2 to 4 days. The majority of bleeding is from peripheral vessels along the nephrostomy tract and the aforementioned measures are usually successful. Significant bleeding from the main renal vein can also be controlled using a tamponade approach. Gupta and colleagues *(23)* reported successful management of this complication in four patients by inflating a

Councill balloon catheter adjacent to the point of venous injury. When these measures are unsuccessful or the patient is hemodynamically unstable, renal arteriography should be undertaken with the intent to proceed with embolization.

Significant hemorrhage can develop when the ureteropelvic junction is incised during endopyelotomy. This can be avoided by carefully aligning the incision to avoid crossing vessels. Preoperative computed tomographic or magnetic resonance angiography is recommended for secondary UPJ obstruction (UPJO) and cases involving ectopic kidneys as vascular anatomy is not highly predictable. Others advocate endoluminal ultrasonography for this purpose *(24)*. When significant hemorrhage arises from the incised UPJ, a 24-Fr dilating balloon should be placed across this area and inflated for 10 minutes. The balloon is then deflated and if bleeding persists or the patient is hemodynamically unstable, the balloon is reinflated and angiographic embolization undertaken if possible. Open surgical exploration with vascular repair or nephrectomy may be needed if these measures are unsuccessful.

Postoperative Hemorrhage

Significant hemorrhage may occur at any time following surgery. Fortunately, serious postoperative bleeding requiring intervention other than tamponade occurs rarely *(21,25)*. If postoperative bleeding occurs with the nephrostomy tube in place, the previously discussed measures should be undertaken. When the tube is out and there is high volume bleeding from the tract, initial digital tamponade is recommended with subsequent placement of a tamponade catheter under fluoroscopic guidance. Management then includes bedrest and blood transfusions as necessary. If bleeding persists, transfusion-dependent anemia develops, or the patient becomes hemodynamically unstable, renal arteriography with superselective embolization may be performed.

The most common causes of postoperative bleeding are laceration of segmental renal vessels, and development of an arteriovenous fistula or pseudoaneurysm *(5,6,18,26)*. Kessaris and colleagues *(25)* reported that 17 of 2200 patients (0.8%) who underwent percutaneous renal procedures over a 10-year period required angiography and embolization for uncontrolled significant bleeding. Twenty-four percent of these patients presented in the immediate postoperative period (<24 hours), 41% in the early postoperative period (2 to 7 days), and 35% March in the late postoperative period (>7 days). These patients require selective or superselective angiographic embolization and results are generally excellent. Kessaris and colleagues *(25)* reported success in 15 of 17 such cases and Patterson and associates *(26)* in 7 of 7 cases treated with selective or superselective embolization. The nephrostomy catheter must sometimes be removed so that the bleeding site may be localized. Open surgical exploration with vascular repair, partial or total nephrectomy may be necessary if the aforementioned measures are unsuccessful.

Perinephric hemorrhage should be suspected if the patient has a decreasing hemoglobin level in the face of clear urine draining from the bladder and nephrostomy tube. This situation may develop following difficult access, or malpositioning of the working sheath outside the renal parenchyma. As well, sandwich therapy with shockwave lithotripsy (SWL) and subsequent second look PCNL is another potential risk factor, as subcapsular or perinephric hemorrhage from SWL may be exacerbated by further tract and collecting system manipulation. The patient should be evaluated with a CT scan if this is suspected (Fig.1).

INJURY RESULTING FROM ENERGY SOURCES

Technological advances in the design of lithotripsy and ablative energy sources have facilitated percutaneous renal surgery. However, the potential for energy-related complica-

Fig. 1. Right perinephric hematoma.

tions is real, and intracorporeal damage from these sources can range from minor to extensive. The surgeon should be familiar with each energy source and its potential dangers prior to its use.

Ultrasonic lithotripsy is a commonly used energy source for PCNL *(2)*. If excessive pressure is applied to this device, collecting system or ureteral perforation may occur. If the probe becomes clogged with debris, the device may overheat and thermal injury can occur.

Electrohydraulic lithotripsy (EHL) is less frequently used for PCNL owing to the availability of newer devices with better safety profiles *(27)*. The most common complications associated with EHL are perforation of the collecting system and bleeding, which are managed as previously discussed.

The holmium:YAG laser is frequently used to fragment stones, incise strictures, and ablate upper tract tumors. Although the holmium laser has a high safety profile, hemorrhage, perforation of the collecting system, and thermal injury may still occur *(28)*. Such occurrences are minimized with careful technique and utilization of appropriate energy settings. Heat generated from laser lithotripsy can interact with hydrogen gas and generate an explosion potentially resulting in collecting system perforation and hemorrhage *(29)*.

Pneumatic lithotriptors and hybrid devices (pneumatic/ultrasound) are also used during PCNL *(30–32)*. There is a small risk of perforation and hemorrhage with their utilization, which can be reduced with appropriate precautions.

Electrical generators may be employed during percutaneous renal surgery to facilitate electrocautery or tumor resection. The patient must be properly grounded to prevent thermal burns. Only nonconductive materials should be in contact with the collecting system and ureter to prevent current dispersal and possible thermal injury. The risk of hemorrhage is minimized by maintaining proper orientation with respect to adjacent vascular structures. Sterile glycine is used as an irrigant in this setting so there is a potential for fluid absorption syndrome. This is limited by reducing irrigant pressure and resection time.

INJURY TO PERINEPHRIC STRUCTURES

Lung and Pleura

The lung and pleura are the perinephric structures at greatest risk for injury during percutaneous renal surgery *(5,6)*. Most injuries to these structures occur when a supracostal approach is employed *(33,34)*. Hopper and Yakes *(35)* performed CT imaging during maximal inspiration and expiration of 43 randomly selected patients and predicted that in full expiration the pleura and lung would be traversed 86% of the time on the right and 79% of the time on the left with an 11th rib approach, and 29% of the time on the right and 14% of the time on the left with a 12th rib approach. Reported experiences suggest that clinically significant injuries occur with less frequency, as pneumothorax has been reported in 0 to 4% and hydrothorax in 0 to 8% of individuals subjected to supracostal access *(36,37)*. Munver et al. *(33)* recently compared complications associated with supracostal access to those occurring with an infracostal approach. Approximately 33% of their upper pole access cases required a supracostal approach and, of the supracostal approaches 73.5% of the tracts were above the 12th rib and 26.5% were above the 11th rib. The overall complication rate for supracostal access was 16.3% (supra-11th, 34.6%; supra-12th, 9.7%); 87% of the intrathoracic complications occurred with supracostal access; hemothorax/hydrothorax in 4% of supracostal access tracts, nephropleural fistula in 2%, and pneumothorax in 1%. A working sheath should be utilized with a supracostal approach, as this provides a barrier to the influx of fluid and air into the pleural cavity if the parietal pleura is violated. Routine intraoperative chest fluoroscopy is recommended at the termination of PRS to evaluate for obvious hydrothorax or pneumothorax *(38)*. Routine postoperative chest radiography is not necessary when fluoroscopy is normal and the patient has no signs of pulmonary compromise *(39)*.

Patients found to have a small-volume pneumothorax or hydrothorax may be observed, providing there are no signs of pulmonary compromise (Fig. 2). Aspiration of the pneumothorax or tube thoracostomy may be required for larger pneumo/hydrothoraces or in cases of patient instability. A nephropleural fistula should be suspected if drainage persists after tube thoracostomy. This will usually resolve after placement of an internalized ureteral stent *(40)*.

The intercostal vessels may be lacerated during a supracostal approach and hemothorax may result. Tube thoracostomy or thoracotomy may be required if this occurs.

Colon

Colonic perforation is a rare complication of percutaneous renal surgery, reported in less than 1% of cases *(1,2,41–44)*. This low incidence is likely the result of the colon rarely being retrorenal. Hadar and Gadoth *(45)* and Sherman and associates *(46)* have reported that the colon is retrorenal in approx 0.6% of the general population. Individuals at higher risk for colon injury are those with horseshoe kidney and other forms of renal fusion and ectopia and those with colonic distention owing to jejunoileal bypass, partial jejunoileal bypass, neurological impairment, and “institutional” bowel. Preoperative CT is recommended in high-risk groups to assess for retrorenal colon (Fig. 3). CT-guided access should be considered if this exists as the window of entry into the collecting system may be quite small *(47)*.

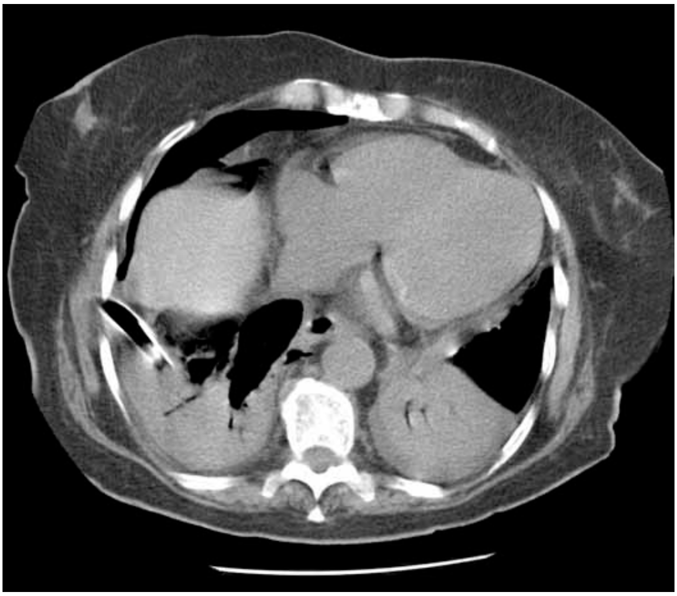

Fig. 2. Computed tomography scan demonstrating right hydrothorax.

Fig. 3. Computed tomography scan demonstrating retrorenal colon.

Prompt recognition of a colonic perforation is critical to limit serious infectious sequelae (Fig. 4). Passage of gas or feculent material through the nephrostomy tract, intraoperative diarrhea or hematochezia, and peritonitis are signs of a possible colonic perforation.

The majority of patient with colonic injuries can be managed without open surgical intervention if the penetration is retroperitoneal and the patient does not have

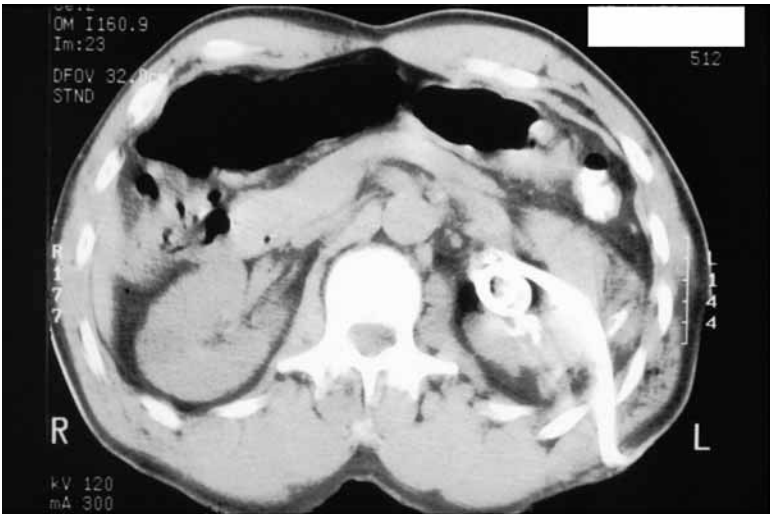

Fig. 4. Retrorenal left colon traversed by nephrostomy tube.

peritonitis or sepsis *(48)*. An indwelling ureteral stent should be inserted and the nephrostomy tube should be pulled back into the colon (Fig. 5). Broad-spectrum antibiotic therapy is administered. The patient is placed on a low-residue diet. Seven to ten days following the injury a contrast study is performed through the colostomy tube and the tube is removed if there is no evidence of a nephrocolic fistula *(41,43)*. Open surgical management is required in patients with transperitoneal perforation, peritonitis, or sepsis.

Small Intestine

The second and third portions of the duodenum are adjacent to the right kidney and may be rarely injured during percutaneous renal surgery *(49)*. This can occur when the renal pelvis is perforated during dilation, placement of the working sheath, or stone or tumor removal. This complication can be avoided with careful fluoroscopic monitoring during access, tract dilation, working sheath placement, and proper endoscopic manipulations. The diagnosis should be suspected if intestinal mucosa or contents are visualized, or if communication with the small bowel is demonstrated on a nephrostogram. In the face of a large perforation or patient instability, open surgical repair is required. However, for patients with small injuries and no signs of peritonitis or sepsis, nonoperative management may be attempted. For this group, antibiotics are administered and bowel rest is achieved with nasogastric suction and parenteral hyperalimentation. The nephrostomy tube should be positioned correctly to assure adequate drainage. A nephrostogram and upper gastrointestinal X-ray study are performed 10 to 14 days following injury to assess for closure of the fistula.

Liver and Spleen

Splenic injury is uncommon in percutaneous renal surgery, likely owing to the organ's cephalad position *(50,51)*. Hopper and Yakes *(35)* also performed a study of the relationship between the kidney, spleen, and lower ribs, and noted that the spleen should

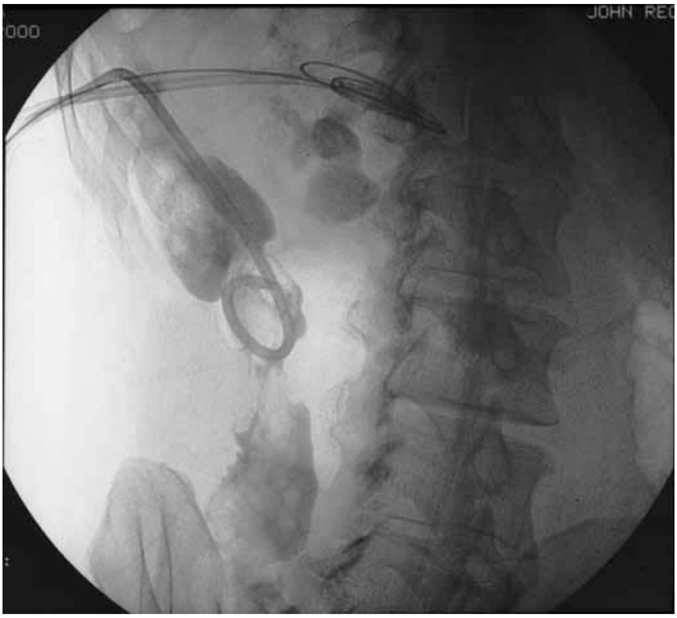

Fig. 5. Nephrostomy tube withdrawn into the ascending colon.

not be traversed if an 11th-12th rib supracostal approach to the collecting system is undertaken during expiration. However, there is a 13% risk if access is performed during inspiration, and the risk increases to 33% if a 10th-11th rib approach is utilized. The risk is also increased in patients with splenomegaly; cross-sectional imaging should be performed in these cases to assist with preoperative planning and possibly to facilitate nephrostomy tube placement. Splenic injury can cause significant internal bleeding and in some cases hypovolemic shock. The diagnosis is established with ultrasonography or CT. Although some patients with splenic laceration can be managed nonoperatively, most will require splenectomy *(5,6,51)*.

In the aforementioned study, Hopper and Yakes *(35)* also examined the likelihood of liver injury during percutaneous access, and reported that the risk of injuring the liver during an 11th-12th rib intercostal approach was minimal and would occur in only 14% of patients if a 10th-11th rib route was taken during inspiration. Hepatomegaly does place the patient at increased risk for this complication; such patients should be evaluated with a preoperative CT scan. For these patients, CT-guided access may help prevent this injury. If liver injury is diagnosed postoperatively, the nephrostomy tube should be left in place at least 7 to 10 days to allow for tract maturation. The tube can then be carefully removed, but, if high-volume bleeding occurs, it should be reinserted. Retrograde placement of an internalized ureteral stent at the time of nephrostomy tube removal may prevent development of a renobiliary fistula.

Lymphatic

Perforation of the collecting system during percutaneous renal surgery may disrupt adjacent renal lymphatics, leading to chyluria *(52)*. Management of this complication consists of optimizing urinary drainage and administering total parenteral hyperalimentation until the chyluria resolves. Somatostatin administration may also be effective in these cases *(53)*. If the chyluria does not resolve with conservative management, renal pedicle lymphatic ligation may be required *(54,55)*.

MEDICAL COMPLICATIONS

Infection and Sepsis

It is axiomatic that patients with urinary tract infection (UTI) be treated with appropriate antibiotic therapy prior to percutaneous renal surgery because of the risk of sepsis from intravasation of bacteria via pyelovenous or pyelolymphatic pathways. Antibiotic therapy for patients with UTI is generally started at least 1 week prior to the planned procedure. Importantly, the results of urine cultures from patients with struvite stones are not predictive of stone bacteriology. Therefore this cohort should be administered broad spectrum antibiotic therapy that is specific to the cultured organism but also likely to be effective against urease-producing organisms residing in the stone *(56,57)*. Stone culture is recommended as it will direct the choice of postoperative antibiotic therapy. Prophylactic antibiotic therapy is another method of limiting septic events. Inglis and Tolley *(58)* reported a prospective study that found prophylactic antibiotic therapy reduced the risk of infectious complications in patients with sterile urine and noninfectious calculi. Rao and colleagues *(59)* have also demonstrated that patients without bacteriuria undergoing percutaneous stone removal may still develop bacteremia, endotoxemia, and increased release of tumor necrosis factor.

Purulent urine may be unexpectedly encountered at the time of accessing the collecting system. In these cases, treatment should be postponed, the renal collecting system drained, urine from the targeted kidney cultured, and appropriate antibiotic therapy administered.

