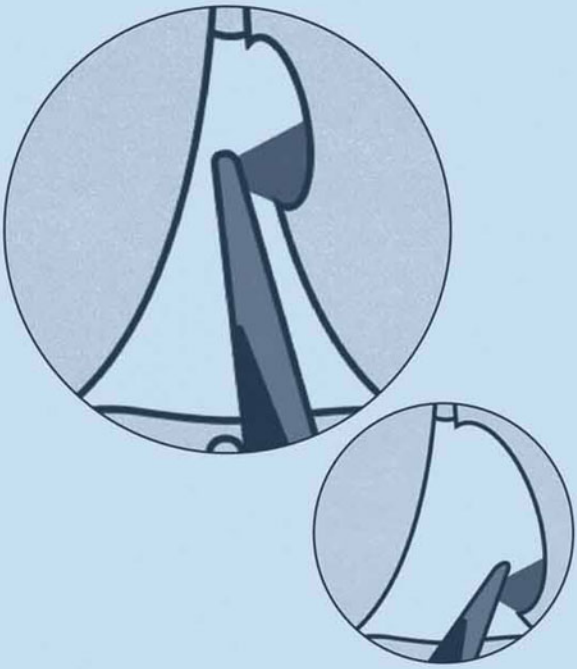
Recent Advances in Endourology 8

Interventional Management of Urological Diseases

S. Baba • Y. Ono (Eds.)



Springer

Recent Advances in Endourology, 8

S. Baba, Y. Ono (Eds.)

Interventional Management of Urological Diseases

Recent Advances in Endourology, 8

S. Baba, Y. Ono (Eds.)

Interventional Management of Urological Diseases

With 37 Figures, Including 18 in Color

Springer

Shiro Baba, M.D., Ph.D.
Professor and Chairman
Department of Urology, Kitasato University School of Medicine
1-15-1 Kitasato, Sagamihara, Kanagawa 228-8555, Japan

Yoshinari Ono, M.D., Ph.D.
Associate Professor
Department of Urology, Nagoya University School of Medicine
65 Tsurumai, Showa-ku, Nagoya 466-8550, Japan

Cover: Steps in vaporization of left lateral lobe. *See* Fig. 3d,e, p. 111.

ISBN-10 4-431-35641-X Springer-Verlag Tokyo Berlin Heidelberg New York
ISBN-13 978-4-431-35641-7 Springer-Verlag Tokyo Berlin Heidelberg New York

Library of Congress Control Number: 2006930400

Printed on acid-free paper

Springer is a part of Springer Science+Business Media
springer.com

Typesetting: SNP Best-set Typesetter Ltd., Hong Kong
Printing and binding: Nikkei Printing, Japan
SPIN: 11784746 series number 4130

Preface

We have published a monograph every year since 1999. *Recent Advances in Endourology, Volume 8* deals with new, clinically relevant developments in interventional management of urological diseases. Members of the medical profession know that few procedures can be carried out by only one method. Endourology has developed significantly as a result of rapid changes in surgical techniques and innovative instruments, aided by the use of new energy sources. Endourological procedures now can be performed via the urethra or tiny incisions, eliminating the need to make large incisions. Postoperative patient recovery and pain can be dramatically reduced by the endoscopic surgical approach, and cosmetic effects can also be significantly improved by such surgical procedures. In the past 30 years, transurethral resection of the prostate, bladder, and ureteral tumors has been refined, using a variety of instruments and energy sources such as laser beams. Transurethral microwave thermotherapy (TUMT) has matured in the past 10 years as a nonsurgical option for treatment of benign prostatic obstruction. There also has been significant change in percutaneous surgery, made possible by the miniaturization of the endoscope and by newly developed instruments. Needle ablation techniques, which have been added to the armamentarium for treatment of small renal cell tumors, have significantly decreased pain and shortened hospital stays of patients.

The goal of this volume is to provide the most recent clinical information on various endourological treatment modalities and innovative materials. For that purpose, we asked recognized experts to outline their techniques clearly and concisely. We are deeply grateful to the authors for contributing their enlightening, informative chapters. This book could never have appeared without the exceptional cooperation of all concerned.

Shiro Baba, M.D., Ph.D.
Professor and Chairman, Department of Urology
Kitasato University School of Medicine
Kanagawa, Japan

Yoshinari Ono, M.D., Ph.D.
Associate Professor, Department of Urology
Nagoya University School of Medicine
Nagoya, Japan

Contents

Contributors

Access Techniques for Percutaneous Renal Surgery

Nicole L. Miller, Brian R. Matlaga, Samuel C. Kim, and James E. Lingeman

Summary. Percutaneous nephrolithotomy (PNL) remains an important part of the urologist's armamentarium. Although PNL can be used to treat upper tract calculi of any size, it is particularly effective for treating patients with complex stone disease or coexisting renal pathology such as ureteropelvic junction obstruction or stone-containing calyceal diverticula (CD). Since its introduction in the late 1970s, PNL has undergone a considerable evolution in technique. However, the performance of PNL is entirely dependent on achieving satisfactory access. This chapter reviews the current access techniques for percutaneous renal surgery.

Keywords. Kidney, Nephrolithiasis, Percutaneous nephrolithotomy, Calyceal diverticulum, Upper pole access

Introduction

Modern urological management of nephrolithiasis has evolved significantly with the introduction of shock wave lithotripsy (SWL) and advances in endoscopic technology. Presently, SWL and other endourological procedures, such as ureteroscopy (URS) and percutaneous nephrolithotomy (PNL), have supplanted the use of open stone procedures. These minimally invasive techniques allow the safe removal of virtually any urinary calculus regardless of composition, location, or stone burden. The fundamental principle guiding treatment selection is to maximize stone clearance while minimizing patient morbidity. To this end, PNL is ideally suited for the treatment of complex stone disease and/or coexisting renal pathology [i.e., ureteropelvic junction obstruction (UPJO), calyceal diverticulum (CD)].

Methodist Hospital Institute for Kidney Stone Disease, Indiana University School of Medicine, and International Kidney Stone Institute, 1801 North Senate Boulevard, Suite 220, Indianapolis, IN 46202, U.S.A.

Since its introduction by Fernstrom and Johanssson in 1976 [1], there has been considerable refinement in the technique of PNL due to increased experience, advances in endoscopic instruments, and more effective intracorporeal lithotripsy devices (pneumatic, Ho:YAG laser). The most critical step in performing successful PNL is establishing safe and effective percutaneous access. The ideal site of percutaneous puncture should be selected to maximize the use of rigid instruments, minimize the risk of complications, and achieve stone-free status. For optimal outcomes, it is necessary to outline criteria for proper patient selection, preoperative planning, and postoperative management. In this chapter, we review the current access techniques for percutaneous renal surgery.

Indications

Stone-related characteristics (size, number, location, and composition), renal anatomy, and patient clinical factors should all be considered, in conjunction with equipment availability and procedural morbidity, when selecting a surgical approach for renal calculi (Table 1). Although SWL and URS are less invasive modalities than PNL, they do not provide adequate treatment for all stones. Stone burden is perhaps the most important factor in determining the appropriate treatment modality [2]. As stone burden increases, stone-free rates with SWL decline [3,4]. Furthermore, the higher rate of residual stones after SWL increases the need for ancillary procedures and retreatment.

Significant risk of treatment failure exists with SWL for stones greater than 2 cm, especially with newer SWL devices. URS can be used to treat upper tract stones larger than 2 cm; however, stone clearance is significantly less than with PNL and recurrence can be rapid (16% over 6 months) [5]. PNL is a more effective approach for larger stones [6].

In 2005, the American Urological Association (AUA) published guidelines for the management of staghorn calculi [7,8]. The panel recommended PNL as the first treatment for most patients with staghorn calculi. Combined PNL and SWL (sandwich therapy) for complex stones was common in the 1990s; however, PNL techniques have improved and the need for SWL has declined. PNL

Table 1. Indications for percutaneous nephrolithotomy (PNL)

1. Staghorn calculi
2. Large calculi >2.0 cm
3. Calculi composed of cystine, brushite, struvite, or calcium oxalate monohydrate
4. Impacted or large proximal ureteral calculi
5. Calyceal diverticular calculi
6. Ectopic renal calculi (horseshoe kidney, pelvic kidney, or transplant kidney)
7. Coexisting ureteropelvic junction obstruction (UPJO) and renal calculi
8. Lower pole renal calculi >1.0 cm
9. Ureteroscopy (URS) or shock wave lithotripsy (SWL) failures

monotherapy has become an attractive option with the expanding role of flexible nephroscopy with holmium laser lithotripsy. Even the largest of staghorn calculi can be cleared percutaneously with the aid of second-look nephroscopy and/or multiple accesses [8].

Recent studies have focused on outlining the best treatment strategy for lower pole calculi. Although clearance rates for PNL and SWL are comparable for small (<10 mm) lower pole calculi, as the stone size increases the stone-free rate dramatically decreases. A prospective randomized multicenter trial showed the superiority of PNL over SWL in clearance of lower pole calculi greater than 10 mm (stone-free rates of 91% vs 21% for PNL and SWL respectively) [9]. Retreatment rates (16% vs 9%) and ancillary treatment rates (14% vs 2%) were also higher for the SWL group. A second prospective, randomized trial by the Lower Pole Study Group compared URS and PNL for the treatment of lower pole calculi. Stone-free rates for larger stones (11–25 mm) as determined by noncontrast computed tomography (NCCT) were 70.6% for PNL versus 29.6% for URS [10].