Sepsis has been reported to occur in 0.6 to 1.5% of patients undergoing percutaneous stone removal *(2,5,6,60)*. Antibiotic therapy, fluid resuscitation, and even the administration of steroids and pressors may be required to treat these patients. If the patient does not improve with the aforementioned measures, CT imaging is recommended to assess for unsuspected abdominal, retroperitoneal, or thoracic complications contributing to sepsis.

Fluid Overload

Sterile normal saline should be used as an irrigant during percutaneous renal surgery, except when electrocautery or electroresection are performed to limit the development of hyponatremia. Nonetheless, patients may absorb high volumes of fluid in the setting of extravasation or venous injury. Careful intraoperative monitoring for a discrepancy in input and output of irrigation fluid, unexpected hypertension, and hypoxemia will facilitate identification of this problem. Using the lowest irrigating pressure that will permit adequate visualization, discontinuing the procedure when perforation of the collecting system is encountered, and limiting the duration of the procedure will limit this occurrence. Administration of diuretic therapy may be required for managing the hypervolemic patient.

Hypothermia

Hypothermia may occur during percutaneous renal surgery as a result of vasodilation related to anesthesia, length of the procedure, exposed body surface, low ambient room temperature, and use of room temperature irrigant. The potential consequences include impaired platelet function, altered enzymatic drug clearance, and postoperative shivering causing up to a 400% increase in oxygen consumption *(61)*. The latter problem places patients with compromised cardiac reserve at risk for myocardial ischemia and cardiac arrhythmia. The use of warmed irrigating fluid and proper coverage of patients (blankets and heat-preserving surgical drapes) can attenuate hypothermia.

Positioning Related Injuries

It is essential that a patient is properly positioned to prevent a unique set of complications. Brachial plexus damage, shoulder dislocation, other forms of peripheral nerve injury, and cutaneous trauma can occur if this is not performed properly. Prompt neurologic evaluation should be undertaken if neuropraxia is suspected. These injuries usually resolve over time and physical therapy can hasten recovery.

Air Embolism

Air embolism may occur after injection of air or carbon dioxide into the collecting system or if there is reversal of airflow in an ultrasonic lithotripter *(62)*. Patients typically manifest hypoxemia, cardiac instability, and, in extreme cases, circulatory arrest. A machinery-type murmur may also be heard on cardiac auscultation. Management consists of placing the patient in a left lateral decubitus position with the head and thorax tilted downward. A central venous access line is placed through which the air is aspirated.

Deep Vein Thrombus/Pulmonary Embolism

One to three percent of patients undergoing percutaneous renal surgery will develop clinically apparent deep veinous thrombosis *(2,63)*. The utilization of thromboembolic disease prevention stockings, sequential compression devices, and early postoperative ambulation minimize this risk. If postoperative deep venous thrombophlebitis, treatment goals are to prevent extension of the thrombus or embolic events *(64)*. Anticoagulation therapy is initially undertaken, but placement of an inferior vena caval filter may be required if hemorrhagic complications develop. If the patient has a mature nephrostomy tract, anticoagulation is usually well tolerated.

Mortality

Postoperative death is extremely rare and has been reported in 0.1 to 0.3% of patients undergoing percutaneous renal surgery *(1,2)*. The majority of deaths are because myocardial infarction or pulmonary embolism and occurred in high-risk patients. Therefore, careful preoperative medical evaluation, patient preparation, and postoperative cardiac monitoring should be considered for patients with significant cardiopulmonary disease.

Loss of Renal Function

Patients undergoing uncomplicated percutaneous renal surgery suffer minimal renal damage. Lechevallier et al. *(65)* evaluated patients with single photon emission CT prior to and following PCNL and found that small scars usually involving less than 4% of renal cortical mass developed in the treated area. Ekelund et al. *(66)*, having evaluated patients with pre- and postoperative intravenous pyelography, nuclear renography, and CT, reported maintenance of renal function and only the development of small, discrete parenchymal scars at the tract site. Urivetsky et al. *(67)* evaluated patients with urinary enzyme studies before and after PCNL and reported no change in enzyme activity.

Some patients treated for staghorn calculi may be at long-term risk for future renal functional deterioration. Teichman et al. *(68)* have reported that 25% of these patients develop renal functional deterioration. This is most likely the result of nonprocedural related factors. This is supported by the findings of this group who found that solitary kidney, development of recurrent calculi, hypertension, urinary diversion, and neurogenic bladder were risk factors for renal functional deterioration.

Renal loss owing to a percutaneous renal procedure is unusual. Acute renal loss is usually the result of uncontrollable hemorrhage. This has been reported to occur in only 0.1 to 0.3% of cases. A meta-analysis of the literature on percutaneous removal of staghorn calculi indicated that the long-term risk of renal loss is 1.6% *(69)*.

CONCLUSIONS

It is inevitable that complications will periodically occur during and after percutaneous endorenal surgery. Patients need to be informed about the risks of developing these complications during preoperative counseling. Proper patient selection and preparation, meticulous operative technique, and fastidious postoperative care help prevent the occurrence and lessen the magnitude of complications. Prompt diagnosis of the complication and institution of appropriate measures to rectify the problem will also limit its impact.

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Complications of Ureteroscopic Approaches, Including Incisions

Farjaad M. Siddiq, MD
and Raymond J. Leveillee, MD

CONTENTS

SUMMARY

Ureteroscopy has progressed from cystoscopic examination of a dilated ureter in a child in 1929 and the initial use of rigid ureteroscopes in the 1980s, to its current state of small caliber semirigid and flexible instruments. In this chapter the authors review complications of ureteroscopy including those associated with incisional techniques where one would anticipate a higher incidence of complications. They review the history and development of modern ureteroscopes, focusing on engineering advances. Clinical points made include proper patient selection and preparation; proper use of dilators, wires, and ureteral access sheaths; and the incidence, identification, and management of complications associated with ureterorenoscopy (both intraopertively and postoperatively).

Key Words: Ureteroscopy; calculi; urinary stones; stricture or ureter; urothelial carcinoma; surgical complications.

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INTRODUCTION

Ureteroscopy has progressed from cystoscopic examination of a dilated ureter in a child with posterior urethral valves by Young and McKay *(1)* in 1929 and the initial use of a rigid ureteroscope by Perez-Castro Ellendt and Martinez-Pineiro *(2,3)* in the early 1980s, to its current state of small caliber semirigid and flexible instruments. In addition, there has been a concurrent improvement in endoscopic lithotrites and other ureteral access and interventional accessories. This has facilitated retrograde endoscopic diagnosis as well as therapeutic intervention for a multitude of upper tract disease processes. Indeed, while the most common application of ureteroscopy remains the management of urinary calculi, treatment of strictures, upper tract transitional cell carcinoma (TCC), and essential hematuria has become commonplace.

Although ureteroscopy has come to be considered a relatively benign procedure with an acceptably low complication rate, major and minor complications do occur. This chapter provides a summary of various complications associated with ureteroscopic access, treatment of calculi, TCC, and strictures, as well as historical perspectives on the trends in complications of ureteroscopy since its inception. In addition, technical hints to prevent complications and manage them once they occur will be offered in a timeline extending from patient selection and preoperative preparation to long-term postoperative care.

PREPARATION FOR URETEROSCOPY

Sepsis, active urinary tract infection, and untreated bleeding diatheses are absolute contraindications to ureteroscopy. All patients should have sterile preoperative urine cultures. In addition, broad spectrum prophylactic antibiotics covering common genitourinary pathogens should be administered. In most instances, the use of sufficient anesthesia is critical. Although general anesthesia is preferred, use of local anesthetic with sedation may be adequate in some situations. For therapeutic procedures, we prefer a general anesthetic as a sudden move by a lightly sedated patient can be catastrophic with the ureteroscope *in situ*. Although regional anesthesia (i.e., spinal) may be safely utilized for distal ureteroscopic procedures, it may not provide adequate analgesia during ureterorenoscopy where renal distention may occur.

URETERAL ACCESS

Access failure prohibits ureteroscopy and is a significant complication. The initial step once the patient is anesthetized and positioned is cystoscopy followed by a retrograde pyelogram to “roadmap” the collecting system. Care must be taken at this seemingly simple initial step as trauma to the ureteral orifice or intramural mucosa may make subsequent ureteroscopy difficult. Ureteral orifices may be difficult to visualize, much less canulate, in men with large intravesical prostates. Even if the ureter can be accessed and a wire placed, “J-hooking” of the distal ureter may preclude the insertion of a ureteroscope. Further, the angulation between the bladder neck and the ureteral orifice may be too severe to negotiate with a semirigid ureteroscope. In this situation, attempting to straighten the ureter with a super-stiff wire or using a flexible ureteroscope may be helpful. Women with large cystoceles offer a similar challenge. These ureters, nevertheless, can be canulated if the bladder is lifted transvaginally. Previous pelvic or retroperitoneal surgery or radiation therapy can fix the ureter in the deep pelvis. This increases the risk of perforation significantly, particularly when a rigid instrument is used. Orthopedic abnormalities and contractures, which limit hip mobility and contralateral lower extremity

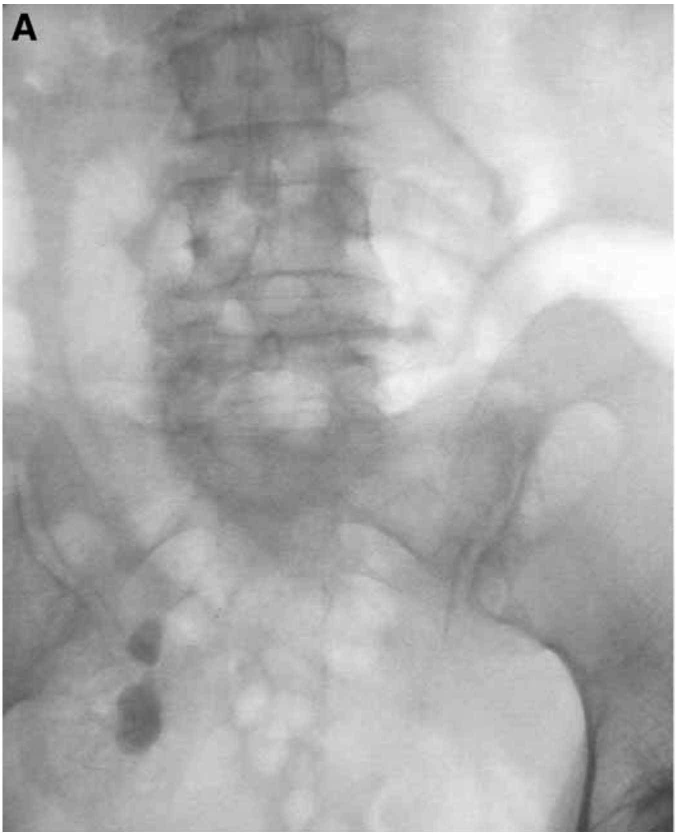

Fig. 1. (**A**) Scout film demonstrates two large distal ureteral calculi, known to be present for several months. (**B**) Retrograde ureterography demonstrated failure of contrast to bypass the obstructing calculi. (**C**) The Glidewire coiled at the level of the stones and could not be passed proximally. (**D**) Ureteroscopy was performed up to the level of the stone, but the Glidewire could not be placed. In order to avoid ureteral trauma, no further attempts at retrograde manipulation and ureteroscopy were

hyperflexion, may hinder the introduction of a ureteroscope. Previously reimplanted ureters, ectopic ureters, and duplicated ureters may be difficult to access as well.

If the ureteral orifice can be identified and accessed, a floppy tipped guidewire should be placed in the renal pelvis under cystoscopic and fluoroscopic guidance. If resistance is encountered, other options should be sought. The wire should never be forced. On occasion, if a mucosal flap has been raised, the guidewire may need to be placed under vision through a ureteroscope. Ureteral stricture, ureteral tortuosity, or an impacted stone may hinder insertion of a wire or ureteroscope. A hydrophilic Angled Glidewire (Terumo, Japan; Microvasive, Boston Scientific Corporation, Watertown, MA) is relatively atraumatic and may safely negotiate a strictured or tortuous ureter. Once wire access is obtained, the stricture can be dilated and the wire exchanged with a super-stiff wire through a ureteral catheter to straighten a tortuous ureter. Impacted stones may be negotiated by injection of lidocaine jelly into the ureter *(4)*. However, systemic absorption of the lidocaine must be considered. An Angled Glidewire may be helpful. This can be exchanged with a stiffer and more secure wire prior to lithotripsy. The exchange may be facilitated by an angled hydrophilic Glide Catheter *(5)*. Nevertheless, if contrast does not bypass the obstruction, it is unlikely that a wire will

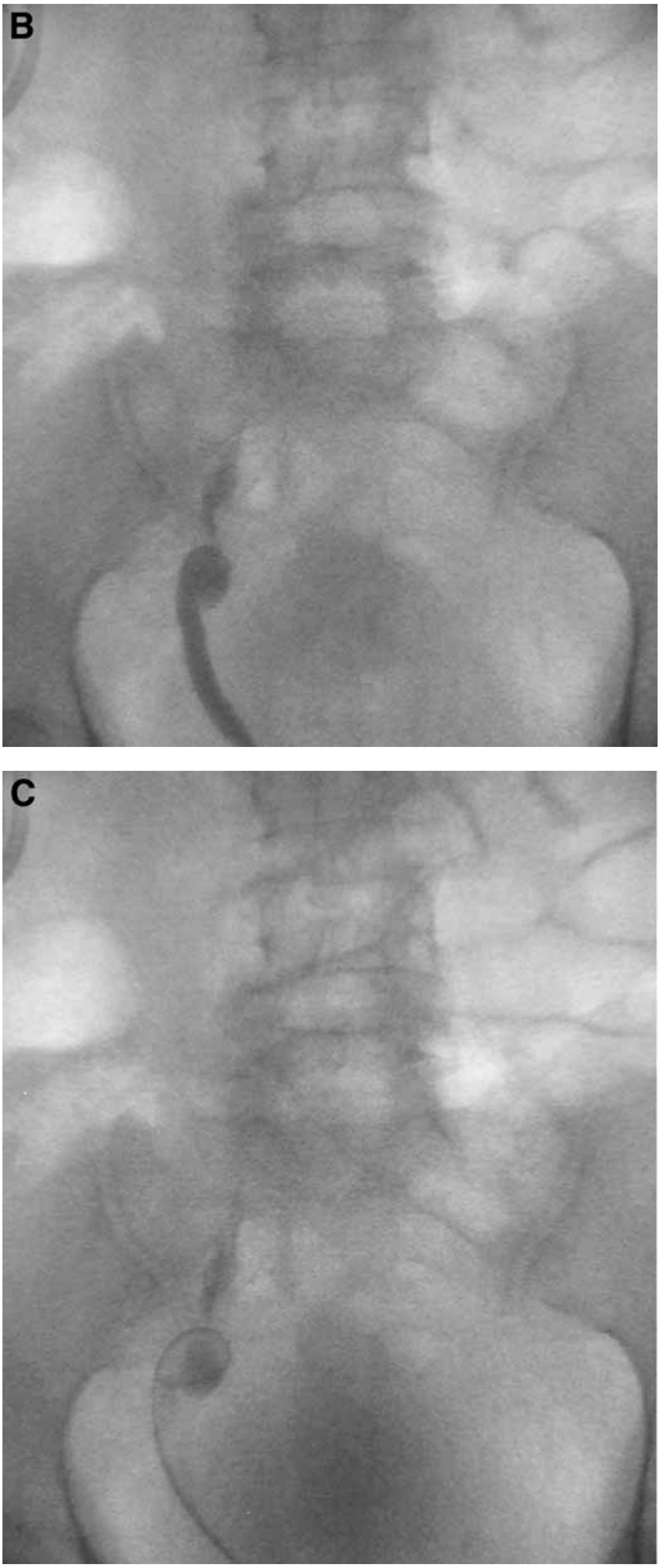

Fig. 1. (*Continued*)

Fig. 1. (*Continued*)

find the right path (Fig. 1). In this instance, aggressive wire manipulation will only lead to ureteral trauma. A safety guidewire should be in place prior to instrumentation. This will allow stent placement in case of ureteral injury. If a wire cannot be placed, further ureteroscopy should not be attempted. Percutaneous renal access or extracorporeal shockwave lithotripsy (in case of stone disease) remains an option in case of failed ureteroscopic access.

DILATION OF THE URETERAL ORIFICE: IS IT NECESSARY?

Although routine ureteral dilation was necessary for ureteroscopy using the early model larger (>10 Fr) ureteroscopes, this "dogma" has been brought into question with the advent of smaller caliber rigid and flexible ureteroscopes. Prior to the advent of balloon dilators, ureteral dilation was performed with serial dilators. Sequential fascial dilators, bougies, or olive-tipped dilators were often used and dilation to 16 to 18 Fr was necessary to allow introduction of the larger ureteroscopes. The shearing forces applied by these dilators often resulted in linear tears of the mucosa and significant tissue trauma. High-pressure balloon dilators have largely replaced these dilators.

Most commercially available balloons are 4 to 10 cm long and inflate to 4 to 6 mm in diameter (12–18 Fr). They are placed over a wire under fluoroscopic and cystoscopic guidance, taking care to remain distal to the stone if one is present. If the balloon is deployed alongside the stone, the stone may become impacted or may be extruded through a perforation. Further, the balloon may be ruptured by a sharp stone. The balloon can also rupture with overinflation or if the inflation is performed too rapidly. This can be severely traumatic given the pressure (18 atm/~265psi) under which contrast will exit through a "pinhole" resulting in bleeding, mucosal tearing, and extravasation. Mucosal injury is less likely with slow radial balloon dilation until the "waist" is eliminated, never exceeding manufacturer specified tolerances. Garvin and Clayman *(6)* demonstrated no strictures and a 20% incidence of transient vesicoureteral reflux from balloon dilation of the ureteral orifice to 24 Fr at 6 weeks. Nevertheless, balloon dilation to greater than 18 Fr is rarely necessary given the current diameter of ureteroscopes (<10 Fr).

Ureteral access sheaths may also be used to dilate the ureteral orifice. These sheaths also allow ureteral access under vision through the lumen of the sheath and are particularly advantageous during procedures involving ureteral biopsy or treatment of a large stone where repeat ureteral insertion of the ureteroscope may be necessary. Earlier ureteral access systems required multiple steps and sequential passage of rigid dilators with a peel away outer sheath prior to ureteroscope insertion *(7,8)*. However, the process was risky with a 31% perforation rate in one study *(9)*. In contrast, the current ureteral access sheath is a flexible and hydrophilic single step two-piece system available in a variety of lengths and diameters. Kourambas et al. *(10)* evaluated the newer sheaths in a prospective randomized study. Operative time and costs were lower in patients who underwent access sheath dilation. Stents were required in 43% of patients undergoing access sheath dilation and 100% of patients undergoing balloon dilation. Although use of the access sheath minimized ureteral trauma, ureteral dilation was successful in 71% of patients in comparison with a 100% success rate for the balloon dilator. They reported no intraoperative complications from the newer sheaths with no strictures at 3 months postoperatively. Another study evaluated ureteral blood flow in a porcine model after access sheath insertion *(11)*. A transient decrease in blood flow was noted with restoration of blood flow to near-baseline during the course of the study. This effect was most pronounced with the larger diameter sheaths. Histologically, there was no evidence of ischemic damage. Hence, the authors concluded that the ureteral access sheath was safe but that care must be taken in selecting an appropriate size sheath for each individual case.

Stoller et al. *(12)* found ureteral dilation necessary in 16% of their population using semirigid ureteroscopes ranging from 9.5 to 12.5 Fr and concluded that routine dilation of the ureteral orifice was not necessary. Netto et al. *(13)* came to the same conclusion, failing to access 1 ureter out of 73 without dilation using semirigid ureteroscopes. Kourambas et al. *(10)* noted that 24% of their patients required dilation using 6.5-Fr semirigid and 7.5-Fr flexible ureteroscopes. Indeed, although ureteral dilation was once considered an essential step in ureteroscopy, the authors find it infrequently necessary in current clinical practice and, therefore, routinely access the ureter atraumatically without ureteral dilation.

COMPLICATIONS OF URETEROSCOPY

The incidence of major and minor complications has decreased significantly since the inception of ureteroscopy. The decline in the incidence of ureteral injury has been particularly significant (Table 1). This trend may be counterintuitive given the large number of interventional procedures ureteroscopy currently facilitates. Nevertheless, with the advent of improved imaging, smaller diameter endoscopes, and increasing surgeon experience, the incidence of complications has actually decreased while the success rate has

Table 1
Trends in Ureteroscopic Ureteral Injury

		Major Ureteral Injury (%)			
Authors	*No. of Procedures*	*Unspecified*	*Perforation*	*Avulsion*	*Stricture(%)*
Carter et al. *(14)*	125		4.0	—	4.0
Flam et al. *(4)*	180	4.0	—	—	1.0
Blute et al. *(15)*	346		4.6	0.6	1.4
Harmon et al. *(16)*	209		1.0	0.0	0.5
Grasso et al. *(17)*	560		0.0	0.0	0.5

increased. In 1986, Carter et al. *(14)* reported a 67% success rate for ureteroscopic ureterolithotomy with a 15% open ureterolithotomy rate secondary to ureteroscopic failure. No lithotrite was used for *in situ* stone fragmentation. The main complication was failure to access the ureter or reach the stone in 15% of patients. Major ureteric injury requiring open repair occurred in 2.4% of patients with additional perforations managed conservatively in 3.2%. Flam et al. *(4)* subsequently reported an overall success rate of 78% for ureteroscopic stone removal with ureteral injury occurring in 4% of patients. They found that larger (>8 mm) stones located in the proximal ureter were the most difficult to treat resulting in the poorest success rate and highest complication rate. In addition, surgeon experience had a positive effect on outcomes as evidenced by later patients faring better. In a similar study, Blute et al. *(15)* reported a 5.2% ureteral injury rate.

These studies uniformly employed rigid endoscopes larger than 10 Fr. Ureteral dilation to 18 Fr, using a balloon or serial dilators, was standard practice. Earlier studies described stone removal without fragmentation. Technology has advanced significantly since these earlier reports. The advent of small caliber semirigid and flexible ureteroscopes as well as improvements in accessories has allowed the endourologist to perform complex stone manipulation in the upper urinary tract with greater success and minimal morbidity. The success of the technology is also evident in the rapid proliferation of indications for ureteroscopy with calculus extraction as the indication for ureteroscopy in 67% of patients in current series and 84% of patients in early series *(16)*.

Harmon et al. *(16)* reported on the impact of technological advancement and surgeon experience on ureteroscopic outcomes by comparing a contemporary cohort of patients with a cohort previously reported by Blute et al. *(15)* from the same institution. The overall ureteroscopic success rate increased from 86 to 96%. Failure in the earlier experience was largely owing to the inability to access the ureter or approach the stone (54% of cases). In contrast, failure in the newer cohort was largely owing to the impassable ureteral strictures (63%). The overall complication rate decreased from 20 to 12% and the rate of significant ureteral injury decreased from 5.2 to 1.5%. Stricture formation decreased from 1.4 to 0.5%. Grasso and Bagley *(17)* reported an overall complication rate of 11.2% with a stricture rate of 0.5% and no significant ureteral injuries, using small diameter actively deflectable flexible ureteroscopes.

Although the overall complication rate has declined, one cannot ignore the possibility of major or minor complications that may occur. Indeed, although appropriate precautions may decrease the frequency and seriousness of complications, accidents will happen. Complications can be divided into perioperative and postoperative. Each category can be further subdivided into major and minor complications and early and late

Table 2
Classification of Complications

Perioperative complications	*Postoperative complications*
Major	Early
• Avulsion	• Colic
• Perforation	• Infection
• Intussusception	• Bleeding
• Equipment failure	Late
Minor	• Ureteral necrosis
• Bleeding	• Stricture
• Mucosal tear	• Reflux
• Proximal calculus migration	
• Extrusion of calculi	
• Thermal injury	

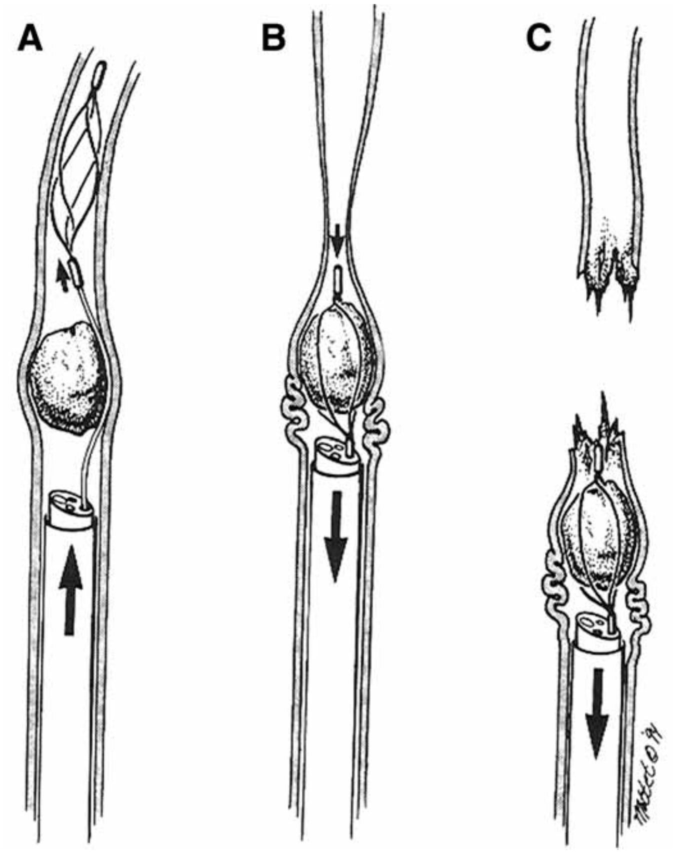

Fig. 2. Mechanism of ureteral avulsion. **(A)** Passage of stone basket proximal to large calculus. **(B)** Stone is engaged and retrograde extraction attempted. Note proximal thinning of ureteral wall (small arrow) prior to avulsion. **(C)** Complete avulsion with persistent pulling.

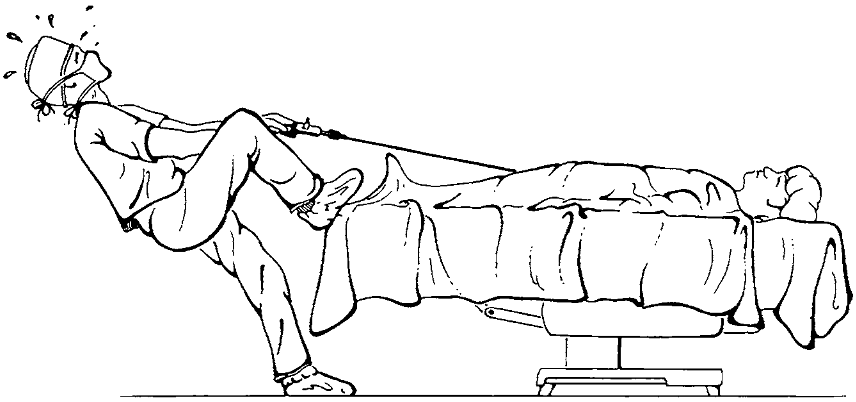

Fig. 3. The golden rule: *Don't pull too hard!*

complications, respectively (Table 2). Some of the more common injuries and suggestions on how to treat and avoid them will be discussed.

Perioperative Complications

MAJOR

Avulsion. Avulsion is a major intraoperative complication usually resulting from blind forceful manipulation. The most common scenario is forceful extraction of a large proximal ureteral calculus that has been engaged in a basket (Fig. 2). The most common site of ureteral avulsion is the proximal third of the ureter *(18)*. The ureter is thinnest at this level with the least well-defined muscular layers and a greater percentage of fibroconnective tissue, placing this portion of the ureter at greatest risk of avulsion *(19)*. The incidence of this catastrophic injury ranges from 0.5% in the earlier series *(20)* to 0% in the more recent series *(17,21)*.

If a ureteral avulsion is recognized, the procedure must be stopped and percutaneous drainage should be obtained. A safety wire will not prevent an avulsion and, if the injury is severe, a stent offers inadequate drainage. Primary repair may be feasible if a small portion of the ureter is injured. However, if the defect is large or if the ureter is devascularized at the site of avulsion and significant debridement is required, more complex reconstruction including ileal interposition and renal autotransplatation may be required. If the kidney functions poorly, nephrectomy may be an option. Transureteroureterostomy is contraindicated in patients with nephrolithiasis or upper tract TCC. *The best therapy for this complication is prevention.* Clearly, stones that have failed to pass or are larger than the diameter of the ureteroscope or the nondilated ureter will prove difficult to remove without lithotripsy. These stones should be fragmented prior to attempts at retrieval. The time and money savings hoped for by taking a "short cut" are miniscule compared to the cost of trauma to the patient. If a situation occurs where the stone is entrapped in a basket and cannot be removed, the basket should be disassembled and the stone fragmented after the ureteroscope is reinserted alongside the wire allowing removal of the smaller stone and basket. Removing the basket from the ureteroscope may not be necessary in ureteroscopes with two channels. The basket should *never* be forcefully pulled (Fig. 3).

Perforation. The incidence of ureteral perforation ranges from 0% in the more recent flexible ureteroscopy series *(17)* to as high as 17% in earlier series (*22*). Although major perforation may occur during forceful manipulation of the ureteroscope, it more commonly results from an endoscopie lihotrite. Santa-Cruz et al. *(23)* studied the perforation potential of four lithotripters ex vivo. The electrohydraulic lithotripter (EHL) and the holmium:YAG (Ho:YAG) laser could easily perforate the ureter while the coumarin pulsed-dye laser and the pneumatic impactor had a significant margin of safety. Nevertheless, the Ho:YAG laser was unable to perforate the ureter at a distance of greater than 2 mm, providing a margin of safety if the laser is directed away from the ureteral mucosa. Therefore, the electrohydraulic lithotripter offers the smallest margin of safety *(23,24)*. In an analysis of predictive factors of ureteroscopic complications, Schuster et al. *(21)* reported perforations in 15 of 322 patients undergoing ureteroscopy (4.7%). The type of ureteroscope used (flexible or semirigid) was not contributory. There was, however, a significant association of ureteral perforation with operative time, correlating with the difficulty of the procedure. Eight ureteral perforations occurred while extracting impacted stones. An additional six perforations occurred while trying to gain access past an impacted stone.

If a perforation is noted intraoperatively, the presence of a preplaced safety guidewire cannot be overemphasized. The procedure should be stopped and the ureter stented in anticipation of a staged procedure. Persistence may convert a minor perforation to a major perforation with significant extravasation or complete avulsion. If water or another hypotonic solution is being used, the irrigation should be changed to saline. Fluid is readily absorbed from the retroperitoneum. Extravasation of hypotonic fluids may result in severe symptomatic hyponatremia. Most ureteral perforations will heal spontaneously with a double-J stent in place and appropriate antibiotic coverage *(4)*. Rarely, placement of percutaneous nephrostomy to drain the kidney or a percutaneous abdominal drain to evacuate a urinoma may be necessary. Radiological evaluation of the affected ureter is critical 4 to 6 wk after the stent is removed to screen for ureteral stricture formation and obstruction.

Intussusception. Ureteral intussusception is a rare complication involving avulsion of the ureteral mucosa (Fig. 4). It can occur in both an antegrade and retrograde direction. Intussusception can occur with forceful extraction of large ureteral calculi. It has also been reported in association with ureteral polypoid TCC *(25)*. Park et al. *(26)* described retrograde intussusception caused by retrograde pyelography. Another case report described retrograde intussusception of the ureter before ureteroscopy during dilation of the ureter with a 12-Fr peel-away sheath *(27)*. The injury went unrecognized. Ureteroscopy and stent placement was possible through the intussuscepted segment. The only suspicious finding was that the ureteral lumen appeared pale white and narrow. Obstruction developed immediately once the stent was removed, requiring ureteroneocystostomy. Prevention of this injury requires a careful and gentle technique. A safety guidewire should always be present prior to any ureteral manipulation. Instruments should be advanced without force and under vision where possible.

Equipment Failure. The current state of ureteroscopy is entirely dependent on complex and costly equipment. Poor vision or a malfunctioning accessory instrument can result in patient injury. Instrument breakage in the patient has been reported *(4)*. Anderson et al. *(28)* recently reported a fractured flexible ureteroscope with locked deflection *in situ* requiring cutting the ureteroscope and open extraction. Postoperative evaluation revealed that a deflection ring in the distal portion of the scope had failed causing opposing control cables to slide to the same side and locking the ureteroscope in a kinked position. The authors recommended checking all instruments before introducing them into patients.

Nevertheless, poor handling and damage to the instrumentation caused by surgeon error can also be considered a complication. Firing an EHL probe close to the uretero-

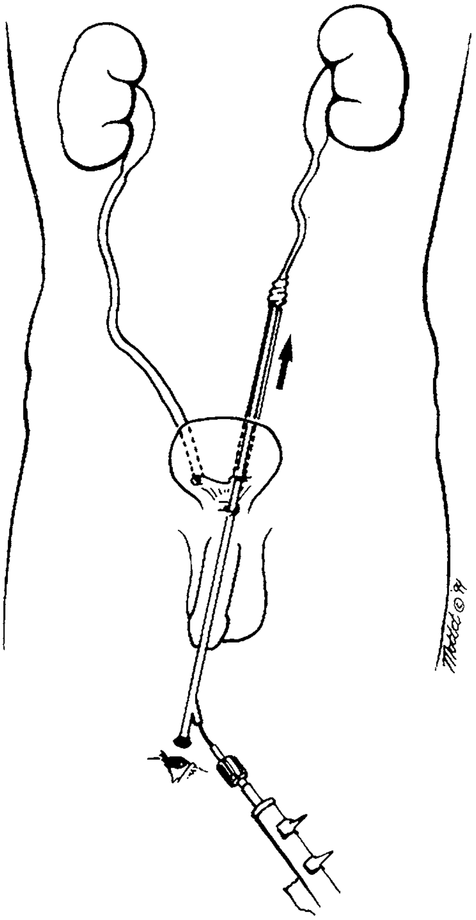

Fig. 4. Ureteral intussusception can occur with advancement of the ureteroscope if excessive force is applied or if the ureter is narrower than the scope.

scope tip can crack the lens as easily as it can fragment a stone. Similarly, firing a laser fiber in close proximity or within a ureteroscope can result in costly damage. The flexible ureteroscopes are fragile and most susceptible to damage. Sharp angulations of the scope during storage and cleaning may damage the scope. These instruments should never be passed through a cystoscope sheath as kinking at the sheath inlet will damage the ureteroscope. Forceful attempts at passage of an instrument through a flexed ureteroscope will also damage the working channel. In fact, we advocate straightening the scope prior to advancement of an accessory instrument. As with prevention of complications to patients, prevention of damage to equipment requires a gentle touch.