Stone composition is another important factor when considering the most appropriate treatment. Cystine, brushite, and calcium oxalate monohydrate stones are noted to be resistant to fragmentation with SWL [11,12]. Stone-free rates for cystine calculi are significantly better following PNL (67.2%) than when treated with SWL (14.8%) or URS (11.5%) [11]. PNL has also been shown to produce superior results in the treatment of brushite calculi. Klee and colleagues [12] reported a 100% stone-free rate with PNL versus 66% and 11% for URS and SWL, respectively. Finally, patients suspected of having struvite or infection calculi may achieve better outcomes following PNL due to the thorough removal of all stone fragments and optimal drainage of the collecting system [13–17].

CD are nonfunctioning, congenital urothelial-lined outpouchings of the renal collecting system. Calculous formation occurs in up to 50% of CD [18,19]. Traditionally, these diverticula were treated with open surgical techniques [18–20]; however, these approaches have largely been replaced by minimally invasive treatments such as ureteroscopy [21–23], laparoscopy [24,25], and percutaneous procedures [21,26–28].

Although SWL has been shown to offer symptomatic pain relief for CD calculi in 36%–70% of patients, the narrow neck of the diverticulum can impede passage of fragments and fulguration of the diverticulum is not possible [28,29]. URS is minimally invasive and allows for incision of the narrow infundibulum and ablation of the diverticulum; however, accessing the diverticulum may be difficult, particularly in the lower pole. Stone-free rates following URS have ranged from 19% to 58% [21,22]. URS may be best employed for anterior upper pole CD with minimal stone burden. Laparoscopy may be best for treating CD with thin overlying parenchyma, or those that are large and anterior [24].

PNL is an ideal treatment for CD because it allows for both stone removal and ablation of the diverticular cavity [27,28,30–32]; this is particularly true for lower pole diverticula and those greater than 1.5 cm [21,22,33]. PNL offers excellent stone free rates (93%–100%) and successful obliteration of the diverticular

cavity (76%–100%) [27,28,32]. Percutaneous access is the main challenge in treating CD with PNL.

Urinary calculi are often associated with UPJO. Stasis of urine and metabolic factors are thought to play a role in stone formation [34,35]. SWL is not a treatment option due to impaired drainage and obstruction. Patients with UPJO and concurrent renal calculi have traditionally been treated with open pyeloplasty and pyelolithotomy. Less invasive approaches such as PNL with antegrade endopyelotomy and laparoscopic pyeloplasty with pyelolithotomy are now more commonly employed. Ramakumar et al. [36] reported on 19 patients who underwent laparoscopic pyeloplasty with concurrent pyelolithotomy. The pyeloplasty was successful in 90% with a stone-free rate of 90%. Although laparoscopic stone removal is feasible, PNL with antegrade endopyelotomy is a more efficient treatment for larger stone burdens. This approach has a reported success rate of 86% [37] and allows secondary access for any residual stone.

Calculi formation in horseshoe kidneys occurs in 20%–61% of patients [38–40]. Although SWL may be used as initial treatment, stone-free rates vary greatly [41–45]. PNL is the most definitive treatment for calculi within a horseshoe kidney with stone-free rates of 75%–87.5% [46–48]. Furthermore, PNL allows for simultaneous endoscopic treatment of UPJO that can coexist with horseshoe kidney.

The anatomy of the pelvic kidney prevents a standard approach to the treatment of urinary calculi. The retroperitoneal location, posterior to the peritoneal cavity and anterior to the sacrum, with interposing bowel loops precludes a direct puncture with fluoroscopic techniques alone. SWL has been used to treat small stones in ectopic pelvic kidneys [49], but it is not efficient for treating larger stone burdens. Similarly, malrotation and difficulty accessing the lower pole of the pelvic kidney makes URS a less desirable option, especially for larger stone burdens. Laparoscopic-assisted PNL techniques have been developed to treat ectopic kidney calculi [36,50–55]. Holman and Toth [56] reported a technique in which the bowel was mobilized laparoscopically to visualize the pelvic kidney and percutaneous access was then attained under laparoscopic visualization, allowing successful removal of all stones with minimal morbidity. Zafar and Lingeman [55] described a modified laparoscopic-assisted transperitoneal PNL technique involving intracorporeal suturing of the nephrotomy site and ureteral stent placement to eliminate the need for a nephrostomy tube. In addition, Matlaga et al. [57] have utilized CT guidance to obtain percutaneous access in select patients with calculi in ectopic kidneys.

Calculi within a transplant kidney pose some of the same difficulties as those in the pelvic kidney. The use of SWL [58], URS [59], and PNL [60,61] have all been reported. SWL is best reserved for small stones as ureteral obstruction from residual fragments may lead to acute renal failure in transplant patients. PNL is a better option for larger stones. Placement of the donor kidney extraperitoneally within the iliac fossa causes the kidney to be rotated 180° on its axis. The posterior calyces point anteriorly and the renal pelvis medially. Therefore, an anterior approach for percutaneous access to the transplant kidney can be

performed similar to a posterior approach to native kidneys. Some have advocated the concurrent use of fluoroscopy and ultrasound for percutaneous access to avoid bowel injury [60].

While SWL is successful in treating 84% of proximal ureteral stones less than 1 cm and 72% of stones over 1 cm [62], large and/or impacted proximal ureteral stones are more resistant to SWL [62–63]. URS with holmium laser lithotripsy is an effective method for treating proximal ureteral calculi; however, PNL should be considered in cases of complex proximal ureteral calculi, such as impacted stones that have failed other modalities, dilated renal collecting systems, large stone burdens, urinary diversions, and distal ureteral strictures [64].

Preoperative Evaluation

A complete medical history and physical examination should be performed in all patients before PNL. Special attention should be paid to identifying conditions in which PNL is contraindicated, such as bleeding disorders and active urinary tract infection. If medically feasible, aspirin and other antiplatelet medications should be discontinued 7 days before the date of surgery [65]. Preoperative laboratory evaluation should include complete blood count, serum electrolytes, and renal function measurement.

All patients should have a preoperative urine sample sent for culture and sensitivity to identify the presence of infection; this is particularly important in patients with neurogenic bladder and urinary diversion who are often colonized with bacteria and/or infected with organisms that are resistant to commonly prescribed antibiotics [66]. In patients with preoperative bacteriuria, Larsen and associates [67] found stone cultures produced bacteria in 77% of cases. Even if the preoperative urine culture is negative, the stone itself may harbor bacteria. Mariappan and associates [14] reported that the best correlate with post-PNL sepsis is stone culture or renal pelvic urine culture, not bladder urine culture. For this reason, a 2-week course of broad-spectrum preoperative antibiotics is recommended. Antibiotic therapy may also reduce bleeding by decreasing inflammation and friability of the renal parenchyma. Cephalosporins are the most appropriate antibiotics for surgical prophylaxis immediately before surgical procedures in noninfected stone patients, as the most common secondarily infecting organism is *Staphylococcus epidermidis*. High-risk patients can be treated with intravenous ampicillin and gentamicin.

Morbidly obese patients warrant special preoperative consideration. They often have cardiac and/or pulmonary disease that can represent a challenge for the anesthesiologist. Careful positioning of these patients is important to avoid position-related injuries. PNL in obese patients achieves stone-free rates comparable to the nonobese population [68,69]. The major difficulty in performing PNL in the morbidly obese patient is the long distance from the skin to the collecting system, which may exceed the length of the working sheath and/or the

length of the rigid nephroscope. Therefore, when performing PNL in these patients it is important to have an extra-long Amplatz working sheath (20 cm) and rigid nephroscope readily available.

Finally, preoperative imaging is essential in planning PNL. Intravenous pyelography (IVP) has been largely supplanted by NCCT. NCCT is particularly useful in cases of congenital renal anomalies, transplant kidney, morbid obesity, and spinal cord deformities to allow evaluation of adjacent visceral structures. NCCT can also identify the presence of a retrorenal colon. Although rare (<1%), the incidence may be higher in patients with jejunoileal bypass and spinal cord injury [70]. IVP and/or retrograde pyelogram (RPG) remain useful in patients with CD to define the relationship between the diverticular cavity and the renal collecting system.

Access Techniques

The spectrum of access techniques may be best understood as a process of matching the proper percutaneous approach to the clinical situation. These access techniques include standard lower pole, CD/obstructed calyx, supracostal, and nondilated punctures.

Standard Lower Pole

The first step in performing PNL is cystoscopic placement of a ureteral catheter for retrograde opacification of the collecting system. Placement of the ureteral catheter is performed in the dorsal lithotomy position as catheter placement is rapid and all anatomical conditions, such as urethral or ureteral strictures, can be easily addressed. A 5 or 6 Fr open-ended ureteral catheter is routinely used; however, a 7 Fr occlusion balloon catheter should be considered when stone burden is large or the proximal ureter is dilated. A Foley catheter ensures bladder drainage during PNL.

The patient is placed in the prone position with the side to be treated elevated on a foam pad at 30°. This position aids in ventilation of the patient and brings the posterior calyces into a vertical position. All pressure points are padded. The patient's arm on the side of the stone is flexed at the elbow and placed on an arm board, while the contralateral arm is placed at the patient's side. For bilateral PNL, 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. Intravenous extension tubing is connected to the ureteral catheter, or the occlusion balloon port, to allow inflation or deflation of the balloon or the instillation of contrast material.