MINOR

Bleeding. Minor bleeding secondary to ureteral trauma is a frequent finding during ureteroscopy. It is seldom severe and transfusion is required only rarely *(20)*. More commonly, it obscures vision. The incidence of bleeding has ranged from 3.1 to 0% *(15–17,29)*. Minor bleeding is usually self limiting. Nevertheless, severe bleeding may

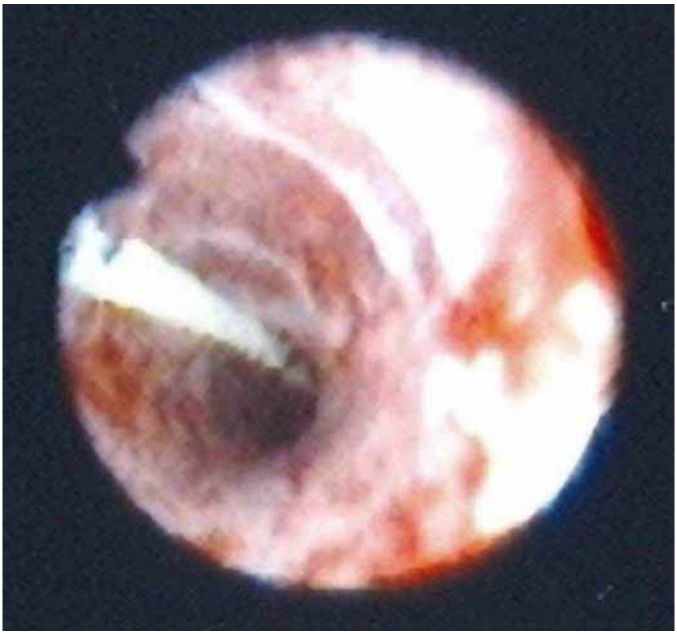

Fig. 5. Mucosal tear noted after balloon dilation in the mid-ureter to facilitate insertion of a ureteroscope.

occur requiring embolization or open repair. This is more likely when incisions of the collecting system are undertaken.

Mucosal Tear. Minor mucosal injury to the ureter is common, especially during ureteral dilation or insertion of the ureteroscope (Fig. 5). Mucosal trauma can also occur during stone manipulation. These injuries are self limiting and will usually heal within 48 to 72 hours with conservative management and drainage with a double-J stent. A small mucosal abrasion can be converted to a submucosal tunnel with inappropriate passage of a ureteroscope, wire, or catheter, causing devascularization of the ureter. This may result in postoperative stricture formation or, rarely, ureteral necrosis *(22)*.

Proximal Calculus Migration. Proximal calculus migration is no longer considered a treatment failure given the widespread availability of extracorporeal shockwave lithotripsy and flexible ureteroscopy. Nevertheless, proximal migration of a calculus does prolong anesthesia and operative time and may submit the patient to a second procedure. Placing the patient in a reverse Trendelenburg position and minimizing the irrigant pressure can limit proximal stone migration. Various devices ranging from the Dretler laser basket to the Lithocatch and Parachute baskets to the Passport balloon (Microvasive, Boston Scientific Corp.) have been used to prevent proximal stone migration *(30)*. These devices were suboptimal for a variety of reasons ranging from inadequate ureteral occlusion to limiting intraluminal space as all required an additional safety wire. The Stone Cone (Microvasive, Boston Scientific Corp.) is the newest advance. It prevents stone migration and promotes sweeping multiple stone fragments in a single pass, while substituting for the ureteral guidewire *(30,31)*.

Extrusion of Calculi. The reported incidence of retroperitoneal extrusion of a calculus through a ureteral perforation is between 0.5 and 2.3% *(4,20,32–36)*. The concern is that paraureteral calculi hinder ureteral healing and increase the risk of stricture formation. There is additional apprehension that extrusion of infected or struvite calculi may result in periureteral abscess formation *(33,36)*. Several studies, however, have shown that the risks of stricture and periureteral abscess formation are negligible. Evans and Stoller *(35)* reported a 1.2% incidence of iatrogenic retroperitoneal stones in 400 patients undergoing ureteroscopy. No abscess formation or infectious complications were noted. One patient developed a ureteropelvic junction (UPJ) stricture requiring open repair, but the stricture formation was felt to be a result of aggressive ureteroscopic manipulation in an attempt to retrieve the stone. Chang and Marshall *(34)* also documented an increased severity of ureteral injury with persistent attempts to remove the stone. Kriegmair and Schmeller *(37)* provided long-term follow-up of 15 patients with paraureteral calculi. One stricture was noted, which was easily treated endoscopically. No abscesses were noted. More recently, Lopez-Alcina et al. *(38)* reported a 1.1% incidence of calculus extrusion in 1047 patients. At a mean follow-up of 18 mo, no infection or secondary ureteral strictures were found.

Owing to the low incidence of secondary complications from extrusion of calculi and risk of worsening injury, persistent ureteroscopic manipulation to retrieve an extruded stone is not recommended. We suspect that the real risk factor for stricture formation is the perforation itself and the associated extravasation rather than the extruded calculus. Stent drainage along with a short course of perioperative antibiotics is recommended by the above authors. Follow-up imaging should be obtained to confirm adequate renal drainage (Fig. 6). The infection stone may be followed with a computed tomography (CT) scan to rule out abscess *(38)*. However, given the extremely low risk of abscess formation, imaging should be guided by clinical suspicion. *Patients should be educated about persistent calculi to avoid future mismanagement by other physicians (35).*

Thermal Injury. Ureteroscopic treatment of stones is often performed with lithotrites which can cause thermal injury to the ureter, resulting in delayed fibrosis and stricture formation. The ultrasonic lithotripter achieves fairly high temperatures and can cause thermal ureteral injury if not allowed to cool periodically *(22)*. It is seldom used since the advent of EHL and Ho:YAG. EHL also generates enough heat to cause thermal or blast injury to the ureteral wall *(23,24)*. In recent years, lasers have become the most commonly used lithotrites. The coumarin pulsed-dye laser is not absorbed by hemoglobin or soft tissues and is not associated with a risk of thermal injury. The Ho:YAG laser not only fragments, but also vaporizes stone to fine dust. It can also cause thermal injury and perforation, but there is a margin of safety if the laser is kept at a distance greater than 2 mm from the ureteral wall *(23)*. In addition, adequate irrigation is critical to allow cooling and prevent thermal injury. Recently, a pulsed solid-state laser system that has been used for biliary and salivary lithiasis has been applied to urinary calculi. The Frequency-Doubled Double-Pulse Neodymium:YAG (FREDDY) laser (World of Medicine, Berlin Germany) lacks clinical data regarding efficacy and safety in treatment of urinary calculi. However, it has been shown to be an efficient lithotripter in vitro with only superficial tissue injury *(39,40)*.

Postoperative Complications

EARLY

Colic. Postoperative colic following a ureteroscopic procedure is common and may be a result of transient obstruction from ureteral edema, clots, or stone fragments. The incidence ranges from 3.5 to 9.0% *(16,17,29)*. This can be averted with placement of a

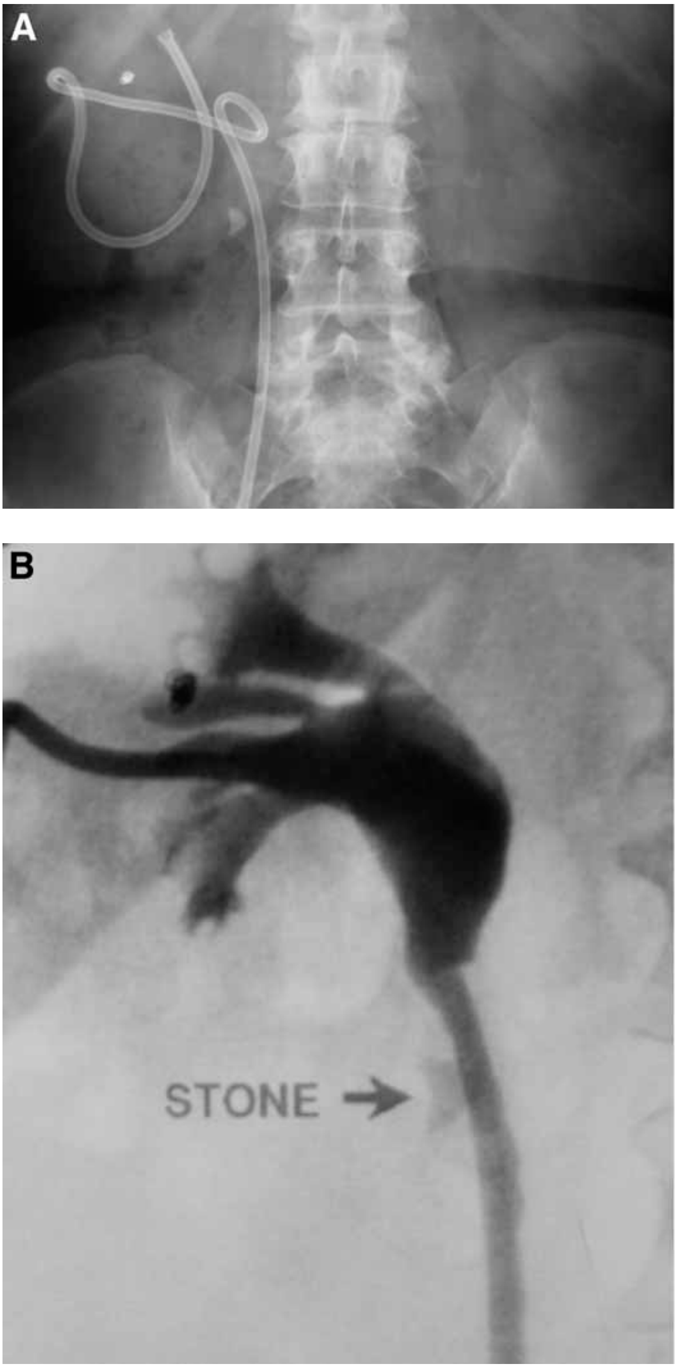

Fig. 6. (A) Extruded calculus. Kidneys, ureter, and bladder after ureteroscopy complicated by perforation and placement of a percutaneous nephroureterostomy tube. **(B)** Antegrade nephrostogram demonstrates no obstruction several weeks after the injury. Antegrade ureteroscopy confirmed that the calculus was not in the ureteral lumen with minimal impression in the mucosa. No further management was undertaken.

stent, which has its own attendant morbidities. Colic often lasts less than 24 to 28 hours and can be controlled with oral analgesics. Flam et al. *(4)* reported a 1.1% incidence of postoperative admission for control of flank pain. The necessity of stent placement postureteroscopy has recently been questioned and is addressed below.

Infection. Symptoms of postoperative infection range from a low-grade fever to pyelonephritis with bacteremia and sepsis. Significant infection in the presence of sterile preoperative urine and use of preoperative antibiotics is rare, occurring in 0.3 to 1.3% of patients in a large series *(14,15,19)*. Nevertheless, low-grade fever is much more common, occurring in as many as 6.9% of patients in one series *(29)*. A clinical history of urinary tract infection (UTI) or infectious calculi increases the risk of postoperative infection considerably *(18)*. If purulent drainage is noted during any portion of upper tract evaluation, the collecting system should be drained and further manipulation halted until infection has resolved. Ureteroscopy in a febrile patient with an obstructing stone is contraindicated and can result in life-threatening urosepsis.

LATE

Ureteral Necrosis. Ureteral necrosis is the postoperative outcome of a severe intraoperative injury involving intussuception, severe thermal injury, or mucosal dissection. Lytton *(41)* reported loss of the entire ureter attributed to partial perforation of the ureter followed by devasculariztion secondary to submucosal irrigation. Kaufman *(42)* reported distal ureteral necrosis in a patient after ureteral injury and extravasation during stone extraction. This is a rare but major complication and prompt diagnosis is dependent on clinical suspicion.

Stricture. Ureteral stricture formation after ureteroscopy is a major late complication that subjects patients to additional procedures or, if left untreated, puts them at risk for renal loss. Although ureteral stricture rates as high as 37% after instrumentation have been reported in one series *(43)*, most series document stricture rates less than 2% with uncomplicated ureteroscopy *(15–17,29)*. There has been a trend toward a decrease in the incidence of strictures. Blute et al. *(15)* noted a 1.4% stricture rate in 1988, whereas Harmon et al. *(16)* noted a 0.5% stricture rate in 1997 at the same institution.

In contrast, Roberts et al. *(44)* noted a 24% incidence of ureteral strictures in 21 patients undergoing ureteroscopy for impacted stones. Four of the five patients who developed postoperative stricture had suffered ureteral perforation during ureteroscopy. Therefore, the authors concluded that ureteral perforation was a significant risk factor for stricture formation in patients with impacted stones. Mugiya et al. *(45)* demonstrated a stricture in 17% of patients undergoing ureteroscopic management of impacted stones. They found a correlation between the duration of impaction and the incidence of strictures. Histological studies have revealed chronic inflammation, fibrosis, and urothelial hypertrophy at the site of the impaction *(44)*. Dretler and Young *(46)* found granulomatous inflammation around residual embedded stone fragments at the site of strictures in patients who underwent stone fragmentation prior to extraction. They suggested that residual stone fragments and the resultant inflammation were an etiological factor in stricture formation.

The inflammation in progress around impacted stones may predispose to perforation in addition to stricture formation. Contradictory evidence exists regarding the role of perforation in stricture formation. Kramolowsky *(43)* reported strictures in 37% of patients who suffered a perforation. In contrast, Stackl and Marberger *(32)* found no correlation between perforation and stricture formation with no late complications at a minimum of 16-months follow-up. Lytton *(41)* had similar outcomes with no stricture formation in 12 patients managed conservatively after perforation.

Therefore, the etiology of stricture formation is likely multifactorial. Impacted stones, ureteral perforation and extravasation, mechanical trauma from the ureteroscope or an accessory instrument such as a lithotrite, ureteral ischemia, and thermal injury may all play a role in stricture formation *(24)*. The common thread here is urothelial trauma. In addition, inflammation is a key step towards stricture formation *(44,47)*.

The management of ureteral strictures is dependent on length and duration of the stricture as well as the degree of periureteral fibrosis. Short annular strictures respond well to endoscopic management with balloon dilation or incision. Longer strictures and those associated with significant periureteral fibrosis are best managed with open or laparoscopic reconstruction. The type of procedure performed is variable and depends on the location and length of the ureteral stricture. If the ipsilateral renal function is poor, nephrectomy remains an option in lieu of reconstruction.

Reflux. Vesicoureteral reflux (VUR) has been described as a late complication of ureteroscopy. However, VUR in uninfected adults is of little clinical significance *(22)*. Garvin and Clayman *(6)* demonstrated a 20% incidence of VUR after ureteral dilation to 24 Fr. In 1999, Richter et al. *(48)* found a 10% incidence of VUR after ureteral dilation to 13.5 Fr. These authors followed their patients prospectively; the patients demonstrated complete resolution of reflux at 2 weeks postoperatively. Further evaluation or screening for this complication is unnecessary given the low incidence of reflux after ureteroscopy and the minimal pathologic effect of VUR on a fully developed adult kidney.

URETERAL STENTS: ARE THEY NECESSARY?

Routine placement of ureteral stents in all patients after ureteroscopy has been considered essential *(24)*. The evidence to support this practice is sparse and based on animal models demonstrating ureteral injury and obstruction after ureteral dilation *(49,50)*. The presumption is that placement of a stent serves to protect against postoperative complications including ureteral obstruction from edema, clot or stone fragments, as well as stricture formation *(16)*. However, ureteral stents are not without their own morbidity. Complications associated with stents include bladder and flank pain, irritative voiding symptoms, infection, stent migration, encrustation, and retention in patients lost to follow-up. Several studies report a 10 to 85% incidence of stent related symptoms *(51–53)*, whereas others note a 94 to 100% rate of symptom resolution after stent removal *(51,54,55)*. In addition, stents add to the operative time and cost. Cystoscopy is required to remove the stent, unless a pull string is left. Given the relatively atraumatic state of current ureteroscopic equipment and technique, elimination of stents in ureteroscopy patients has become a viable option.

There is mounting evidence supporting the selective use of ureteral stents. Hosking et al. *(56)* reviewed 93 consecutive unstented patients, 88% of whom also underwent ureteral dilation. The majority of patients had no postoperative pain or required minimal oral analgesics. Rane et al. *(57)* treated distal stones using semirigid ureteroscopes without ureteral dilation with similar results and minimal postoperative flank pain. In addition, four randomized trials have demonstrated similar complication rates between stented and unstented patients, with the stented groups experiencing significantly greater irritative and painful symptoms *(58–61)*. Stented patients also had longer operative times and higher overall cost *(59)*. No strictures were noted on postoperative imaging in unstented patients.

Although three trials exluded patients undergoing ureteral dilation, 57% of patients without stents in one study underwent intraoperative distal ureteral dilation *(60)*. These patients did as well as the unstented patients who did not undergo ureteral dilation. Readmission rates among the unstented patients were 3 to 7% in the different studies with short-term stent placement required in two patients in a single study *(60)*.

Recently, Hollenbeck et al. *(62)* retrospectively evaluated 219 patients undergoing stentless ureteroscopy to identify factors associated with postoperative complications in this group. Renal pelvic stones, lithotripsy, bilateral procedures, operative time 45 minutes or greater, recent/recurrent UTIs, diabetes mellitus, and history of urolithiasis were associated with postoperative morbidity in this unstented cohort. The authors suggest that these findings may serve as guidelines for selecting patients who may undergo stentless ureteroscopy.

The current standard of care regarding stenting after ureteroscopy is evolving. Clearly, a large number of patients undergoing uncomplicated diagnostic and/or therapeutic ureteroscopy may safely remain unstented. Nevertheless, common sense and clinical judgment should prevail. Patients undergoing complicated ureteroscopy with mucosal trauma, perforation, impacted stones, or solitary kidneys should be stented. We continue to stent patients undergoing ureteral dilation and bilateral ureteroscopy.