The preferred access site into the lower pole of the kidney is through a posterior calyx because the posterior calyces are usually oriented toward the avascular area between the anterior and posterior arterial divisions of the kidney (Brödel's bloodless line of incision). Therefore, a puncture through a posterior

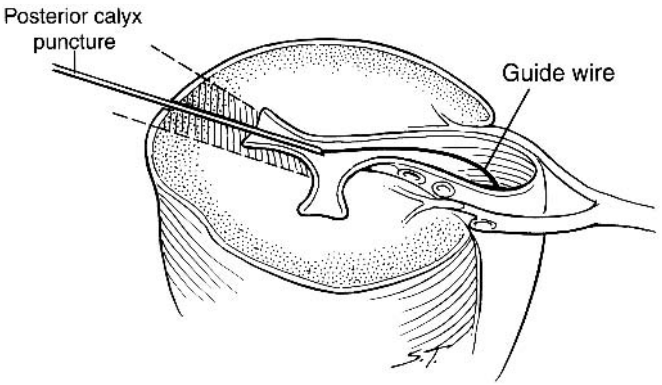


FIG. 1. The ideal percutaneous access traverses the renal parenchyma at the posterolateral aspect of the kidney through the relatively avascular Brödel's zone, entering a posterior calyx. (Reprinted with permission from Indiana University Office of Visual Media)

calyx traverses this line, avoiding the major branches of the renal artery (Fig. 1) [71]. In addition, puncture through a posterior calyx is the shortest access path to the renal collecting system. The determination of calyceal orientation and the selection of the optimal calyx of entry are best determined using biplanar C-arm fluoroscopy. A C-arm fluoroscopic unit is preferable to a urotable with a fixed X-ray tube because it permits more active movement between anteroposterior and oblique views of the kidney and reduces operator exposure to radiation scatter as the X-ray source is under the table rather than over it.

The skin puncture is usually performed approximately 1 cm inferior and 1 cm medial to the tip of the 12th rib (Fig. 2). The preferred point of entry into the collecting system is along the axis of the calyx, through the papilla. Aligning the access with the infundibulum also allows the most efficient use of a rigid nephroscope and reduces the need for excessive torque on the rigid instruments, which may cause renal trauma and bleeding. Infundibular puncture should be avoided if possible, as should direct puncture of the renal pelvis with its elevated risk of vascular injury, potential prolonged urinary leak, and easy tube dislodgment.

Biplanar fluoroscopy permits careful identification of the point of entry into the collecting system to avoid through-and-through puncture. After the targeted calyx is identified with fluoroscopy, orientation of the line of puncture is performed using a triangulation technique. 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. To reduce radiation exposure to the surgeon, the C-arm is

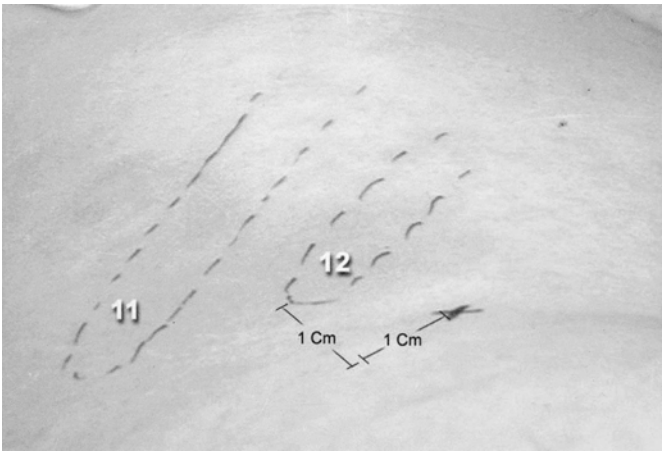


Fig. 2. For a lower pole puncture, a good starting point is 1 cm inferior and 1 cm medial to the tip of the 12th rib. *11*, *12*, 11th and 12th rib. (Reprinted from [72] with permission from Humana Press)

angled away from the line of puncture with the image intensifier angled toward the patient's head. Maintaining the needle orientation in one plane while making adjustments in the other plane is critical to preserve proper orientation. If the surgeon rests his or her forearm on the patient's torso, the line of puncture is stabilized and drift is minimized, facilitating precise puncture.

Once the proper orientation of the line of puncture has been obtained, respirations are suspended in full expiration. Contrast is instilled through the retrograde catheter to opacify and distend the collecting system. An 18-gauge diamond-tipped needle is advanced toward the desired calyx in the oblique position to gauge the depth of puncture. Before the renal capsule is entered, final adjustments are made. Manipulating the needle after entering renal parenchyma is discouraged because it may displace the kidney, affecting the position of the target calyx.

Puncture lateral to the posterior axillary line can result in injury to the colon [73]. A very medial puncture should also be avoided because it may traverse the paraspinus muscles, increasing postoperative pain. Finally, puncture should not be performed too close to the rib as it may injure the intercostal nerve and vessels.

Aspiration of urine will verify proper calyceal puncture. A hydrophilic nitinol core glidewire is then passed through the needle and into the collecting system. This type of wire is preferred for obtaining initial access because it is quite maneuverable and resists kinking. Under fluoroscopic guidance, an attempt is made to advance the glidewire down the ureter. If the wire does not pass easily into the ureter, it can be coiled in the renal pelvis. An 8 Fr fascial dilator is passed into the calyx followed by a 5 Fr cobra-tipped angiographic catheter. The angio-

graphic catheter helps direct the glidewire toward the ureteropelvic junction, facilitating placement of the wire down the ureter. Once the glidewire is positioned in the ureter, it is exchanged for a stiffer, Teflon-coated working wire such as an Amplatz super-stiff wire. The glidewire should not be used as a working wire because its lubricious nature makes it prone to displacement. An 8–10 Fr coaxial dilating system is then used to place a second safety wire, usually a 0.035-in. straight removal core wire. It is imperative to have a safety wire in place before proceeding with dilation of the percutaneous tract.

Several methods of tract dilation are available, including metal telescoping dilators, semirigid Amplatz dilators, and balloon dilators [74–76]. Balloon dilators have been reported to cause significantly less bleeding than sequential dilators [77] because the radial force used to spread the renal parenchyma is less traumatic than the shearing or cutting action of sequential Amplatz dilators or metal telescoping dilators. Sequential dilators (Amplatz or metal dilators) may be useful in the setting of extensive perirenal fibrosis from previous renal surgery. Alternatively, in the presence of flank scarring, a 4.5-mm fascial incising needle (Cook Urological, Spencer, IN, USA) can be placed over the working wire to facilitate balloon dilation. An Amplatz working sheath is placed following balloon dilation of the tract to 30 Fr. Care should be taken to avoid overadvancement of the sheath as this may cause bleeding and trauma to the renal parenchyma or the collecting system.

Rigid nephroscopy is performed through the Amplatz sheath. The stone burden can be treated with a combination of intracorporeal lithotripsy and a rigid grasper or stone basket. As the entire renal collecting system cannot usually be evaluated by rigid nephroscopy alone, flexible nephroscopy is used during every PNL to systematically survey the entire collecting system for residual stone fragments. Pressurization of irrigation fluid is necessary during flexible nephroscopy to permit adequate visualization. Contrast instillation through the flexible nephroscope is also helpful in verifying that all calyces have been inspected. Depending on size, stones can be fragmented with the holmium laser and/or removed with a nitinol basket. Alternatively, stone fragments can be flushed or manipulated into the renal pelvis with a combination of high-pressure irrigant and a floppy-tipped J-wire, where they may be retrieved with rigid instruments. Stone fragments should be routinely sent for analysis and culture. At the end of the procedure, a nephrostomy tube is placed through the access tract. Factors in choosing a nephrostomy tube are discussed next. A single dose of intravenous furosemide is administered when the nephrostomy tube is placed to promote diuresis and prevent plugging of the nephrostomy tube.

Calyceal Diverticulum/Obstructed Calyx

Percutaneous access into a CD or a calyx with an obstructed infundibulum containing stone material warrants a special access technique. Direct puncture of the diverticulum can be difficult due to the small size of the cavity or if the diverticulum is in the upper pole. Even when the diverticulum is successfully

punctured, passing a guidewire through the communication with the renal collecting system is usually not possible.

The surgical technique used in the percutaneous treatment of CD and diverticular stones has varied. Some advocate dilation of the diverticular communication or creation of a neoinfundibulum to theoretically improve the drainage of the diverticulum and reduce the risk of stasis [26,27,30,32,78,79]. Unfortunately, these techniques require prolonged nephrostomy tube drainage across the infundibulum. Monga and associates [31] questioned the need for establishing communication between the diverticulum and the renal collecting system. They performed direct percutaneous puncture of the diverticulum and fulguration of the diverticular lining without cannulation or dilation of the diverticular infundibulum. Obliteration of the diverticular cavity was documented in all patients by contrast radiography.

Opinions have also varied as to the necessity of diverticular fulguration. In a meta-analysis, Shalhav et al. [32] noted a higher rate of diverticular persistence (38% vs 9%) in patients who did not undergo fulguration. However, Hulbert and coworkers [27] reported treating 10 patients with CD and suggested that trauma to the wall of the diverticulum caused by the dilation process is sufficient to ablate the diverticular lumen. In this series however, a nephrostomy tube was left in place for 2 weeks.

The author's preferred technique involves a single-stage percutaneous approach that obviates placement of a ureteral catheter or entrance into the renal collecting system [80]. The patient is placed in the prone position with the side containing the CD elevated 30°. A C-arm fluoroscopy unit is used to visualize the diverticular calculi, and a direct infracostal puncture is performed using an 18-gauge diamond-tipped needle and a biplanar fluoroscopic triangulation technique as described previously. When access is achieved, a 0.035-in. J-tipped removable core guidewire is coiled inside the diverticular cavity. The major advantage of the removable core J-wire is that the flexible distal end of the wire can be adapted to the size of the diverticulum, while the wire proximal to the removed core remains rigid enough to function as the working wire. The lubricious nature of a hydrophilic wire, such as a glidewire, makes it prone to dislodgement, which can result in loss of access with manipulation of the wire. With the J-wire in place, an 8/10 Fr coaxial dilator is passed over the J-wire in a sequential fashion. The 8 Fr dilator is removed, and a second 0.035-in. J-tipped removable core wire is curled inside of the diverticulum to be used as a safety wire.

A balloon dilator (NephroMax; Boston Scientific, Natick, MA, USA) is passed over the working wire, and dilation of the nephrostomy tract performed. A 30 Fr Amplatz sheath is then advanced over the balloon dilator using fluoroscopic guidance. Special attention is paid to prevent overadvancement of the balloon dilator and sheath to avoid traumatizing the opposite wall of the diverticulum (Fig. 3A). The balloon dilator has a tapered distal end that often precludes placement of the sheath directly into the diverticular cavity unless the diverticulum is large. A 24.5 Fr rigid offset nephroscope (Richard Wolf, Vernon

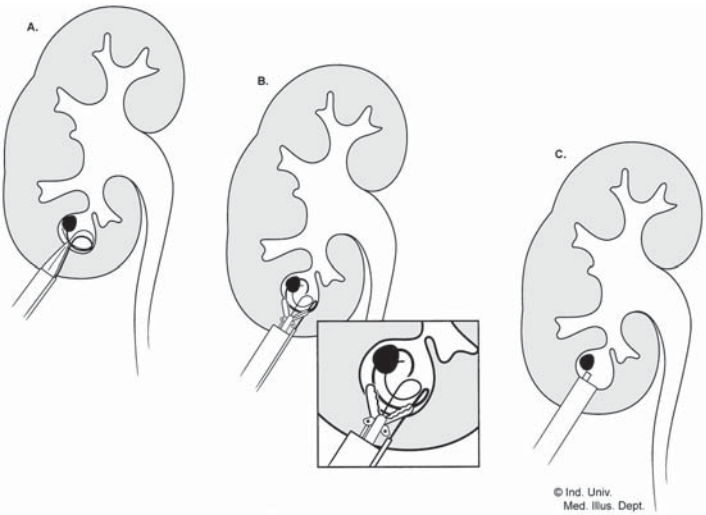


Fig. 3. Percutaneous access into calyceal diverticulum. **A** Balloon dilator is advanced as far as possible without perforating the back wall of the diverticulum. **B** Alligator forceps are used to spread the parenchyma and allow advancement of the nephroscope under direct vision into the diverticulum. **C** The working sheath is then advanced over the nephroscope into the diverticulum. (Reprinted with permission from Indiana University Office of Visual Media)

Hills, IL, USA) without the external sheath is placed through the Amplatz sheath in conjunction with normal saline irrigation. An 11 Fr alligator forceps is used to manually dilate the tract as needed immediately adjacent to the diverticulum (Fig. 3B). Once the tract is adequately dilated, the offset nephroscope is gently advanced into the diverticular cavity and ultrasonic lithotripsy is used to treat any existing calculi (Fig. 3C). Careful inspection of the urothelium with the rigid nephroscope is performed in an effort to verify that a true diverticulum exists rather than a flattened renal papilla associated with an obstructed calyx.

Following stone removal, a 24 Fr resectoscope (Karl Storz Imaging, Goleta, CA, USA) is passed into the diverticulum. Using 1.5% glycine irrigation, a roller-ball electrode is employed to fulgurate the diverticular lining. The communication between the diverticulum and the renal collecting system is not dilated, nor is any neoinfundibulum attempted. A 20 Fr red rubber catheter or an 8.5 Fr Cope loop catheter is placed within the cavity at the conclusion of the procedure. Proper tube placement is confirmed by contrast instillation under fluoroscopy.

All available stone material is sent for analysis. A NCCT is performed on the first postoperative day to identify any residual stone material. If the patient is stone free and nephrostomy tube drainage is low, the nephrostomy tube is removed. If the NCCT reveals any residual stone fragments, a second look is performed using flexible nephroscopy and intravenous sedation. An IVP is

performed at 3 months to assess size and resolution of the diverticulum. Using this technique, Kim et al. [80] have reported an 85.7% (18 of 21 renal units) stone-free rate. Of the 16 renal units imaged with IVP at 3 months, all revealed a reduction in diverticular size, and 87.5% had complete resolution of the diverticulum. The access technique described above for CD is easily adapted for the treatment of kidneys where the infundibulum of the desired calyx of puncture is impassable, as commonly occurs with staghorn calculi.

Supracostal or Upper Pole

Supracostal or upper pole percutaneous access is necessary in certain clinical situations. The main advantage of this access technique is that the line of puncture directly aligns with the renal axis. For this reason, it is advantageous in cases of coexisting renal calculi and UPJO or impacted proximal ureteral calculi because it allows excellent visualization of the ureteropelvic junction and proximal ureter for stone removal and/or antegrade endopyelotomy [3]. Supracostal or upper pole access may also be necessary in cases where there is large stone burden located in the upper calyces such as a complete staghorn calculus, or in the presence of multiple stone-containing lower pole calyces [81–84]. PNL for calculi occurring in a horseshoe kidney is often accomplished through an upper pole access due to the incomplete ascent of the kidney.

Although the percutaneous technique is similar to that described for the lower pole, certain aspects of supracostal or upper pole access are worthy of emphasis. The main risk of a supracostal puncture is injury to the lung and pleura because the upper poles of both kidneys lie immediately anterior to the posterior portion of the 11th and 12th ribs, and can even be as high as the 10th rib [85]. The risk of pleural injury is greatest during the inspiratory phase of respiration; therefore, general anesthesia is essential to control respiratory movements during puncture. For supracostal access, the puncture site should be placed in the middle of the intercostal space, just lateral to the paraspinus muscles and puncture above the 11th rib avoided when possible (Fig. 4). Occasionally, the upper pole can be accessed via a laterally situated tract between the tips of the 11th and 12th ribs or even by an infracostal approach (Fig. 5). This type of intercostal access has been shown to decrease the risk of pleural injury when compared to a vertical supracostal puncture [86].

The use of an Amplatz working sheath is mandatory in patients with supracostal access to reduce the risk of hydrothorax. Pulmonary complications have been reported in approximately 16% of cases [82,83,85,87,88]. Ogan and associates [89] have demonstrated the utility of using intraoperative fluoroscopy to detect a clinically significant hydropneumothorax following supracostal access. This technique is advantageous as it allows aspiration of the pleural fluid while the patient is under anesthesia. If intraoperative fluoroscopy of the chest is normal, a formal chest radiograph in the recovery room is recommended only if the patient is symptomatic. Minor pleural effusions can be managed conservatively, but larger effusions or the presence of significant pneumothorax will

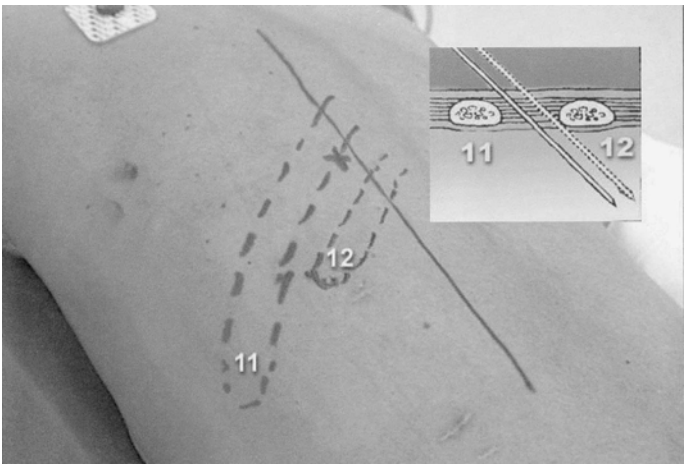


FIG. 4. For a supracostal upper pole puncture, the point of entry at the skin is at the inferior border of the 11th rib lateral to the paraspinus muscles. (Reprinted from [72] with permission from Humana Press)

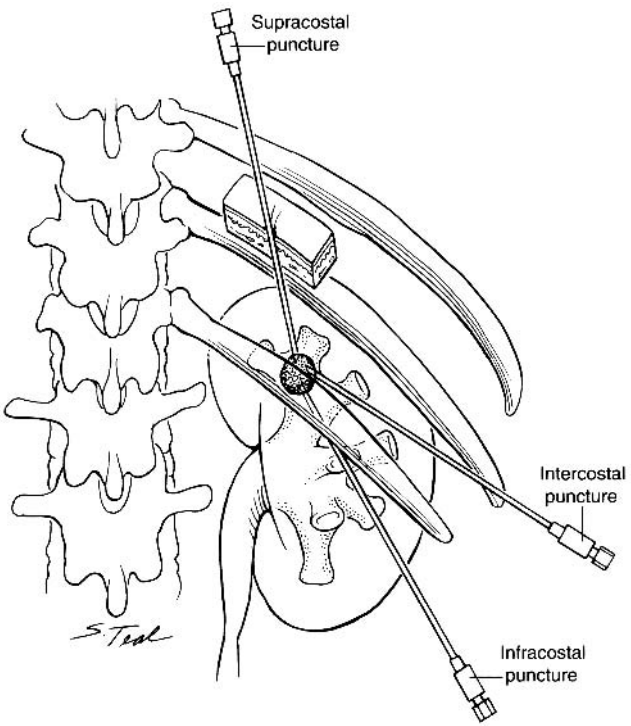


FIG. 5. Upper pole access can be performed by a supracostal, intercostal, or infracostal approach. A supracostal approach most closely aligns the puncture with the renal axis and allows access to the proximal ureter and ureteropelvic junction. (Reprinted with permission from Indiana University Office of Visual Media)

require placement of a chest tube [90]. Small pigtail-type catheters are usually sufficient and are more comfortable for the patient than larger chest tubes.