POSTOPERATIVE IMAGING

Postoperative imaging is another evolving issue in endourology. The rationale behind routine surveillance postoperative radiographic imaging has been detection of *silent obstruction* or stricture formation that may have an adverse effect on renal function. However, the advent of small caliber urteroscopes, safer lithotripters, and other accessories has resulted in low postoperative complication and high success rates. This has led some to suggest that routine postoperative imaging may not be necessary after ureteroscopy *(63,64)*. In a retrospective review of 189 patients undergoing ureteroscopy, Karod et al. *(64)* found that although all 10% of patients with radiographically confirmed obstruction had flank pain, none of the asymptomatic patients were obstructed on radiologic follow-up at a median of 60 days. Stricture was the source obstruction in 0.8%. They concluded that routine postoperative imaging to rule out obstruction is not necessary in asymptomatic patients, as obstructed patients will present with flank pain.

However, in another retrospective study *(65)*, 30 of 241 patients (12.3%) developed postoperative obstruction at a mean follow-up of 5.4 months. Although 23 of these 30 patients (76.7%) had pain, 7 patients (23.3%) with obstruction were asymptomatic. Therefore, silent obstruction developed in 2.9% of the total population undergoing ureteroscopy. One patient with asymptomatic obstruction received chronic hemodialysis for renal failure. Although patients with pain after ureteroscopy were more likely to have obstruction than those without pain, no parameters reliably predicted silent obstruction. The authors felt the possibility of missing 2.9% of patients with silent obstruction posed a significant risk and recommended routine imaging of the collecting system within 3 months of ureteroscopy. The use of pain to predict obstruction in another study had a negative and positive predictive value of 83 and 75%, respectively *(63)*.

There is likely a cohort of postureteroscopy patients who do not require routine imaging. Absence of symptoms, nevertheless, is not an adequate criterion to omit imaging as the morbidity of undiagnosed obstruction is significant. Other variables may exist that could suggest obstruction, or lack thereof. However, these are lacking to date. In the meantime, the authors continue to image patients postureteroscopy. Depending on the clinical situation, a renal ultrasound, intravenous pyelography, CT, or a nuclear scan may be adequate.

COMPLICATIONS OF URETEROSCOPIC MANAGEMENT OF UPPER TRACT TCC

Ureteroscopic management of upper tract TCC has become routine with the availability of small caliber semirigid and flexible ureteroscopes allowing tumor visualization, biopsy, resection, or ablation. Whereas nephroureterectomy remains the standard for patients with high-grade TCC and most patients with low-grade TCC, endoscopic tumor therapy is an option in patients with solitary kidneys, renal insufficiency, bilateral TCC, or significant medical comorbidities *(66)*. More recently, attention has turned to renal preservation in patients with normal contralateral kidneys and small volume focal low-grade upper tract TCC. Recent studies have shown that this is a safe therapeutic modality in this population, which traditionally would have undergone a nephroureterectomy *(67,68)*. Life-long frequent endoscopic and radiological surveillance is required. Complications of ureteroscopic management of upper tract TCC include loss of access, equipment failure, and bleeding and are similar to complications of ureteroscopy in general, which have already been discussed. Perforation and stricture formation, however, deserve additional mention.

Perforation is a rare occurrence. Grasso and Bagley *(17)* reported no perforations in 101 patients undergoing treatment of upper tract TCC. However, Elliott et al. *(67)* and Martinez-Pineiro et al. *(69)* reported two and four perforations, respectively. Perforation can occur with the guidewire or the endoscope. In addition, the ureter may be perforated when a grasper or basket is used to biopsy the tumor. The basket and tumor sample should be withdrawn under vision to prevent ureteral avulsion. Injury is more likely when tissue other than the tumor is grasped or the amount of tissue grasped is large. The ureter can also be perforated with electrocautery (the Ho:YAG and the neodymium:YAG [Nd:YAG] laser) if the power settings are too high, the ablation too deep, or if the instrument is misdirected onto the ureteral wall. Most ureteral perforations can be managed conservatively with a stent *(69)*. Thus the presence of a safety wire is critical. Once a perforation is diagnosed intraoperatively, discontinuation of the procedure should be considered to prevent tumor seeding. Nevertheless, to our knowledge, retroperitoneal seeding after perforation has not been reported. Larger perforations may require percutaneous drainage or even nephroureterectomy *(66)*.

The incidence of ureteral strictures after treatment of upper tract TCC has ranged from 5 to 25% *(70)*. Chen and Bagley *(66)* reviewed 139 patients in five series and found an overall stricture incidence of 8.6%. This is in stark contrast to the 0.5% stricture rates reported by Harmon et al. *(16)* and Grasso and Bagley *(17)* in series with large stone populations. The higher stricture rate after treatment of upper tract TCC compared with stones is largely because of the different targets during therapy. Although stones absorb most of the energy during laser lithotripsy, treatment of TCC requires that the laser, resectoscope, or fulgerating probe be directed at the urothelium. Patients undergoing circumferential or deep ablation are at higher risk of scarring and stricture formation. The Nd:YAG laser may result in less stricture formation than electrocautery *(71)*. However, the Nd:YAG laser penetrates to a depth of 5 to 6 mm and may be more damaging than the Ho:YAG laser, which penetrates only to 0.5 mm. Keeley et al. *(72)* reported two strictures in 19 patients using fulgeration and/or the Nd:YAG laser and none in 22 patients using the Ho:YAG laser. Directing the tip of the laser fiber only onto the visible tumor can minimize the risk of stricture formation. If a stricture develops, management is similar to strictures resulting from other causes. However, the strictured area should be biopsied to rule out a malignant stricture.

Incomplete tumor resection is a significant complication of endoscopic management of upper tract TCC and is more common with large tumors (>1.5 cm) and tumors located in the lower pole of the kidney. Although significant bleeding is rare, clot and debris can obscure the margins of larger tumors. If the tumor is low grade, a staged approach may be used with retreatment at a later date. However, nephroureterectomy should be seriously considered in patients whose tumors are too large or multifocal to adequately ablate endoscopically even if low grade, the tumor is inaccessible, or if it is high grade.

COMPLICATIONS OF URETEROSCOPIC INCISIONS

Ureteroscopic incisions can be used to treat a variety of upper tract obstructive processes including ureteral stricture, UPJ obstruction, calyceal diverticulum, and infundibular stenosis. Complications attendant to ureteroscopy, in general, may occur with upper tract incisions as well. Incising the upper tract, however, involves purposeful perforation with healing over a stent. Several studies have addressed ureteroscopic endopyelotomy *(73–75)*. The complication rates are low with no intraoperative or immediate postoperative complications reported in a recent series by Giddens and Grasso *(76)*.

In addition to stent-related complications and urinoma formation, the major risk of ureteroscopic incisions is intraoperative hemorrhage. An incision at the UPJ may inadvertently cut through a crossing vessel resulting in immediate bleeding. Similarly, incision of a stricture over the iliac vessels or injury to an intrarenal artery during incision of an infundibulum may result in severe bleeding. The key to management is prevention of vascular injury. Knowledge of renal vascular anatomy is imperative. All incisions at the UPJ should be directed laterally. Posterior incisions should be avoided at the iliacs. Bagley et al. *(77)* have championed the use of intraluminal ultrasonography to define vascular anatomy and direct incisions away from them. If hemorrhage is encountered or the patient complains of excessive postoperative pain, emergent imaging should be performed. Persistent bleeding with a continued transfusion demand or an unstable patient necessitates emergent arteriography and selective embolization. In rare instances, a nephrectomy may be necessary *(78)*.

CONCLUSION

Clearly, the current state of ureteroscopy has provided an efficacious minimally invasive alternative for a number of upper tract disease processes with minimal morbidity. The progress in patient outcomes and advancement in technology is undeniable. Ureteroscopy, however, continues to evolve with advent of larger working channels in small caliber scopes, as well as smaller and more efficient accessory instruments. Dependability and longevity of the equipment remains to be addressed and represents the next frontier in instrumentation. The ureteroscope, in the end however, is only as safe as its operator. Proper patient selection, knowledge of potential complications, the capabilities and limitations of the instruments, and common sense and sound judgment will result in improved outcomes and reduced morbidity.

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VI

PEDIATRIC MINIMALLY INVASIVE SURGERY

19

Pediatric Endourology

Christina Kim, MD *and Steven G. Docimo,* MD

CONTENTS

SUMMARY

Minimally invasive surgery is gaining popularity in both adult and pediatric urology. There are multiple applications with varied outcomes comparable to open surgery. The goal is to decrease postoperative discomfort, minimize hospital stays, and improve cosmesis. It is imperative to gain more information about the long-term outcomes so we can decide the best applications.

Key Words: Pyeloplasty; orchidopexy; nephrectomy; bladder reconstruction; urolithiasis; laparoscopy; nephrolithotomy; pediatric.

INTRODUCTION

Pediatric endourology is a changing and evolving field. The optimal use of minimally invasive surgery is being explored in both adult and pediatric urology. The indications for these interventions have been better defined in adults with advantages of shorter hospitalizations, quicker return to normal activity, and less visible scarring. Although these advantages are less obvious in the pediatric population, minimally invasive techniques are becoming increasingly important. This chapter summarizes current indications, technique, outcomes, and controversies of commonly used pediatric endourologic techniques. These

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include laparoscopic orchidopexy, laparoscopic partial and total nephrectomy, laparoscopic pyeloplasty, minimally invasive lower tract reconstruction, and stone manipulation.

OPERATIVE LAPAROSCOPY

Pediatric urologists have greatly expanded the use of laparoscopy. Initially it was used as a diagnostic tool for the nonpalpable testes *(1)*. Now it can facilitate a one or two stage Fowler-Stephens orchidopexy. It has an increasing role for nephrectomy and pyeloplasty. Some emerging uses include ureteral reimplantation and bladder reconstruction.

The first step in laparoscopy is access into the peritoneum or retroperitoneum. In children, many prefer an open technique to place the initial trocar. A radially dilating trocar introduced via a small umbilical incision induces less trauma to the muscles and may not require external fixation. It has been associated with minimal risk of complications and gas leakage *(2)*. Another method is using a Veress needle to achieve pneumoperitoneum with either blind or visually-assisted initial trocar placement *(3,4)*. A variation of this is the 2-mm port with an *in situ* Veress needle introducer *(5)*. The complication rate of open access is 1.2 to 3.8% vs 2.6 to 7.8% for Veress needle technique. For both techniques, the rate it is related to operator experience (*6,7*). It is important for the surgeon to be comfortable with various approaches.

Most of the initial attempts at laparoscopy in pediatric urology have been performed via a transperitoneal approach. There is increased comfort with this approach because it is used for many general surgical cases. In addition, there is a larger working space and surgical landmarks are easier to identify (*8–10*). When compared to a retroperitoneal approach, some have suggested an increased morbidity from future adhesion formation and injury to intraabdominal organs. These concerns have not been borne out in clinical studies (*11,12*).

Because the retroperitoneal approach is common in many open urological operations, there is a growing number of practitioners that prefer this approach. Some advantages of retroperitoneal access are shorter distance to the kidney and less manipulation of other organs. Some disadvantages are decreased working space and less obvious anatomic landmarks *(9)*. This can make suturing and knot tying more difficult. In addition, if bleeding occurs, it can be more difficult to see and to control. One of the most common complications with retroperitoneal access is violating the peritoneum (24–30%) *(13,14)*. The gas insufflation will leak and decrease the size of the working space. The lateral peritoneal reflection is the most vulnerable. One way to avoid this is freeing the peritoneum off the iliac fossa before placing accessory trocars. If a tear is created, it can be dealt with in different ways. Often the tear will be closed with a laparoscopic suture. Another option is placing a Veress needle into the peritoneum to vent the leak during the case. If the tear occurs late in the case, it may be possible to continue with no direct intervention *(14)*. There are times when the working space can not be maintained. Therefore, the retroperitoneal surgeon should be able to convert to transperitoneal dissection if necessary *(15)*.

Once access is obtained, the surgeon has many ways to manipulate the tissue. Hand instruments vary in size from 2, 3, 5, 10, and 12 mm. Most equipment that is available for open surgery is also available for laparoscopy. The 2-mm instruments available have less rigidity and fewer functional variations. The 2-mm suction aspirator has low flow that is inadequate to aspirate blood for a clean surgical field *(5)*. Ten and twelve millimeter ports are rarely needed in pediatrics. They are primarily used if a vascular stapler is needed for a larger vessel, such as the renal vein.

One of the most challenging and time consuming maneuvers is suturing. Laparoscopic needle drivers come in 10, 5, and 3 mm sizes. Some common challenges include difficulty orienting the needle on the driver, as well as orienting the needle to the tissue. One device that can be helpful is a self-righting needle driver. Another potential tool is an automatic suturing device (Endo-Stitch, US Surgical, Norwalk, CT). However, this requires larger suture material, which leaves larger suture tracks. This is not suitable for most pediatric procedures.

Hemostasis can be achieved in many ways. Electrocautery can be attached to most hand instruments. It is available in both monopolar and bipolar forms. Some prefer bipolar because the current does not pass through the entire body. This reduces the risk of burns distant from the forceps and decreases the depth of injury to adjacent tissue. Another option is harmonic (ultrasonic) energy. This cuts and coagulates tissue simultaneously at a lower temperature than electrocautery (50–100°C). The harmonic scalpel blade vibrates at 55,500 Hz and couples with protein to denature the tissue. Once denatured, it forms a coagulum that seals small vessels *(16)*.

Larger structures such as the renal vessels and ureter may require individual ligation. This can be done by tying a suture or applying an individual clip. The smallest clip applier currently available fits through a 5-mm port. If an anastomic stapler is needed, the port must be at least 12 mm.

General Laparoscopic Complications

There are some inherent risks of laparoscopic surgery. In 1996, Peters et al. *(7)* performed a survey to assess complications in pediatric urological laparoscopy. The overall incidence was 5.36%. The majority of these complications were CO_2-related morbidities including preperitoneal insufflation and subcutaneous emphysema. The need for surgical repair of complications occurred in only 0.38%. The rate of complications correlated with the level of laparoscopic experience. Some have found these complications more frequently during extraperitoneal insufflation *(17)*.

There have been concerns regarding the hemodynamic changes that occur with pneumoperitoneum. A recent review by Halachmi et al. *(18)* showed decreases in oxygen saturation and heart rate and increases in respiratory rate and positive airway pressure during CO_2 insufflation. However, there were no associated complications, so the significance of these findings is unclear.

Pneumothorax is another possible complication of laparoscopy. It has been reported in both adults and children. Waterman et al. *(19)* recently reviewed 285 laparoscopic cases, 4 of which developed a pneumothorax. It is important to have a high index of suspicion when the oxygen saturation drops in these cases. Often, these patients can be managed conservatively.

Laparoscopic vascular and bowel injury is most often associated with Veress needle or trocar placement. It is not a frequent complication of the surgical dissection. This risk can be reduced by open placement of the first port and direct visualization of all additional ports *(20)*.

LAPAROSCOPIC ORCHIDOPEXY

The incidence of undescended testis in premature infants is 30% and in term infants is 3%. Twenty percent of undescended testis are nonpalpable *(21)*. There is still debate regarding the best technique to evaluate and treat a nonpalpable testis. Laparoscopy has been used as a diagnostic procedure for nonpalpable testes for nearly three decades *(1)*.

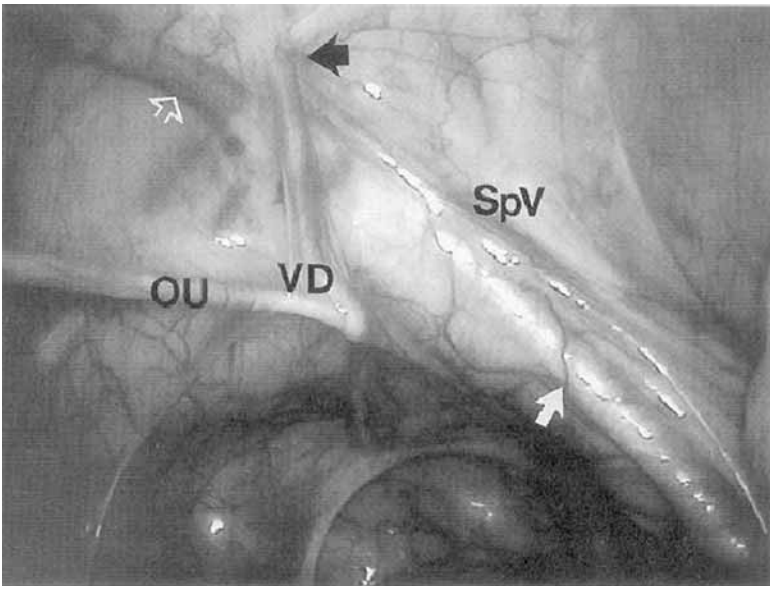

Fig. 1. Normal internal ring. The obliterated umbilical (OU) artery is seen medially with the vas deferens (VD) adjacent to it. The spermatic vessels (SpV) are traveling in a cephalad direction. (Reprinted from ref. *27a*, with permission.)

Imaging studies have been found inadequate as a diagnostic tool. If the testis is absent on imaging, it does not rule out the possibility of its existence *(22)*. In fact, imaging studies have a fairly low rate of accuracy of only 44% *(23)*. Therefore, whether or not a testis is found on imaging, surgical intervention will be necessary.

Diagnostic laparoscopy gives the most comprehensive assessment by delineating testicular location, testicular absence, vas deferens location, and the route of the testicular vessels. Criticism of its use focuses on the patients who have inguinal testes or remnants. These patients could have adequate treatment by an inguinal approach alone, which has been reported to occur in up to 60% of cases. Therefore, it is imperative to perform a thorough physical examination when the patient is under anesthesia. When a thorough examination is performed under anesthesia, 18% of testes which were not felt in the clinical setting will be palpable. If the testis is indeed nonpalpable, laparoscopy is an excellent tool *(24)*. We advocate scrotal exploration in any case in which tissue is palpable in the scrotum. Identification of hemosiderin, atretic vessels, or both is evidence of a scrotal vanishing testis described by Belman and Rushton *(25)*. If a testis is found, another potential advantage of laparoscopy is guiding the incision. Cisek et al. *(26)* found that laparoscopy altered the operative approach in 66% of their cases.