In the absence of splenomegaly or hepatomegaly, injury to the liver and spleen are extremely rare when the access puncture site is below the 12th rib. However, supracostal access can be associated with an increased risk of injury to the liver and spleen, particularly if the puncture is performed during the inspiratory phase of respiration rather than the expiratory phase or if the puncture is above the 11th rib [91,92]. To reduce the risk of liver or spleen injury, the skin puncture site should be located as far medial as possible, adjacent to the lateral border of the paraspinal muscles.

Supracostal puncture has also been associated with increased postoperative pain [85], as is particularly true when a nephrostomy tube is placed through the upper pole tract. Kim and associates [93] have reported utilization of lower pole nephrostomy drainage following PNL through an upper pole access. Both dilated and nondilated lower pole access was used. Secondary procedures for residual stone were easily performed through the lower pole tract. A flexible ureteroscope was used through nondilated lower pole tracts and a flexible nephroscope through previously dilated tracts. The use of rigid percutaneous instruments was necessary in only 3 of the 62 patients to dilate a previously nondilated lower pole access. This technique allows the advantages of a supracostal puncture while minimizing patient discomfort from an intercostal nephrostomy tube. "Tubeless" upper pole access should be reserved for those cases where the surgeon is confident that all stone material of interest has been removed.

Nondilated Puncture

The nondilated puncture technique is particularly useful for PNL in certain clinical scenarios. For example, in the presence of an eccentric calyx that is difficult to identify via the established access. In this situation, needle puncture into the desired calyx without tract dilation can be helpful (Fig. 6). Once the desired calyx has been punctured, an attempt is made to pass a guidewire into the renal pelvis where it can serve as a road map to the area of interest. Alternatively, methylene blue or carbon dioxide can be injected through the needle, and the colored stream or gas bubbles may be used to guide a flexible nephroscope into the desired calyx. Occasionally, a narrow infundibulum prevents advancement of the nephroscope into the calyx. In this instance, use of a flexible ureteroscope or balloon dilation of the infundibulum may be necessary. Back-loading of the flexible nephroscope or ureteroscope over a guidewire into the desired calyx can be accomplished via a push–pull technique [94]. The advantage of this approach is that a nephrostomy tube is not necessary afterwards.

As mentioned briefly above, a nondilated puncture may also be useful for insertion of a small-diameter nephrostomy tube into a lower pole calyx in cases of "tubeless" upper pole or multiple accesses. The technique reported by Kim and associates [93] involves puncture of the lower pole onto a flexible nephroscope inserted through the upper pole access and directed into the desired lower

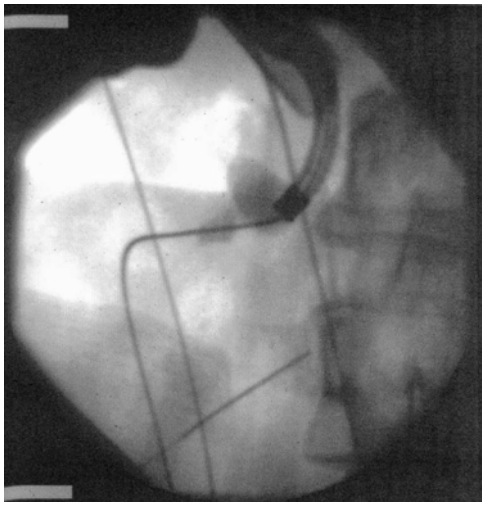


Fig. 6. Nondilated puncture used to place a guidewire into a difficult-to-access calyx. Back-loading of the flexible nephroscope over the guidewire allows visualization of the calyx

pole calyx. Therefore, the nondilated puncture technique for placement of a lower pole nephrostomy tube following supracostal or upper pole access allows the surgeon to take advantage of the benefits of a supracostal access while minimizing patient discomfort.

Postoperative Considerations

Nephrostomy Tube Selection

A nephrostomy tube following PNL functions to ensure proper drainage of urine and facilitate access to the collecting system if a secondary PNL is required [95]. The size and type of catheter chosen depends on stone and patient factors as well as the surgeon's preference. Although a variety of nephrostomy tubes exist, small self-retaining tubes (such as 10 Fr cope-loop catheters) cause less patient discomfort than stiffer, larger-diameter tubes. Kim and associates [96] have demonstrated the efficacy of using small-diameter nephrostomy tubes. They reviewed 106 consecutive renal units undergoing PNL 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. 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%). There were no difficulties with drainage or access for secondary PNL. Infection stones were much more likely to require a reentry Malecot or circle catheter (57.1%).

Despite the utility of small-diameter nephrostomy tubes, there are clinical situations in which other types of nephrostomy tubes are advantageous. For example, morbidly obese patients are prone to tube displacement following PNL; therefore, balloon-type catheters or reentry Malecot catheters may be preferable [97]. The reentry catheter consists of a Malecot catheter with a ureteral catheter attached to the tip of the Malecot that extends across the ureteropelvic junction into the midureter. The reentry catheter maintains access to the collecting system even in cases where the nephrostomy tube is partially dislodged. Alternatively, an open-ended ureteral catheter or angiographic catheter can be placed over the safety wire at the end of the procedure to ensure that access is maintained. Malecot nephrostomy catheters should also be considered in cases where there is gross infection, substantial residual stone burden requiring a secondary procedure, or complex renal anatomy that requires secure access. In complex stone cases that require multiple accesses and/or a secondary procedure, a 20 Fr circle (or loop) nephrostomy tube is beneficial. Before nephrostomy tube removal, an antegrade nephrostogram is routinely performed to document free flow of contrast down the ureter.

Pain Control

Pain following PNL can be reduced by utilizing local anesthetics. We rountinely inject 0.25% bupivicaine into the nephrostomy tract to minimize postoperative pain. In addition, a rib block can be performed by injecting 0.25% bupivicaine adjacent to the intercostal neurovascular bundles of the 11th and 12th ribs. Ketorolac can also be a useful adjunct to standard postoperative narcotic analgesic regimens in patients with normal renal function. An initial bolus can be given in the operating room at the conclusion of the procedure while the patient is still under anesthesia. The bolus is then followed by a continuous infusion for the length of time the nephrostomy tube is in place. Monitoring of renal function is imperative when using ketorolac.

Complications

The most significant complication of PNL is bleeding. Hemorrhage requiring blood transfusion has been reported to be 5%–15% [77,98,99]. Utilizing the access techniques described above, blood transfusion is necessary in only 1%–2% of PNL procedures performed currently at the author's institution. Substantial bleeding during PNL usually requires cessation of the procedure due to impaired visualization. The bleeding is usually venous in nature and can often be controlled with placement of a nephrostomy tube. If bleeding persists, clamping the nephrostomy tube may help tamponade the bleeding [100]. If these measures do not control the hemorrhage, a Kaye nephrostomy tamponade balloon catheter (Cook Urological) consisting of a low-pressure 12-mm balloon may be left inflated in the nephrostomy tract [101]. Hemorrhage despite these maneu-

vers may indicate the presence of an arteriovenous malformation or pseudoaneurysm and warrants angiographic embolization. Fortunately, this is rare, occurring in less than 0.5% of patients.

Although postoperative fever (less than 38.5°C) is found in almost one-fourth of patients, sepsis occurs in only 0.3%–2.5% [73,99]. The risk of sepsis can be minimized by appropriate antibiotic therapy tailored to the preoperative urine culture and intraoperative stone culture.

Perforation of the renal pelvis can occur during PNL. Therefore, physiological solutions such as normal saline are mandatory to prevent significant electrolyte abnormalities. In the presence of minor perforation, it is usually not necessary to terminate PNL because the low-pressure system limits retroperitoneal extravasation. More extensive perforations or those that are intraperitoneal are best treated by terminating the procedure and placing a nephrostomy tube [102].

As mentioned previously, supracostal puncture is associated with a 4%–16% risk of pneumothorax or pleural effusion requiring drainage [82,85,87,88,103, 104]. The risk can be minimized by suspending respirations in expiration during needle puncture. Intraoperative fluoroscopy can be used to identify and treat pneumothorax or hydrothorax [89]. If the surgeon has a high index of suspicion for a thoracic complication, a chest X-ray may be obtained postoperatively.

Fortunately, visceral organ injury is a rare complication of PNL. Colonic injury is the most common of these, occurring in less than 1% of cases. Signs of colonic perforation include passage of gas or feculent material through the nephrostomy tract, intraoperative diarrhea, hematochezia, peritonitis, or an unanticipated septic event. Because the injury is usually retroperitoneal, signs and symptoms of peritonitis may not be present, and diagnosis is not uncommonly made on postoperative CT or nephrostogram. Extraperitoneal perforation can be managed expectantly with placement of a ureteral catheter or double-J stent to decompress the collecting system and withdrawal of the nephrostomy tube from an intrarenal position to an intracolonic position to serve as a colostomy tube [105]. The colostomy tube is left in place for a minimum of 7 days and is removed after a nephrostogram or a RPG showing no communication between the colon and the kidney [86,106]. In cases of intraperitoneal injury or sepsis, abdominal exploration is warranted.

Conclusion

PNL remains an integral part of the treatment for nephrolithiasis. The procedure has evolved over time with the introduction of new access techniques, instrumentation, and endoscopic technology. Percutaneous access is perhaps the most critical factor in determining the safety and efficacy of PNL. Strict adherence to the basic principles outlined in this chapter will help ensure the success of the procedure while reducing the risk of complications.

References

1. Fernstrom I, Johansson B (1976) Percutaneous pyelolithotomy. A new extraction technique. Scand J Urol Nephrol 10:257–259
2. Motola JA, Smith AD (1990) Therapeutic options for the management of upper tract calculi. Urol Clin N Am 17:191–206
3. Lam HS, Lingeman JE, Mosbaugh PG, Steele RE, Knapp PM, Scott JW, Newman DM (1992) Evolution of the technique of combination therapy for staghorn calculi: a decreasing role for extracorporeal shock wave lithotripsy. J Urol 148:1058–1062
4. Lingeman JE, Coury TA, Newman DM, Kahnoski RJ, Mertz JH, Mosbaugh PG, Steele RE, Woods JR (1987) Comparison of results and morbidity of percutaneous nephrostolithotomy and extracorporeal shock wave lithotripsy. J Urol 138:485–490
5. Grasso M, Conlin M, Bagley D (1998) Retrograde ureteropyeloscopic treatment of 2 cm or greater upper urinary tract and minor staghorn calculi. J Urol 160:346–351
6. Consensus Conference (1988) Prevention and treatment of kidney stones. JAMA 260:977–981
7. Meretyk S, Gofrit ON, Gafni O, Pode D, Shapiro A, Verstandig A, Sasson T, Katz G, Landau EH (1997) Complete staghorn calculi: random prospective comparison between extracorporeal shock wave lithotripsy monotherapy and combined with percutaneous nephrostolithotomy. J Urol 157:780–786
8. Preminger GM, Assimos DG, Lingeman JE, Nakada SY, Pearle MS, Wolf JS Jr (2005) Chapter 1: AUA guideline on management of staghorn calculi: diagnosis and treatment recommendations. J Urol 173:1991–2000
9. Albala DM, Assimos DG, Clayman RV, Denstedt JD, Grasso M, Gutierrez-Aceves J, Kahn RI, Leveillee RJ, Lingeman JE, Macaluso JN Jr, Munch LC, Nakada SY, Newman RC, Pearle MS, Preminger GM, Teichman J, Woods JR (2001) Lower pole I: a prospective randomized trial of extracorporeal shock wave lithotripsy and percutaneous nephrostolithotomy for lower pole nephrolithiasis-initial results. J Urol 166:2072–2080
10. Kuo RL, Lingeman JE, Leveillee RJ, Pearle MS, Watkins S, Fineberg NS, Group LPS (2003) Lower Pole II: initial results from a comparison of shock wave lithotripsy (SWL), ureteroscopy (URS), and percutaneous nephrostolithotomy (PNL) for lower pole nephrolithiasis. J Urol 169:1821A
11. Chow GK, Streem SB (1998) Contemporary urological intervention for cystinuric patients: immediate and long-term impact and implications. J Urol 160:341–344; discussion 344–345
12. Klee LW, Brito CG, Lingeman JE (1991) The clinical implications of brushite calculi. J Urol 145:715–718
13. Margel D, Ehrlich Y, Brown N, Lask D, Livne PM, Lifshitz DA (2006) Clinical implication of routine stone culture in percutaneous nephrolithotomy—a prospective study. Urology 67:26–29
14. Mariappan P, Smith G, Bariol SV, Moussa SA, Tolley DA (2005) Stone and pelvic urine culture and sensitivity are better than bladder urine as predictors of urosepsis following percutaneous nephrolithotomy: a prospective clinical study. J Urol 173:1610–1614
15. McAleer IM, Kaplan GW, Bradley JS, Carroll SF (2002) Staghorn calculus endotoxin expression in sepsis. Urology 59:601
16. McAleer IM, Kaplan GW, Bradley JS, Carroll SF, Griffith DP (2003) Endotoxin content in renal calculi. J Urol 169:1813–1814

17. Paterson RF, Kuo RL, Lingeman JE (2003) Staghorn calculus endotoxin expression in sepsis. Urology 62:197; author reply 197–198
18. Williams G, Blandy JP, Tresidder GC (1969) Communicating cysts and diverticula of the renal pelvis. Br J Urol 41:163–170
19. Yow RM, Bunts RC (1955) Calyceal diverticulum. J Urol 73:663–670
20. Wulfsohn MA (1980) Pyelocaliceal diverticula. J Urol 123:1–8
21. Auge BK, Munver R, Kourambas J, Newman GE, Preminger GM (2002) Endoscopic management of symptomatic caliceal diverticula: a retrospective comparison of percutaneous nephrolithotripsy and ureteroscopy. J Endourol 16:557–563
22. Batter SJ, Dretler SP (1997) Ureterorenoscopic approach to the symptomatic caliceal diverticulum. J Urol 158:709–713
23. Grasso M, Lang G, Loisides P, Bagley D, Taylor F (1995) Endoscopic management of the symptomatic caliceal diverticular calculus. J Urol 153:1878–1881
24. Miller SD, Ng CS, Streem SB, Gill IS (2002) Laparoscopic management of caliceal diverticular calculi. J Urol 167:1248–1252
25. Ruckle HC, Segura JW (1994) Laparoscopic treatment of a stone-filled, caliceal diverticulum: a definitive, minimally invasive therapeutic option. J Urol 151:122–124
26. Auge BK, Munver R, Kourambas J, Newman GE, Wu NZ, Preminger GM (2002) Neoinfundibulotomy for the management of symptomatic caliceal diverticula. J Urol 167:1616–1620
27. Hulbert JC, Reddy PK, Hunter DW, Castaneda-Zuniga W, Amplatz K, Lange PH (1986) Percutaneous techniques for the management of caliceal diverticula containing calculi. J Urol 135:225–227
28. Jones JA, Lingeman JE, Steidle CP (1991) The roles of extracorporeal shock wave lithotripsy and percutaneous nephrostolithotomy in the management of pyelocaliceal diverticula. J Urol 146:724–727
29. Psihramis KE, Dretler SP (1987) Extracorporeal shock wave lithotripsy of caliceal diverticula calculi. J Urol 138:707–711
30. Bellman GC, Silverstein JI, Blickensderfer S, Smith AD (1993) Technique and follow-up of percutaneous management of caliceal diverticula. Urology 42:21–25
31. Monga M, Smith R, Ferral H, Thomas R (2000) Percutaneous ablation of caliceal diverticulum: long-term followup. J Urol 163:28–32
32. Shalhav AL, Soble JJ, Nakada SY, Wolf JS Jr, McClennan BL, Clayman RV (1998) Long-term outcome of caliceal diverticula following percutaneous endosurgical management. J Urol 160:1635–1639
33. Canales B, Monga M (2003) Surgical management of the calyceal diverticulum. Curr Opin Urol 13:255–260
34. Husmann DA, Milliner DS, Segura JW (1996) Ureteropelvic junction obstruction with concurrent renal pelvic calculi in the pediatric patient: a long-term followup. J Urol 156:741–743
35. Matin SF, Streem SB (2000) Metabolic risk factors in patients with ureteropelvic junction obstruction and renal calculi. J Urol 163:1676–1678
36. Ramakumar S, Lancini V, Chan DY, Parsons JK, Kavoussi LR, Jarrett TW (2002) Laparoscopic pyeloplasty with concomitant pyelolithotomy. J Urol 167:1378–1380
37. Goldfischer ER, Jabbour ME, Stravodimos KG, Klima WJ, Smith AD (1998) Techniques of endopyelotomy. Br J Urol 82:1–7
38. Evans WP, Resnick MI (1981) Horseshoe kidney and urolithiasis. J Urol 125:620–621
39. Pitts WR Jr, Muecke EC (1975) Horseshoe kidneys: a 40-year experience. J Urol 113:743–746

40. Weizer AZ, Springhart WP, Ekeruo WO, Matlaga BR, Tan YH, Assimos DG, Preminger GM (2005) Ureteroscopic management of renal calculi in anomalous kidneys. Urology 65:265–269
41. Esuvaranathan K, Tan EC, Tung KH, Foo KT (1991) Stones in horseshoe kidneys: results of treatment by extracorporeal shock wave lithotripsy and endourology. J Urol 146:1213–1215
42. Kirkali Z, Esen AA, Mungan MU (1996) Effectiveness of extracorporeal shockwave lithotripsy in the management of stone-bearing horseshoe kidneys. J Endourol 10:13–15
43. Kupeli B, Isen K, Biri H, Sinik Z, Alkibay T, Karaoglan U, Bozkirli I (1999) Extracorporeal shockwave lithotripsy in anomalous kidneys. J Endourol 13:349–352
44. Lampel A, Hohenfellner M, Schultz-Lampel D, Lazica M, Bohnen K, Thurof JW (1996) Urolithiasis in horseshoe kidneys: therapeutic management. Urology 47:182–186
45. Theiss M, Wirth MP, Frohmuller HG (1993) Extracorporeal shock wave lithotripsy in patients with renal malformations. Br J Urol 72:534–538
46. Al-Otaibi K, Hosking DH (1999) Percutaneous stone removal in horseshoe kidneys. J Urol 162:674–677
47. Jones DJ, Wickham JE, Kellett MJ (1991) Percutaneous nephrolithotomy for calculi in horseshoe kidneys. J Urol 145:481–483
48. Raj GV, Auge BK, Weizer AZ, Denstedt JD, Watterson JD, Beiko DT, Assimos DG, Preminger GM (2003) Percutaneous management of calculi within horseshoe kidneys. J Urol 170:48–51
49. Rigatti P, Montorsi F, Guazzoni G, di Girolamo V, Consonni P, Colombo R, Da Pozzo L, Bocciardi A (1991) Multimodal therapy for stones in pelvic kidneys. Urol Int 46:29–34
50. Eshghi AM, Roth JS, Smith AD (1985) Percutaneous transperitoneal approach to a pelvic kidney for endourological removal of staghorn calculus. J Urol 134: 525–527
51. Figge M (1988) Percutaneous transperitoneal nephrolithotomy. Eur Urol 14:414–416
52. Kim SC, Kuo RL, Paterson RF, JE L (2003) Laparoscopic assisted percutaneous nephrolithotomy: best done tubeless? J Urol 169:79
53. Lee CK, Smith AD (1992) Percutaneous transperitoneal approach to the pelvic kidney for endourologic removal of calculus; three cases with two successes. J Endourol 6:133
54. Toth C, Holman E, Pasztor I, Khan AM (1993) Laparoscopically controlled and assisted percutaneous transperitoneal nephrolithotomy in a pelvic dystopic kidney. J Endourol 7:303–305
55. Zafar FS, Lingeman JE (1996) Value of laparoscopy in the management of calculi complicating renal malformations. J Endourol 10:379–383
56. Holman E, Toth C (1998) Laparoscopically assisted percutaneous transperitoneal nephrolithotomy in pelvic dystopic kidneys: experience in 15 successful cases. J Laparoendosc Adv Surg Tech A 8:431–435
57. Matlaga BR, Shah OD, Zagoria RJ, Dyer RB, Streem SB, Assimos DG (2003) Computerized tomography guided access for percutaneous nephrostolithotomy. J Urol 170:45–47
58. Wheatley M, Ohl DA, Sonda LP 3rd, Wang SC, Konnak JW (1991) Treatment of renal transplant stones by extracorporeal shock-wave lithotripsy in the prone position. Urology 37:57–60