Of nonpalpable testes, 50% are intra-abdominal and 50% are vanishing testes *(27)*. Fig. 1 shows the appearance of a normal internal ring. Fig. 2 shows blind ending vessels above the internal ring, consistent with a vanishing testis.

If the testis is intra-abdominal, it can be anywhere between the internal ring and the ipsilateral kidney. Once the testis is found, the size and location are assessed. A two stage Fowler-Stephens approach may be used if there is a large distance between the testis and the internal ring. Laparoscopy offers the same options for mobilization as transabdominal open orchidopexy, often with superior visualization. The magnification allows significant mobilization of tissue off the testicular vessels and vas deferens if

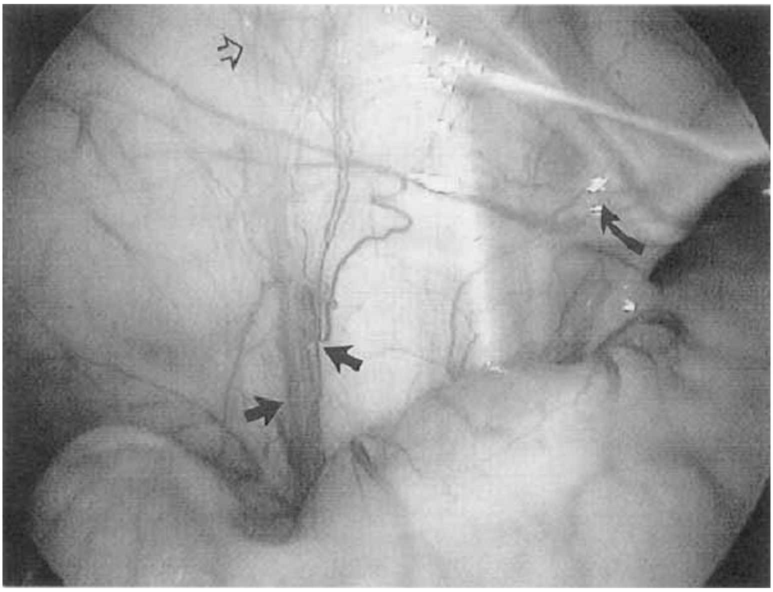

Fig. 2. Blind ending vessels are seen with the short dark arrows. The curved arrow points to the vas deferens. The open arrowhead shows the empty internal ring. (Reprinted from ref. *27a*, with permission.)

indicated. If a Fowler-Stephens approach is used, laparoscopy gives excellent exposure of the peritoneum that must be spared with the vas deferens.

When orchidopexy is performed laparoscopically, three ports are placed: one in the umbilicus and two just below the umbilicus along the anterior axillary line (Fig. 3). To mobilize the testis, a peritoneal incision is made lateral to the spermatic vessels and towards the internal ring. The peritoneum between the vas deferens and the spermatic vessels is spared. This preserves the collateral blood supply in case the spermatic vessels either spasm or need to be cut to get additional length (Fig. 4). If needed, the testicular vessels can be followed proximally to the level of the renal hilum. If the vessels need to be divided, a 5-mm laparoscopic clip applier is usually sufficient in size.

Once there is adequate mobilization, the testis can be delivered into the scrotum. One method is to pass a dilating trocar from the scrotum into the abdomen. First, a subdartos pouch is created in the ipsilateral scrotum. Then, a 2-mm laparoscopic grasper is passed through the internal ring, over the pubis, and out a scrotal incision. If additional length is needed, the trocar can be passed medial to the epigastric vessels or medial to the medial umbilical ligament, taking care to avoid the bladder. From the scrotum, a 2-mm radially dilating trocar sheath is passed over the grasper. The grasper is removed from the sheath, and a 5- or 10-mm dilating trocar is used to create an adequately sized neocanal. A laparoscopic Allis clamp is passed from below to guide the testis into the scrotum. The testis is then secured in the subdartos pouch. If a radially dilating system is not available or adequate, dilation can be achieved with Amplatz dilators over the grasper *(28)*.

Results of Laparoscopic Orchidopexy

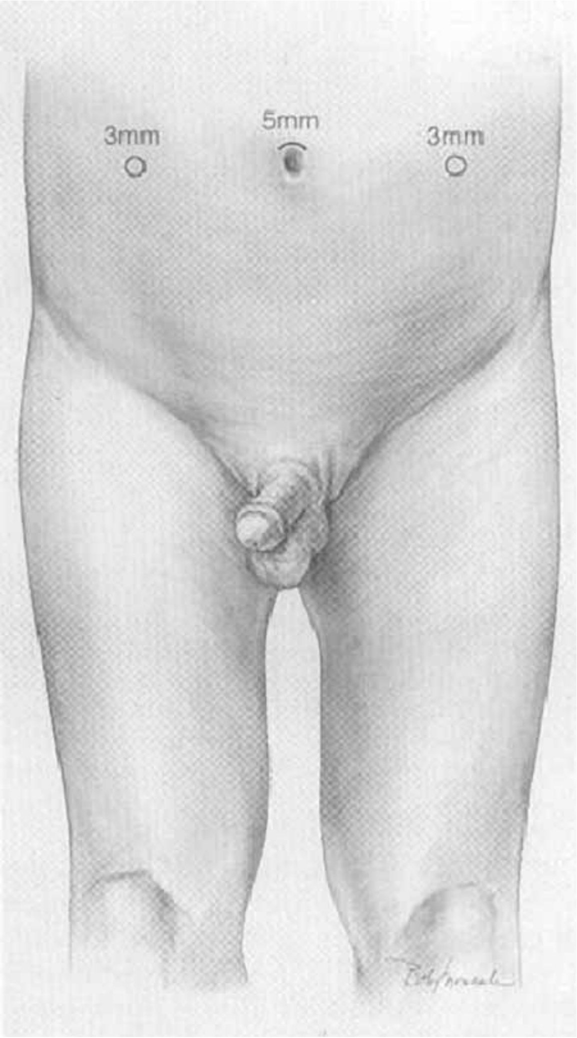

Fig. 3. Port placement for laparoscopic orchidopexy. One in the umbilicus and two below the umbilicus along the anterior axillary line. (Reprinted from ref. *27b*, with permission.)

Testicular atrophy and malposition are the most important outcomes of both open and laparoscopic orchidopexy. Initially it was unclear if the starting position of the testis correlated with the results of orchidopexy. However, a meta-analysis of orchidopexy outcomes showed greater success when the testis started distal to the external ring. Also, outcomes were better if the operation was performed in children younger then 6 years old and if the spermatic vessels were not divided *(29)*. Most reports show a greater than 90% success rate of bringing the testes into the scrotum. A multi-institutional analysis of laparoscopic orchidopexy outcomes found excellent results. Success with single stage Fowler-Stephens laparoscopic orchidopexy was 75 to 92% and two stage was 80 to 88% *(30,31)*. The overall success rate of primary, one- and two-stage laparoscopic orchiopexies was 92%. The atrophy rate was 6.1%. Again, there was an advantage to maintaining intact vessels when possible. It appears that preservation of testicular vessels is more likely when one uses a laparoscopic approach.

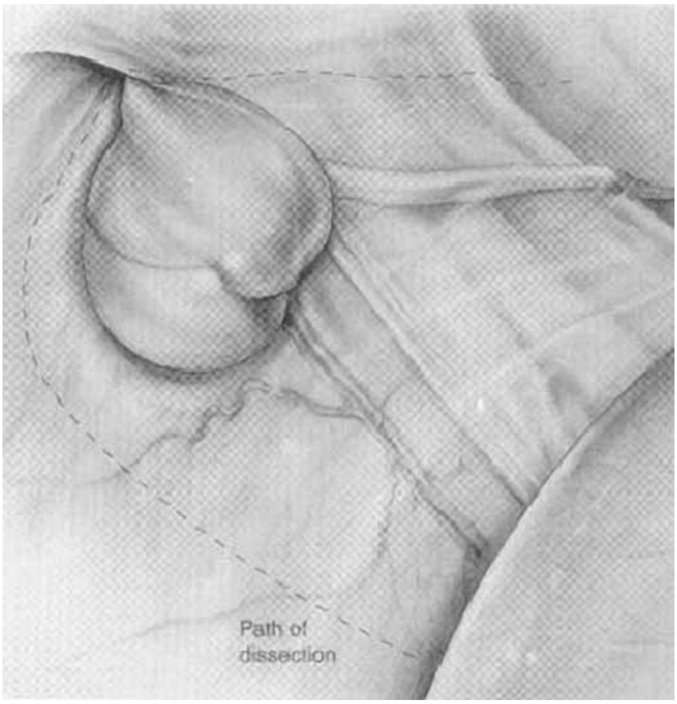

Fig. 4. The peritoneum between the vas deferens and spermatic vessels is outlined and left intact. (Reprinted from ref. *27b*, with permission.)

These results challenge the results of open orchidopexy. Success may be related to magnification, less manipulation of the testicular tissue, and a wider peritoneal window.

LAPAROSCOPIC NEPHRECTOMY

Laparoscopic renal surgery is gaining popularity in both adults and pediatrics. Some well-documented advantages of laparoscopy are improved cosmesis, shorter hospital stays, quicker return to work, and less postoperative pain *(32–35)*. Initially, there was skepticism about the usefulness of this surgery in children. But studies of laparoscopic partial and total nephrectomy have been consistent with the adult data. This approach is feasible with low morbidity and favorable outcomes *(36,37)*.

There are no definite contraindications for a laparoscopic renal approach in children. However, most reserve this approach for benign renal disease, e.g., multicystic kidney, nonfunctioning and hydronephrotic kidney, and pretransplant removal. If malignancy is present, most will choose an open approach *(14)*.

Laparoscopic nephrectomy can be done by a transperitoneal or retroperitoneal approach. The first cases were performed transperitoneally. When using this approach, the initial port is placed at the umbilicus. A second port is placed in the lower quadrant along the midclavicular line between the umbilicus and the pubis. The third port is placed in the midline or midclavicular line above the umbilicus, depending on the size of the patient, avoiding the falciform ligament (Fig. 5). In infants and young children, three midline trocars can be used *(38)*. If an additional port is needed for retraction, it is placed in the anterior axillary line along the superior edge of the kidney.

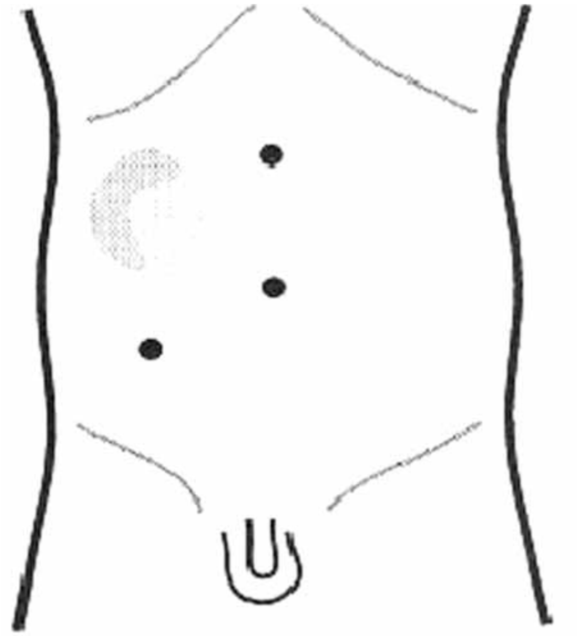

Fig. 5. Placement of ports for a transperitoneal pyeloplasty. Another option in smaller children is placing all three ports in the midline. (Reprinted from ref. *37a*, with permission.)

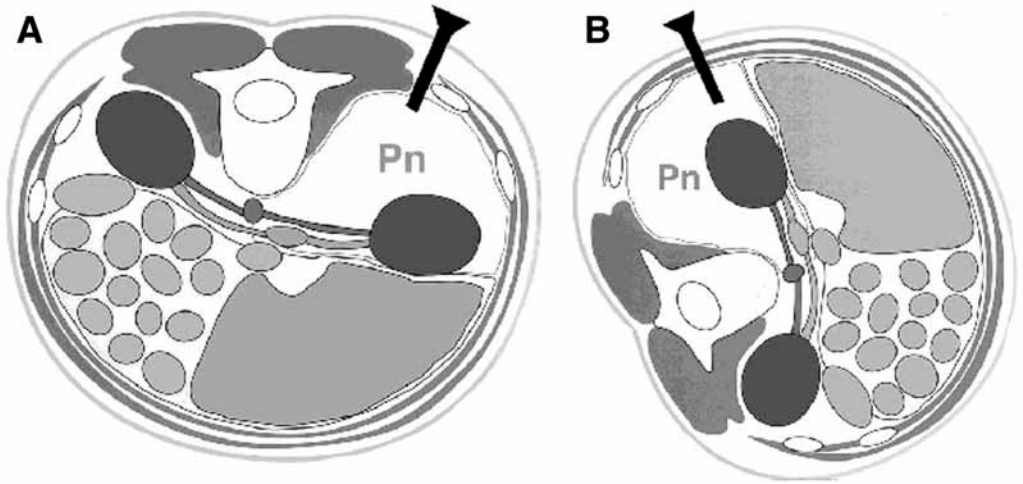

Fig. 6. *(***A***)* Access with the patient prone. Notice how the kidney falls away from the laparoscopic equipment. **(B)** The patient in a lateral position and the kidney is displaced medially. (Reprinted from ref. *37a*, with permission.)

Although the transperitoneal approach is commonly used, the retroperitoneal approach is gaining popularity. Retroperitoneal access can be achieved in either the prone or lateral position. Some find the prone position advantageous because the abdominal contents fall away from the operative field. This helps not only with trocar placement, but also with kidney dissection *(39)* (Fig. 6). When approaching the patient prone, the initial access is on the lateral edge of the paraspinal muscle. A subcostal inci-

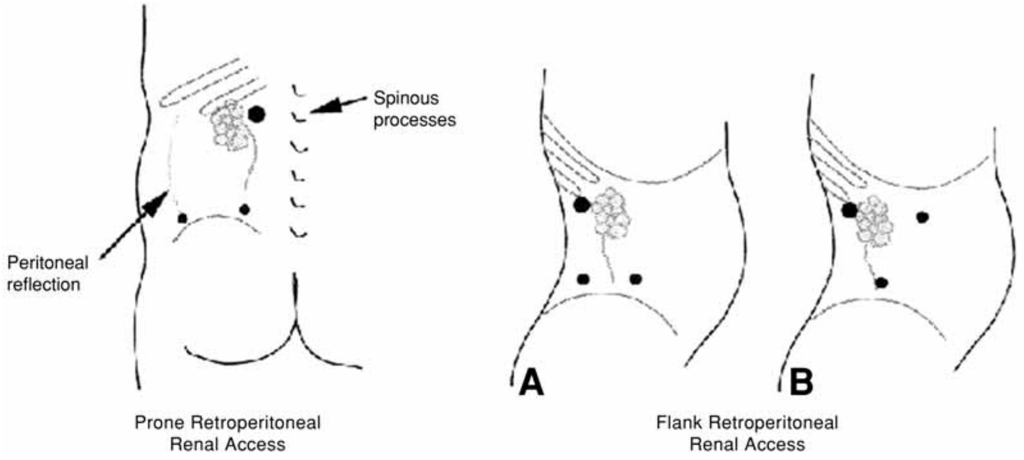

Fig. 7. Diagram on the left shows port placement for a prone retroperitoneal approach. Diagrams on the right **(A,B)** show port placement for flank positioning. (Reprinted from ref. *37a*, with permission.)

sion is made and dissection is between the latissimus and oblique muscles. Gerota's fascia is identified and opened. Finger or balloon dilation will open this space. After the space is developed, a camera can be inserted and the surrounding fascia secured with a box-stitch 3.0 absorbable suture *(9)*. This will not only create a tight seal for pneumoperitoneum, but also be used for ultimate closure of that site. Additional ports are placed above the iliac crest and lateral to the paraspinal muscle and medial to the peritoneum (Fig. 7).

When the patient is positioned prone, it may be difficult to emergently convert to an open incision. Some prefer to put the patient in a lateral position. If access is performed in the lateral position, it is started off the 12th rib with a muscle-splitting incision. Additional ports can be placed above the iliac crest or posteriorly and inferiorly. Compared to the prone retroperitoneal approach, lateral positioning provides a larger working space and allows more extensive ureteral dissection. However, the kidney often falls medially and onto the renal pedicle. Constant lateral traction is needed visualize the pedicle *(40)*.

When approached retroperitoneally, the kidney lies in a more vertical orientation *(41)*. Regardless of the access used, the dissection is similar. It is important to remember that dysplastic kidneys often have aberrant blood supply. It is helpful to keep the dissection close to the renal parenchyma to ensure ligation of the vessels at the appropriate level. The hilum can be approached either anteriorly or posteriorly. It may be helpful to mobilize the kidney inferiorly and follow the ureter up to the hilum. Once the hilum is exposed, the renal vessels can usually be controlled with individual clips. It is rare that a vascular stapler is needed in children. If the renal vein is too large to clip, it can be ligated once with an intracorporeal tie, followed by clips on either side *(14)*.

If operating on a cystic kidney, it is easier to leave the cysts intact until late in the dissection. This allows for easy identification of the planes between the cyst wall and adjacent organs. If the size of the cyst inhibits progress, the cyst can be decompressed by a laparoscopic instrument or by inserting a spinal needle through the body wall. After decompression, the surgeon can grasp the cyst wall to provide traction for easier dissection.

Once the specimen is free, it can often be removed through the 5-mm port incision. The incision may need blunt enlargement to accommodate the specimen. If necessary, one can morcelate the tissue in a bag so that the port site does not have to be significantly enlarged. Because most pediatric nephrectomies are for benign disease, there is little need to maintain the surgical margin for pathological examination.