59. Del Pizzo JJ, Sklar GN (1999) O'Brien peel-away sheath: an alternative for allograft percutaneous nephroscopy. J Endourol 13:31–33
60. Francesca F, Felipetto R, Mosca F, Boggi U, Rizzo G, Puccini R (2002) Percutaneous nephrolithotomy of transplanted kidney. J Endourol 16:225–227
61. Hulbert JC, Reddy P, Young AT, Hunter DW, Castaneda-Zuniga W, Amplatz K, Lange PH (1985) The percutaneous removal of calculi from transplanted kidneys. J Urol 134:324–326
62. Segura JW, Preminger GM, Assimos DG, Dretler SP, Kahn RI, Lingeman JE, Macaluso JN Jr (1997) Ureteral Stones Clinical Guidelines Panel summary report on the management of ureteral calculi. The American Urological Association. J Urol 158:1915–1921
63. Green DF, Lytton B (1985) Early experience with direct vision electrohydraulic lithotripsy of ureteral calculi. J Urol 133:767–770
64. Preminger GM (1992) Management of ureteral calculi: the debate continues. J Urol 148:1102–1104
65. Mak S, Amoroso P (2003) Stop those antiplatelet drugs before surgery! BJU Int 91:593–594
66. Culkin DJ, Wheeler JS, Nemchausky BA, Fruin RC, Canning JR (1990) Percutaneous nephrolithotomy: spinal cord injury vs. ambulatory patients. J Am Paraplegia Soc 13:4–6
67. Larsen EH, Gasser TC, Madsen PO (1986) Antimicrobial prophylaxis in urologic surgery. Urol Clin N Am 13:591–604
68. Koo BC, Burtt G, Burgess NA (2004) Percutaneous stone surgery in the obese: outcome stratified according to body mass index. BJU Int 93:1296–1299
69. Pearle MS, Nakada SY, Womack JS, Kryger JV (1998) Outcomes of contemporary percutaneous nephrostolithotomy in morbidly obese patients. J Urol 160:669–673
70. Sherman JL, Hopper KD, Greene AJ, Johns TT (1985) The retrorenal colon on computed tomography: a normal variant. J Comput Assist Tomogr 9:339–341
71. Dyer RB, Assimos DG, Regan JD (1997) Update on interventional uroradiology. Urol Clin N Am 24:623–652
72. Kim SC, Lingeman JE (2006) Percutaneous access to the urinary tract. In: Nakada SY, Pearle MS (eds) Advanced endourology: the complete clinical guide. Humana Press, Totowa, NJ, pp 43–59
73. Lang EK (1987) Percutaneous nephrostolithotomy and lithotripsy: a multiinstitutional survey of complications. Radiology 162:25–30
74. Alken P, Hutschenreiter G, Gunther R, Marberger M (1981) Percutaneous stone manipulation. J Urol 125:463–466
75. Clayman RV, Surya V, Miller RP, Castaneda-Zuniga WR, Amplatz K, Lange PH (1983) Percutaneous nephrolithotomy. An approach to branched and staghorn renal calculi. JAMA 250:73–75
76. Kerlan RK Jr, Kahn RI, Ring EJ (1984) Percutaneous renal and ureteral stone removal. Urol Radiol 6:113–123
77. Davidoff R, Bellman GC (1997) Influence of technique of percutaneous tract creation on incidence of renal hemorrhage. J Urol 157:1229–1231
78. Al-Basam S, Bennett JD, Layton ZA, Denstedt JD, Razvi H (2000) Treatment of caliceal diverticular stones: transdiverticular percutaneous nephrolithotomy with creation of a neoinfundibulum. J Vasc Interv Radiol 11:885–889
79. Lang EK (1991) Percutaneous infundibuloplasty: management of calyceal diverticula and infundibular stenosis. Radiology 181:871–877

80. Kim SC, Kuo RL, Tinmouth WW, Watkins S, Lingeman JE (2005) Percutaneous nephrolithotomy for caliceal diverticular calculi: a novel single stage approach. J Urol 173:1194–1198
81. Aron M, Goel R, Kesarwani PK, Seth A, Gupta NP (2004) Upper pole access for complex lower pole renal calculi. BJU Int 94:849–852; discussion 852
82. Munver R, Delvecchio FC, Newman GE, Preminger GM (2001) Critical analysis of supracostal access for percutaneous renal surgery. J Urol 166:1242–1246
83. Stening SG, Bourne S (1998) Supracostal percutaneous nephrolithotomy for upper pole caliceal calculi. J Endourol 12:359–362
84. Wong C, Leveillee RJ (2002) Single upper-pole percutaneous access for treatment of > or =5-cm complex branched staghorn calculi: is shockwave lithotripsy necessary? J Endourol 16:477–481
85. Fuchs EF, Forsyth MJ (1990) Supracostal approach for percutaneous ultrasonic lithotripsy. Urol Clin N Am 17:99–102
86. LeRoy AJ, Williams HJ Jr, Bender CE, Segura JW, Patterson DE, Benson RC (1985) Colon perforation following percutaneous nephrostomy and renal calculus removal. Radiology 155:83–85
87. Golijanin D, Katz R, Verstandig A, Sasson T, Landau EH, Meretyk S (1998) The supracostal percutaneous nephrostomy for treatment of staghorn and complex kidney stones. J Endourol 12:403–405
88. Narasimham DL, Jacobsson B, Vijayan P, Bhuyan BC, Nyman U, Holmquist B (1991) Percutaneous nephrolithotomy through an intercostal approach. Acta Radiol 32:162–165
89. Ogan K, Corwin TS, Smith T, Watumull LM, Mullican MA, Cadeddu JA, Pearle MS (2003) Sensitivity of chest fluoroscopy compared with chest CT and chest radiography for diagnosing hydropneumothorax in association with percutaneous nephrostolithotomy. Urology 62:988–992
90. Ogan K, Pearle MS (2002) Oops we got in the chest: fluoroscopic chest tube insertion for hydrothorax after percutaneous nephrostolithotomy. Urology 60:1098–1099
91. Hopper KD, Yakes WF (1990) The posterior intercostal approach for percutaneous renal procedures: risk of puncturing the lung, spleen, and liver as determined by CT. AJR Am J Roentgenol 154:115–117
92. Robert M, Maubon A, Roux JO, Rouanet JP, Navratil H (1999) Direct percutaneous approach to the upper pole of the kidney: MRI anatomy with assessment of the visceral risk. J Endourol 13:17–20
93. Kim SC, Ng JC, Matlaga BR, Lifshitz DA, Lingeman JE (2006) Use of lower pole nephrostomy drainage following endorenal surgery through an upper pole access. J Urol 175:580–584; discussion 584
94. Lingeman JE, Newmark JR, Wong MYC (1995) Classification and management of staghorn calculi. In: Smith AD (ed) Controversies in endourology. Saunders, Philadelphia, pp 136–144
95. Winfield HN, Weyman P, Clayman RV (1986) Percutaneous nephrostolithotomy: complications of premature nephrostomy tube removal. J Urol 136:77–79
96. Kim SC, Tinmouth WW, Kuo RL, Paterson RF, Lingeman JE (2005) Using and choosing a nephrostomy tube after percutaneous nephrolithotomy for large or complex stone disease: a treatment strategy. J Endourol 19:348–352
97. Carson CC III, Danneberger JE, Weinerth JL (1988) Percutaneous lithotripsy in morbid obesity. J Urol 139:243–245