Laparoscopic Partial Nephrectomy

A common indication for partial nephrectomy in children is to remove the nonfunctioning segment of a duplicated system. It is usually easy to distinguish the nonfunctional segment because it will be cystic or hydronephrotic. If it is difficult to distinguish, intraoperative ultrasound can verify composition *(37)*.

Different landmarks can be used to identify the ureter. Once the white line of Toldt is incised, the ureter is found under the peritoneum at the level where it crosses the common iliac vessels. Another useful location is where it crosses the medial umbilical ligament. The ureter of interest is often dilated and easy to identify. If necessary, the duplicated ureters can be followed to the renal pelvis for definite identification.

Once identified, the affected ureter is divided. If there is no associated reflux, the distal ureter can be left open. Otherwise, it is followed to its bladder insertion and ligated with endocorporeal knots or absorbable clips. Ligating the ureter before cutting it allows the upper ureter to remain dilated, which assists in dissection of the upper pole. The upper ureter can be used as a handle for cephalad dissection. It is important to avoid injury of the periureteral tissue around the remaining healthy ureter. The dissected ureter is freed from behind the renal vessels and passed cephalad to facilitate dissection of the upper pole and its vasculature *(42)*.

The biggest concern with a partial nephrectomy is protecting the blood supply to the remnant parenchyma and ureter. There should be minimal mobilization of the functional pole and the hilum near the remnant vessels. In addition, vessels should be ligated as close to the abnormal renal unit as possible. Some find the dissection easier with a retroperitoneal approach because of its direct exposure. In addition, the lower pole does not require any separation from the peritoneum which can help protect the lower vasculature.

Once the vessels are ligated, the renal units can be separated using electrocautery or harmonic energy *(36)*. To minimize bleeding, it is common to leave a small rim of the nonfunctioning segment on the remaining renal tissue.

After laparoscopic nephrectomy, most pediatric patients are started on a diet that is advanced as tolerated. The younger children will often have good pain control within a few hours and go home the same day. Some mild abdominal pain for 24 hours is more common in the older children. This may be related to retained carbon dioxide *(43)*.

Outcome After Laparoscopic Nephrectomy

Most reports of pediatric laparoscopic nephrectomies have shown a low rate of complications *(36,37,43)*. The complications of greatest interest include vascular and visceral injuries.

Excessive bleeding during the operation can originate from tears of the renal vein, its contributing vessels, or accessory or polar renal arteries. Any blood in the field can cover and obscure visualization of the tissues. In addition, the blood will absorb light and further limit the view. The rate of open conversion because of bleeding is low, but has been reported *(14)*.

Another theoretical concern is postoperative bleeding. This usually presents with a change in vital signs. If the patient has left the hospital when this complication occurs, the key is a high level of suspicion for bleeding if the child is not doing well.

Similarly, bowel injury can present late if it was unrecognized in the operating room. This is a complication of both transperitoneal and retroperitoneal nephrectomies. These bowel injuries may result from trauma during access or electrocautery during the case. Most commonly, the patient will have fever and peritoneal irritation, although bowel injury can present subacutely after laparoscopic procedures *(44–46)*.

The choice between a transperitoneal vs retroperitoneal approach is essentially based on the surgeon's preference. Meraney et al. *(47)* reviewed 404 retroperitoneal renal and adrenal cases. They had 1.7% vascular and 0.25% bowel injuries. The complication rate correlated with prior major abdominal surgery and the experience of the surgeon. Studies comparing the two techniques show similar rates for operative time, blood loss, and hospital stay *(48)*. There has not been persuasive data to show an increased morbidity associated with either approach.

LAPAROSCOPIC PYELOPLASTY

Laparoscopic pyeloplasty was first described in both the adult and pediatric populations in 1993 *(49,50)*. So far, the outcomes of laparoscopic repair are comparable to the results of open repair *(8)*. The first series was performed transperitoneally *(51)*, but some are using a retroperitoneal approach.

There are no strict criteria that guide when to use minimally invasive procedures in children. Some prefer open pyeloplasty for all children under 6 months old. Others choose a cut off age of 18 months old. An ideal candidate is an older child with an extrarenal pelvis. There are multiple challenges in the smaller child. Placing a stent has more risk of traumatizing either the infant's delicate ureterovesical junction or the posterior anastomosis. The small diameter of the ureter makes the anastomosis technically difficult, especially within the confines of a small working space.

If the laparoscopic approach is chosen, the first step is positioning the patient. Placing an intravenous line in the ipsilateral hand allows easy access for the anesthesiologist because that arm is draped over the patient, usually on an elevated arm board. Some prefer a preoperative stent placement and others find it cumbersome during the anastomosis. We use a preoperatively placed guidewire that is prepped and draped in the surgical field. The wire allows visualization of the ureteropelvic junction (UPJ) without decompressing the renal pelvis. Once the UPJ is divided, the wire can be used to manipulate the ureter nontraumatically. Before completing the anastamosis, a stent is placed over the wire.

Positioning of the patient is similar to other laparoscopic renal surgery. When operating transperitoneally, the patient is positioned in a 45° flank position. The patient should be close to the edge of the table to maximize the mobility of the instruments. The patient is secured to the table at the level of the thorax and the iliac crest. This enables the surgeon to change the position of the patient from supine to full flank. An axillary gel pad, rather than an axillary roll is placed to prevent excessive pressure on the latissimus dorsi muscle.

The first trocar is placed (usually by an open technique) at the umbilicus. A second trocar is placed in the midline superior to the umbilicus and another trocar is placed in the midclavicular line ipsilateral to the affected kidney halfway between the umbilicus and the pubis. An insufflation pressure of 10 mmHg is used for small patients weighing less than 10 kg and a pressure of 10 to 15 mmHg is used for heavier patients. The white line of Toldt is incised to free the ipsilateral colon and expose the retroperitoneum. The gonadal vessels will run close to the UPJ and need to be reflected medially.

An alternative to mobilizing the colon on the left side is a transmesenteric approach *(52):* instead of incising the line of Toldt, a small window through the mesentery is opened over the UPJ. The location of the UPJ can be revealed by moving a preoperatively placed guidewire. The transmesenteric approach is less appealing on the right side because of the close proximity of the duodenum and great vessels.

When approaching the kidney retroperitoneally, the initial access is 1 cm from the lower edge of the 12th rib. Using blunt dissection, Gerota's fascia is opened under direct vision. Once the first trocar is placed, gas insufflation will create a larger working space. A second trocar is placed posteriorly near the costovertebral angle and a third port is placed along the anterior axillary line, 1 cm above the iliac crest *(53)*.

There are two approaches to division of the UPJ from an anterior approach, depending on the presence of crossing vessels. When vessels are encountered, the ureter is dissected posteriorly until the UPJ is seen behind the vessels. The ureter can be divided just below the UPJ. At that point, attention is turned to the anterior pelvis. As this is freed, the UPJ can be brought anterior to the vessels, where the anastomosis can be performed. The vessels themselves require no manipulation.

Once the UPJ is divided, the ureter is spatulated laterally and the pelvis is spatulated medially. Usually there is no to need to reduce or excise the renal pelvis. When there are no crossing vessels, the approach is straightforward. The UPJ can be divided on the pelvis side, leaving a tag of pelvis on the ureter for manipulation *(51)*.

A stay suture is placed in the anterior renal pelvis and then passed through the lateral abdominal wall. This stabilizes the pelvis for anastomosis and, especially in the case of a transmesenteric approach, improves exposure and access to the UPJ *(52)*. After spatulating the ureter, the anastomosis is started with interrupted sutures at the dependent part of the renal pelvis. Fine absorbable suture is used, e.g., 5.0 or 6.0 polyglactic acid suture. A small (Ethicon, Somerville, NJ), such as a TF, half-circle needle, is preferable. This can pass through a 3.5- or 5-mm port. When passing the needle, it is important not to blunt the tip. Optimal ergonomics would suggest alignment of the needle driver with the line of suturing and to have the second instrument 30° offset from the first.

The remainder of the anastomosis may be done with interrupted or running sutures. Once the posterior wall is completed, the ureteral stent is positioned. As stated before, the stent may be placed preoperatively and the anastomosis sewn around the stent. Another option is placing a wire preoperatively and then guiding a stent retrograde or antegrade after the posterior wall is closed. Also, the stent can be introduced by an angiocatheter and wire. In most cases, it is not necessary to leave a perinephric drain. The stent is left in place for 2 to 4 weeks. Patients can be managed with or without a foley catheter for one night *(53)*.

An alternative to stenting is placing a percutaneous nephrostomy tube. This can be placed under direct visualization and used to confirm postoperative success before removal. Nephroureteral tubes can also be used but must be removed before assessing the anastomosis.

Some prefer robotic assistance to expedite the suturing. The automatic suturing device (Endo-Stitch, US Surgical) is not suitable for use in children. The available sutures for this and other devices are too large, and the needle for the Endo-Stitch is perpendicular to the attached suture. In addition, there is concern for possible stone formation not only from larger sutures, but also from the titanium clips that can accompany these devices *(54,55)*.

Outcomes of Laparoscopic Pyeloplasty

The success for laparoscopic pyeloplasty in adults has been better than 95%, which is comparable to open repair *(56–58)*. The benefits include improved cosmesis and quicker convalescence. El-Ghoneimi et al. *(53)* showed that school-age children returned to full school activities within 1 weeks postoperatively. They also saw a quicker return to painless activity *(53)*.

Complication rates of laparoscopic repair are 10 to 13% *(59)*. Potential complications of laparoscopic pyeloplasty are identical to those of the open procedure. These include urine leakage and postoperative obstruction. The complication rate has been similar with both approaches. The biggest challenge for most is intracorporeal suturing. With smaller and sturdier needle drivers, experienced laparoscopists are improving their operative times while maintaining the key surgical principles.

Postoperative success has been defined both as improved hydronephrosis and improved drainage on renal scan. The long-term success rate of laparoscopic pyeloplasty in children is still unknown. Most series have excellent results, but only have data 6 to 12 months postoperatively *(53,60,61)*.

UROLITHIASIS

Although there is a low incidence of urolithiasis in children, it often poses a therapeutic dilemma. When looking at all patients with urinary stone disease, only 1.3 to 2.0% of them are pediatric patients *(62)*. As with adults, the management in children must take into account multiple factors. This includes stone size, stone location, stone composition, and urinary tract anatomy. Metabolic abnormalities are found in 53 to 80% of pediatric patients with stones *(63)*. Calcium-related abnormalities are the most common type found *(64)*.

Presentation of symptomatic stones can be extremely variable in children. The most common symptom is abdominal pain (53–75%). Another common symptom is hematuria (14–33%). Classic renal colic is only found 7% of the time *(65)*.

The radiographic work up in children is similar to adults. Plain abdominal films can easily miss both radiolucent and small radiopaque stones. Renal ultrasound may miss a nonobstructing ureteral stone. Helical computed tomography scan of the abdomen and pelvis is a reliable method when there is a high suspicion of stones. Since children do not tend to have phleboliths, there is little confusion in differentiating distal stones from phleboliths *(66)*.

Etiology and stone composition are variable based on geography. The majority of patients in Europe have infectious stones, whereas in the United States, it is more common for children to have calcium oxalate stones and metabolic abnormalities. Obtaining a 24-hour urine specimen can be challenging in this population; therefore, one can use spot urine calcium, creatinine, and uric acid levels as a substitute.

Once a stone is identified, it may require treatment secondary to obstruction, infection, or hematuria. The American Urological Association has provided guidelines for treatment of ureteral stones in adults. There is no correlating guideline for children. Van Savage et al. *(67)* looked at their pediatric stone population and found the majority of patients with stones less than 3 mm in size would spontaneously pass. For adults, there is a 98% spontaneous passage rate for stone less than 5 mm. The biggest factor for the lower rate in children is probably the smaller diameter of the ureter. In addition, there is a lower threshold for pain and an increased need for attention which may hasten intervention.

There is no absolute stone size that children will pass. The decision to intervene surgically is similar to adults: associated fever, intractable pain, intractable vomiting, or renal compromise. If mild symptoms are present, many will choose expectant management for stones less than 4 mm in size *(68)*.

Extracorporal Shockwave Lithotripsy

Shockwave lithotripsy (SWL) is often used for renal and ureteral stones in adults. Its role in pediatrics was initially for renal stones only. One problem is patient positioning: it can be challenging to keep a small child in the same position without sedation or a general anesthetic. Some have used a modified infant car seat to help with positioning *(69)*.

A concern with distal ureteral SWL is the potential for ovarian damage from the shock waves. McCullough et al. looked at the function of rat ovaries after SWL. When comparing the control and treated rats, he found no difference in the number of pregnancies, spontaneous abortions, or fetal weights. The short-term complications for human patients are negligible, but the bigger concern is long term effects on the ovaries. Studies have not found an increased risk of renal scar, renal function, linear growth, hypertension, or renal disease in the long term *(71,72)*.

Most pediatric patients do not require ureteral stents with SWL unless the stone burden is large enough for the development of steinstrasse. When treating staghorn calculi with SWL, preoperative stenting has been associated with fewer complications; however, its presence may compromise stone passage.

With regard to stone size, there is no defined cut off for SWL in children. In adults, most will choose percutaneous nephrostolithotomy (PCNL) if the stone burden is greater than 2 cm. A similar size cut off is generally utilized in children. However, some advocate SWL as monotherapy for staghorn calculi as well. It is felt that shockwave fragmentation is more effective in pediatrics because of the overall stone burden is smaller and the stones are often soft. In addition, a smaller body volume allows better transmission of the shockwaves. Children seem to have a greater capacity than adults to pass fragments after lithotripsy.

Success rates of SWL range from 84 to 97%, with some patients requiring more than one treatment *(73,74)*. Pediatric staghorn calculi treated with SWL monotherapy have a success rate of 70 to 80% after multiple procedures *(75–78)*. As expected, success is lower with large stones, lower pole stones, and stones in kidneys with abnormal anatomy. In addition, cystine and calcium monohydrate stones are more resistant to SWL.

Morbidity after SWL is minimal. Gross hematuria is common for a few days. Pulmonary contusions with hemoptysis may occur if shockwaves traverse pulmonary tissue. Pulmonary dysplasia has not been a long-term complication of SWL, but shielding of the lung with foam is recommended in smaller children *(79)*.

Ureteroscopy

Many centers choose ureteroscopy as the first line of treatment for not only distal ureteral stones, but also for proximal stones.

Previously, the problem with ureteroscopy was the need to dilate the ureteral orifice. The biggest concern with this is the possibility of creating reflux, although when this occurs, it appears to be transient *(80)*. There is also a risk of distal ureteral stricture, which has been reported to occur more commonly in children than in adults *(81)*. Our preference is to prestent when necessary, allowing the ureters of even small children to easily accommodate modern, small endoscopes.

One limiting factor associated with the smaller endoscopes is a small working channel. Placing an instrument through the port decreases the level of irrigation and visibility. These issues must be considered before choosing the best intervention for each patient. Often, a 220 μ laser fiber is the best option for stone manipulation through a flexible ureteroscope, although laser lithotripsy may not be available in all pediatric settings. In addition, a range of ureteroscopes are available for purchase, but it is impractical for most centers to carry all types.

A versatile rigid scope is the 6.9-Fr cystourethroscope, which has either 2- and 3.5-Fr working channels, or a single 5-Fr channel. This ureteroscope easily accesses the distal ureter in small and larger children. The 15-cm length endoscopy works well for most situations. The flexible ureteroscopes are also available in 6.9 Fr and allow easy access to the upper ureter and renal calyces. The degree of deflexion of the ureteroscope is at least 180° in most models and active secondary deflection is also available in newer generation ureteroscopes.

If repeated entry is anticipated, one may elect to use an access sheath. The 9.5-Fr access sheath allows easy entry of the ureteroscope into the ureter while allowing antegrade flow around the scope, thereby preventing excess pressure within the collecting system.

For manipulating stone fragments, baskets and grasping devices are available as small as 1.7 Fr. However, these can be difficult to manipulate and frustrating to use. As such, the 3-Fr instruments are more commonly employed.

The technique of ureteroscopy should be strictly followed with the underlying theme of maintaining ureteral access. Whether or not a stent is present, the procedure is started by placing a guidewire into the renal collecting system through a cystoscope. If it is difficult to bypass a ureteral or UPJ calculus, a hydrophilic coated flexible wire can be used or the guidewire can be manipulated from within a ureteral catheter. Once the wire is in place, the cystoscope is removed. A 10-Fr dual-lumen catheter, or an 8/10-Fr dilating system, is used to place a second safety wire that is coiled and either secured to the drapes, sutured to the patient, or both. This step is vital because loss of ureteral integrity and/or primary access can occur in even the most straightforward cases. The ureteroscope can be advanced between the wires, or over one of the wires, depending on the circumstances. The irrigating fluid should be warmed to prevent hypothermia in small children. *Water should never be used as an irrigant because of the risk of hyponatremia and its consequences should extravasation occur (82,83).*

When the stone is visualized, it can either be removed intact or fragmented. Only small stones should be basketed in children because of the risk of ureteral avulsion. Fragmentation can be carried out using a variety of lithotripsy devices, but for flexible ureteroscopy, only laser or electrohydraulic lithotripsy (EHL) are options owing to the flexibility of the probes. If available, the Holmium laser is an ideal instrument for this purpose because it has excellent energy transfer and less likelihood of ureteral or renal pelvic injury than EHL. With either energy source, it is important that the interface of probe/fiber and stone be visible prior to the application of energy.

The use of postoperative stents depends on the degree of manipulation that was required and whether future procedures are anticipated. Leaving a stent often requires an additional anesthetic to perform cystoscopy for stent removal. If the stent is needed for a short period of time, it may be left attached to a string for bedside removal *(84)*.

After the stent is removed, the patient's upper tract must be observed for postoperative hydronephrosis. This is done by ultrasound within 4 weeks. If hydronephrosis is significant or the child has symptoms of obstruction, an intravenous pyelogram or renal scan must be considered to evaluate the ureteral anatomy and degree of obstruction.

There is limited data regarding outcomes for pediatric ureteroscopy. The few reports do show good success rates (87–100%) with minimal complications. The rate of ureteral stricture is probably higher than in adults, and can probably be best avoided by prestenting and avoiding of aggressive ureteral dilation *(81)*.

Percutaneous Nephrolithotomy

The first pediatric series of PCNL was described in 1985 *(85)*. PCNL has an established role both when used alone and as an adjunct to other treatments. Although renal calculi are uncommon in children, when they do occur, they are often associated with a metabolic or anatomic abnormality leading to a high risk of recurrence. As such, procedures that render the patient free of stones in as few procedures as possible are preferable *(86)*.

The trend in adults is to utilize PCNL for a stone burden greater than 2 cm. Stone burden alone does not constitute an absolute indication in children. PCNL is indicated in patients who fail SWL or ureteroscopic therapy and is preferable in patients with anatomic abnormalities that inhibit their ability to drain urine and clear stones, i.e., UPJ obstruction, infundibular stenosis, and calyceal diverticulum. An advantage of PCNL is the ability to simultaneously treat stones and the associated anatomic abnormality. PCNL is a minimally invasive procedure that can be used to avoid multiple surgical procedures in a patient with recurrent stone disease.

Initially, PCNL was always performed using percutaneous access similar to the adult population. Intuitively, this large size is a concern for infants because a 24-Fr tract in children is comparable to a 72-Fr tract in an adult *(87)*. The mini-perc technique, described in 1998, described renal access through an 11-Fr peel-away sheath which could accommodate a 7.5-Fr rigid or a 9.5-Fr flexible scope (Fig. 8). Possible advantages are smaller incisions, decreased pain, shorter hospital stays, and a smaller number of lost nephrons *(88)*.

The initial access into the collecting system is performed either by a radiologist prior to the stone procedure or simultaneously in the operating room with C-arm guidance. Once access is obtained, some prefer to wait a 24–48 hours before enlarging the tract and manipulating the stone. Others will proceed the same day of initial access.

Technique is important to avoid loss of access and to avoid injury to the collecting system. Once access to the collecting system is obtained, a guidewire is introduced. For a miniperc procedure, a small 4-mm fascial incising needle is passed through the fascia (Pediatric Percutaneous Access Set, Cook Urological, Spencer, IN). This is followed by a dual-lumen 10-Fr hydrophilic coated catheter. Ideally the wire has been routed through the UPJ and down the ureter prior to this maneuver. If not, care must be exercised to avoid perforating the renal pelvis by advancing too far. A second safety wire is introduced and sutured to the skin. The 11-Fr peel-away sheath is then introduced and the trocar removed. A "nipple" is present to secure the trocar to the sheath. It is vital that this nipple not be removed prior to initiating the procedure to insure free egress of fluid at all times *(89)*. We prefer to use a 6.9-Fr offset cystoscope with a 5-Fr working channel for

Fig. 8. The “mini-perc” access kit contains two 0.035-in. guidewires, a fascial incising needle, a dual lumen dilator, and a 11-Fr peel away sheath (Cook Urological, Spencer, IN).

stone manipulation, though flexible scopes are also useful. Stones are fragmented using the modalities previously described.

At the end of the procedure, the patient may be left tubeless or with a 6- or 8-Fr nephroureteral stent that can be passed over a wire through the sheath, after which the sheath is peeled away around the stent.

OUTCOMES OF PCNL

PCNL in children is associated with a stone-free rate of 67 to 100% *(85,90–92)*. The most concerning complications are bleeding and hypothermia. In adults, the biggest risk factors for bleeding are preoperative anemia and total blood loss. As in adults, it is rare for children to require blood transfusions after PCNL.

Young patients can quickly become hypothermic. When evaluating PCNL in adults, Roberts et al. found that the majority of patients dropped their core body temperature. In their series, hypothermia was associated with longer operative times and longer induction periods, although the irrigant in this study was room temperature. Al-Shammari et al. *(90)* looked at a pediatric population and found that operative time of more than 150 minutes correlated with hypothermia. Some safeguards against hypothermia include a warm operating room, warmed irrigation solution, and brief anesthetic inductions. Our irrigant of choice is warmed normal saline that not only minimizes hypothermia, but also avoids hyponatremia in the event that extravasation does occur.

LAPAROSCOPIC BLADDER RECONSTRUCTION

The use of laparoscopy in bladder reconstruction has recently been explored, with the first laparoscopic bladder augmentation reported in 1995 *(93)*. This late introduction is partly the result of the complexity of lower urinary tract reconstruction.

Most laparoscopic bladder reconstruction falls into one of three categories: laparoscopic autoaugmentation, laparoscopic enterocystoplasty, and laparoscopic-assisted reconstruction.

Incorporating laparoscopy is appealing because of the improved cosmetic result and decreased morbidity. For instance, patients with myelodysplasia frequently need a large midline incision to access bowel because the cecum can be malrotated or abnormally fixed.

Contraindications to laparoscopic reconstructive procedures include severe inflammatory processes of the bladder or bowel, short gut syndrome, uncontrolled coagulopathies, inability to perform intermittent catheterization, and high risk of intra-abdominal adhesions (e.g., history of radiation therapy, multiple open abdominal surgeries). Presence of a ventriculo-peritoneal shunt and prior surgery are not contraindications.

Laparoscopic autoaugmentation has been reported by using both preperitoneal and transperitoneal access. These reports involved small groups of patients but did show an increase in bladder size with improved continence *(94,95)*. Most long term series of bladder autoaugmentation have been somewhat disappointing in terms of long-term bladder compliance.

Pure laparoscopic enterocystoplasty has also been reported in a small number of patients. However, one disadvantage was long surgical time, which ranged from 5.3 to 9 hours. Long-term follow-up on these patients is still pending *(96,97)*.

The most beneficial aspect of laparoscopy in bladder reconstruction appears to be assisting the mobilization of the cecum, the gastric segment, or the appendix. One can divide the reconstructive procedure into two parts: mobilization of tissue for augmentation and/or stoma creation and actual reconstruction of the bladder. Laparoscopy can accomplish the first half, leaving the final half to be completed through a small Pfannenstiel incision. Often, the lower incision can incorporate multiple laparoscopic port sites. If ileum or sigmoid is being used for the augmentation and no continent stoma is needed, then the entire operation can be done through a lower abdominal incision and laparoscopy is not warranted.

The goal is to maximize the strengths of both laparoscopic and open techniques to minimize patient morbidity. By using laparoscopy to perform tasks that would require upper abdominal access, the patient is spared a larger incision. And by performing the more complex tasks through a small open incision, the patient is spared the longer operative times seen with purely laparoscopic reconstruction.

Technique for Laparoscopic-Assisted Bladder Reconstruction

The day prior to surgery, the patient completes a mechanical and antibiotic bowel preparation.

The patient is positioned in low lithotomy to perform cystoscopy to assure that there are no signs of cystitis. The patient is then repositioned supine and well padded to prevent pressure ulceration. In addition, the patient is secured to the bed by taping across the chest and legs, thereby allowing for safe lateral and deep Trendelenberg rotation.

If a concealed umbilical stoma is planned, a U-shaped incision is made *(98)*. An inferior flap is raised and the umbilical fascia incised sharply. Once the peritoneum is opened, a radially dilating 10- or 12-mm trocar is placed. The remaining ports are posi-

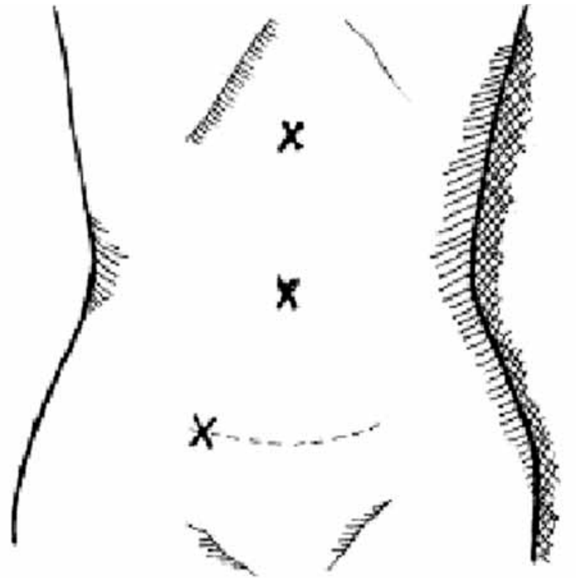

Fig. 9. Port placement for laparoscopic assisted bladder reconstruction. The most inferior port is placed along the planned Pfannenstiel incision. (Reprinted from ref. *98a*, with permission.)

Fig. 10. Appearance after laparoscopic assisted bladder reconstruction with continent stoma. (Reprinted from ref. *99*, with permission.)

tioned based on the procedure planned. If a Malone antegrade continence enema is planned, the second port should be placed at the proposed stoma site. This can be a 3- or 5-mm port. A third 2- or 3-mm port is placed in the midepigastrium (Fig. 9).

To access the appendix, the white line of Toldt is incised to mobilize the right colon. Once the appendix is isolated on its pedicle, it can be divided laparoscopically with an

Endo-GIA stapler or divided after bringing it through the open incision. There is usually little or no dissection needed to mobilize small bowel or sigmoid colon. Occasionally, the lateral peritoneal reflection is incised to give extra length to the sigmoid.

Once the bowel is harvested, a 4 to 5 cm Pfannenstiel incision is made for the enterovesical anastomosis, stomal creation, and any bladder neck manipulation.

To complete the catheterizable stoma, the dorsal aspect is spatulated and sewn to the U flap, leaving a widely patent but well-concealed stoma (Fig. 10).

Outcomes of Laparoscopic-Assisted Bladder Reconstruction

Laparoscopic assisted bladder reconstruction is technically challenging and has only been employed at a few centers. The initial surgical outcomes are comparable to a completely open approach. It has been shown that these patients are quicker to tolerate a regular diet and have shorter hospital stays. This is accomplished without an increase in operative morbidity or operative times.

Chung et al. *(99)* reported the largest series (comprised of 30 patients) of laparoscopic assisted bladder reconstruction to date. There were no intraoperative complications, there was one open conversion, and the mean hospital stay was 6 days.

At 32 months, 95% were continent and could easily catheterize. Stomal stenosis occurred in 5.1% and stomal revision was required in 7.7%. Postoperative complications occurred in 16%. This included ileus, partial bowel obstruction, traumatic bladder perforation, wound infection, and deep venous thrombosis *(99)*.

It has been shown that scars on the torso affect body image *(100)*. The patients who require bladder reconstruction often have other anomalies. Therefore, any steps to minimize the degree of external scarring are desirable. In addition, the likelihood of intraperitoneal adhesions is likely decreased by using this approach, conferring a potentially lifelong benefit to the patient.

VESICOURETERAL REFLUX

Vesicoureteral reflux (VUR) is a common problem that affects 1% of children. The goal of diagnosing and treating VUR is to prevent long-term complications such as pyelonephritis, hypertension, and renal insufficiency *(101)*. Options for treatment include long term antibiotic prophylaxis, subureteral injections, and laparoscopic and open reimplantation. Although open reimplantation provides success rates of 95 to 98% with low morbidity, the search continues for less invasive methods *(102,103)*.

Laparoscopic reimplantation has been performed both intravesically and extravesically. In 1993, Atala et al. *(104)* reported their experience performing laparoscopic transperitoneal extravesical (Lich-Gregoir) antireflux plasty in a pig model. In 1995, Lakshmanan et al. *(105,106)* reported a human series of 71 patients undergoing extravesical ureteral reimplantation. Their series showed low postoperative morbidity with a quick return to full physical activities. This approach was used for both unilateral and bilateral reimplantations. The initial follow-up was comparable to open reimplantation.

In an effort to simplify the approach, the same repair was performed via an extraperitoneal approach *(107)*. Later that year, another small series confirmed the feasibility of showed this technique. Follow-up at 2 months showed no reflux in any patient. Some find this approach easier and less invasive than the transperitoneal approach. It is theorized that limiting the dissection and greater preservation of vascularity around the bladder neck will decrease the risk of postoperative voiding dysfunction.

Intravesical endoscopic ureteral reimplantation was first described in a pig model. Gill et al. *(108)* reported their experience performing transvesical laparoscopic reimplantation with a Cohen technique in a small series of three patients all over the age of 10. Olsen et al. *(109)* described a similar technique in a larger series. The Davinci robot may provide easier access for submucosal tunneling and intravesical suturing of the anastomosis, as suggested in reports in a pig model.

Although these series are promising, there are still concerns. The laparoscopic approach is not advisable in ureters with ureteroceles or megaureters that require tapering. In addition, the small pelvis of children under 4 years old is often a limiting factor. Moreover, there is a risk of voiding dysfunction when reimplanting bilaterally *(110)*. However, despite the feasibility of these approaches, the procedure is still technically challenging and has a steep learning curve. One of the reasons that these techniques have not become more popular is that ureteral reimplantation can be performed through a cosmetically acceptable small Pfannenstiel incision requiring only an overnight hospital stay and no drainage tubes and has a success rate of more than 95% *(111,112)*.

Subureteral Injection Therapy

An alternative to open reimplantation is subureteral injection therapy. This concept was introduced in the 1980s by O'Donnell and Puri *(113)*. The ideal injection substance is biocompatible, nonallergenic, nonmigratory, and durable. Various substances have been tried such as collagen, autologous substances, polyteterflourourethrane (Teflon), polydimethy-siloxane (Macroplastique), and dextranomer/Hyalouronic acid (Deflux).

Polytetraflourourethane (Teflon) has particles that varied in size from 5 to 100 μ and was taken off the US market because the smaller particles could be injected into capillaries and embolize to distal sites. Collagen is not durable because it is biodegradable and contractile *(114)*.

Atala et al. *(115)* first reported injection of autologous chondrocytes in an animal model. Later, Caldamone and Diamond *(116)* reported this technique in a clinical trial. First, posterior auricular cartilage is harvested from the patient. After an enzymatic digestion, the chondrocytes are grown in culture over 6 weeks. Finally, the patient is brought back for endoscopic implantation at the ureterovesical junction.

In 2001, the FDA approved Dx/HA copolymer (Deflux,Q-Med Scandinavia) as an acceptable material for injection therapy to treat VUR. Deflux consists of microspheres that range from 80 to 120 μ in diameter. This larger size prevents migration of material. It consists of crosslinked dextran polysaccharide molecules, so there are no freely circulating dextran molecules, thereby avoiding allergic or immunogenic reactions. Once implanted, Deflux does not contract because of ingrowth of fibroblasts and collagen.

TECHNIQUE OF INJECTION THERAPY

The technique of injection is similar to that previously described for the subureteral transurethral injection prodecure. The patient is placed under general anesthesia and positioned in lithotomy. A 10-Fr cystoscope with an offset lens is used to guide a 3.5-Fr needle containing 0.5 to 1.2 mL of material. The needle is injected into the submucosa at the 6 o'clock position, producing a bulge with a nipple appearance. The orifice should appear slit-like on top of the mound *(113,117)*.

RESULTS OF INJECTION THERAPY

Some significant concerns with endoscopic treatment of VUR include long-term outcomes and overall success rates. Either results are suboptimal compared to open repair or long term results are lacking. Collagen has been shown to be suboptimal because of its tendency to disappear leading to recurrence of reflux. Caldamone and Diamond *(116)* reported 65% success at 1-years follow-up of autologous chondrocytes injection therapy. A series using Macroplastique demonstrated success in more than 80% of patients, with the longest follow up in these series being 94 months *(118)*.

Puri et al. *(117)* reviewed 11- and 17-years follow-up of Teflon injection therapy and found a 5% recurrence rate at 17 years. They noted a 76% success rate with the first injection, and a need for repeat injection in 20% of patients.

Outcomes of Deflux injection are still evolving. Although high success has been reported, the data must be viewed carefully. Kirsch et al. *(114)* reported a 72% success rate at 3 months in 130 patients evaluated by voiding cystourethrography. Puri et al. *(117)* recently reported 3-months and 1-year follow-up of 113 patients after Deflux injection. Although success rate was reportedly 99% after one to three injections, only 9.7% completed follow up at 1-year.

The true test of injection therapy is how it compares to open reimplantation surgery. It is still unknown if long-term outcomes will be comparable. Currently, strict guidelines on when to operate for vesicoureteral reflux are lacking, as is the type of intervention indicated. It remains a challenge to improve on the more than 95% success of open reimplantation. With a small incision and often overnight hospital stay, the morbidity of open intervention is already impressively low.

CONCLUSION

Minimally invasive surgery in children is an exciting and evolving field. Indications have progressed from diagnostic to reconstructive therapy. It is a challenge to find the best application for these techniques given the excellent outcomes of open urologic surgery in children. However, we must continue to explore new ways to provide our patients with the best outcome and the least morbidity.

A few indications are well accepted, such as laparoscopy for intra-abdominal testis. The initial results of laparoscopic nephrectomy and pyeloplasty are encouraging with outcomes comparable to open surgery. These cases are becoming more common at centers across the world. The most technically demanding cases such as laparoscopic bladder reconstruction and reimplantation are still limited in application, but they may gain popularity with the use of robotic assistance.

Urolithiasis is a rare (but still significant) problem in pediatrics. Since the early 1980s, open stone surgery in adults has been replaced by less invasive methods such as PCNL, SWL, and ureteroscopy. This transition has been slower in children primarily because of technical limitations. As endoscopic equipment continues to improve with regard to better optics and instrumentation for smaller scopes, the applications in pediatrics will likewise grow.

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