98. Gallucci M, Fortunato P, Schettini M, Vincenzoni A (1998) Management of hemorrhage after percutaneous renal surgery. J Endourol 12:509–512
99. Lee WJ, Smith AD, Cubelli V, Badlani GH, Lewin B, Vernace F, Cantos E (1987) Complications of percutaneous nephrolithotomy. AJR Am J Roentgenol 148: 177–180
100. Carson CC (1986) Complications of percutaneous stone extraction: prevention and treatment. Semin Urol 4:161–169
101. Kaye KW, Clayman RV (1986) Tamponade nephrostomy catheter for percutaneous nephrostolithotomy. Urology 27:441–445
102. Irby PB, Schwartz BF, Stoller ML (1999) Percutaneous access techniques in renal surgery. Tech Urol 5:29–39
103. Picus D, Weyman PJ, Clayman RV, McClennan BL (1986) Intercostal-space nephrostomy for percutaneous stone removal. AJR Am J Roentgenol 147:393–397
104. Young AT, Hulbert JC, Cardella JF, Hunter DW, Castaneda-Zuniga WR, Reddy P, Amplatz K (1985) Percutaneous nephrostolithotomy: application to staghorn calculi. AJR Am J Roentgenol 145:1265–1269
105. Gerspach JM, Bellman GC, Stoller ML, Fugelso P (1997) Conservative management of colon injury following percutaneous renal surgery. Urology 49:831–836
106. Wolf JS Jr (1998) Management of intraoperatively diagnosed colonic injury during percutaneous nephrostolithotomy. Tech Urol 4:160–164

Percutaneous Access for Urological Disease

Tae-Kon Hwang and Seong-Il Seo

Summary. With the development of techniques for percutaneous access and equipment to disintegrate calculi, percutaneous nephrolithotomy (PNL) is currently used by many urologists, being the procedure of choice for removal of large renal calculi and replacing open surgery for the most part. Although it is more invasive than shock wave lithotripsy (SWL) and retrograde ureteroscopic lithotripsy, PNL has been successfully performed with high efficiency and low morbidity in difficult renal anatomies and patient conditions. These advantages of minimal invasiveness were rapidly perceived and applied to the management of ureteropelvic junction (UPJ) obstruction, calyceal diverticulum, and infundibular stenosis. The basic principle of endopyelotomy is a full-thickness incision of a narrow segment followed by prolonged stenting and drainage to allow regeneration of an adequate caliber ureter. Currently, percutaneous endopyelotomy has become the initial treatment of choice for most adults with UPJ obstruction. The preferred technique continues to be debated for a calyceal diverticulum. Excellent long-term success has been reported with percutaneous, ureteroscopic, and laparoscopic techniques. Each approach is based on the location and size of the diverticulum. So far, percutaneous ablation of the calyceal diverticulum is the best-established minimally invasive technique. Infundibular stenosis is an acquired condition usually associated with inflammation or stones. Reported series of percutaneously treated infundibular stenosis are few. In contrast to the calyceal diverticulum, the infundibular stenosis is a more difficult entity to treat, with only a 50%–76% success rate by percutaneous techniques.

Keywords. Percutaneous nephrostomy, Urinary calculi, Urinary obstruction, Calyceal diverticulum, Infundibular stenosis

---

Department of Urology, Kangnam St. Mary's Hospital, College of Medicine, The Catholic University of Korea, 505 Banpo-Dong, Seocho-Ku, Seoul, Korea

Introduction

Percutaneous renal puncture was first described in 1955 by Goodwin and Casey, who placed a trocar directly into the collecting system [1]. Later, the Seldinger method of nephrostomy placement was adopted, a fine guidewire being placed into the collecting system through the core of the needle that had performed the initial renal puncture. A coaxial catheter could then be placed over this initial guidewire and the renal pelvis drained even if it was not dilated. The addition of a preformed pigtail to these nephrostomy catheters ensured that they could not be easily displaced from the pelvis. In 1976, Fernstrom and Johansson described a method of dilating such an antegrade nephrostomy, utilizing graded plastic dilators introduced coaxially down the tract [2]. After a number of days, the tract was used for intrarenal manipulation utilizing Dormia baskets and other grasping tools. Percutaneous nephrostomy (PCN) was, and will continue to be, the cornerstone of every percutaneous procedure of the upper urinary tract.

Anatomy for Percutaneous Surgery

The topographical position of the kidney depends on its embryological development. Classically, the pelvis lies opposite the lower border of the first lumbar vertebra on the right and slightly higher on the left.

Among numerous factors, enveloping fascia, vascular connections, and intraabdominal pressure are probably the most important factors holding the kidney in position. Within the renal fascia, the surrounding fat allows a considerable amount of renal movement despite its apparent density, although the kidney is tethered by the short vessels rigidly anchored to their midline connections. Abdominal tone provided by the anterior abdominal wall may be the most important factor for renal stability. The position of the liver limits the cranial movement of the kidney on the right side. The close application of the pancreas to the anterior aspect of the left kidney is said to be especially important in limiting the movement of the kidney. The suprarenal attachments and ligaments to the liver and duodenum probably do not play an important role in holding renal position [3].

Movement of the diaphragm in respiration causes the kidney to move downward in inspiration and upward in expiration. The amplitude of movement is quite variable but it is usually within 3–5 cm. Such movement is more pronounced in women than in men and the right than the left kidney. When the patient is in the prone position with bolsters under the chest and upper abdomen, the kidneys are further displaced in a cephalad direction.

Renal Vascular Anatomy

The main renal artery divides into two main branches, the anterior and the posterior. The anterior division further subdivides into the four anterior segmental

arteries, which supply the anterior and polar areas of the kidney. The posterior segmental artery supplies the rest of the posterior area of the kidney. In more than 50% of kidneys, the posterior segmental artery is located in the middle or upper half of the posterior renal surface, and it may be damaged with an excessively medial needle puncture of an upper calyx. The segmental arteries divide into the interlobar arteries after crossing the renal sinus and become the arcuate arteries at the corticomedullary junction. The interlobular arteries branch off the arcuate arteries at right angles. The Brödel line delineates an avascular plane between the anterior and the posterior blood supplies. By taking a posterolateral transparenchymal path, the needle traverses the area of the Brödel line, and damage to major blood vessels could be avoided. A direct posterior puncture that is too medial risks injury to the posterior segmental artery, which is the artery most commonly injured in endourological procedures. A needle directed end on to a posterior calyx passes transparenchymally, and the chance of significant bleeding is minimized.

Percutaneous Nephrolithotomy

Although Rupel and Brown first removed a renal calculus through an operatively established nephrostomy tract in 1941 [4], the first percutaneous nephrolithotomy (PNL) via a nephrostomy tract created for the sole purpose of stone removal was performed in 1976 by Fernstrom and Johansson [2]. The introduction of this technique was further refined over the years. As operative technique and endoscopic equipment improved, PNL was performed with increasing efficacy and decreasing complications [5]. PNL has replaced open techniques in removing complex urinary calculi in most institutions.

The practice of PNL has changed over time and is continuing to evolve. Differing aspects of the procedure such as the ideal dilating method, the type of nephrostomy tube used, and the technique of treating calyceal diverticula have been debated. Even the need for a nephrostomy tube has been questioned.

Technique

An open-ended 5–6 Fr ipsilateral ureteral catheter or occlusion balloon catheter is passed, allowing the injection of contrast material to opacify and distend the collecting system. Once the ureteral catheter is inserted, the patient is placed in a prone position on a C-arm compatible table. The patient also can be placed in a lateral position and punctured under the guidance of ultrasonography. Bolsters are placed to the patient and a sterile drape is applied to the C-arm, enabling its manipulation by the surgeon.

The radiation source is positioned under the patient to minimize scattered radiation exposure to the surgeon. The emission tube is shielded by an additional layer of materials, and the scattered radiation to the operator is also reduced.

It is very important to select the percutaneous tract. The preferred approach is by way of a posterior calyx, because major vascular structures surrounding the renal pelvis can be avoided and the transparenchymal route stabilizes the catheter in an appropriate position. Approach through a short tract perpendicular to the convexity of kidney causes minimal anatomical or functional damage if the tract is dilated using a graded coaxial dilator. Puncture either too medial or too lateral will enter the renal pelvis directly. Direct puncture of the renal pelvis should be avoided because it carries a significant risk of injury to the posterior branch of the renal artery. Also, the tract created from such a puncture provides no stability for the nephrostomy tube because it lacks parenchymal support. A computerized tomogram taken in a prone position could be helpful in a patient with anatomical abnormalities such as a horseshoe kidney.

After opacification of the collecting system by injection of contrast material through the ureteral catheter, puncture is performed in midinspiration using a sheathed needle. The puncture tract should be straight to the target calyx to prevent a false tract during dilation. The position of the needle tip should be checked intermittently by rotating the C-arm. When the needle appears to be in a calyx, the stylet is removed while the sheath is slightly advanced to its position to the calyx, and the correct needle position is verified by aspiration of urine. At times, aspiration of urine might be delayed because of increased mucosity from the injected contrast medium. Then, a guidewire is inserted and advanced with the sheath held immobile by the other hand. The guidewire is advanced until resistance is encountered, and its position is checked by the C-arm at this time. The puncture could be performed under the guidance of ultrasonography. It is easy to make a nephrostomy tract, but dilation of the tract should be performed under fluoroscopy.

If one has punctured a calyx whose neck is filled by a stone, it may be difficult to pass the guidewire into the pelvis. However, there is a narrow space between stone and calyx in most of these situations, so one can try to manipulate the guidewire (sometimes a J-tipped guidewire) beyond the stone using an in-and-out movement of the puncture needle or a preformed catheter such as a "cobra" catheter. It is not recommended to dilate over the guidewire when the stiff portion of the guidewire does not pass to the calyx or pelvis, because it is very possible to "flip" the wire out of the system during dilation, thereby losing the tract.

After the guidewire is well positioned, the needle is removed and a 1-cm incision is made at the wire site. The tract is dilated over the guidewire up to 26–30 F. Efficient dilation is dependent on the maintenance of the same track throughout the procedure, so that each dilator is following the same path into the kidney. The wire must be stiff enough to support the dilatation. Ideally, it reaches down the ureter into the bladder to avoid dislodgment during the use of the fascial dilators. When the placement of the guidewire down the ureter is not feasible, positioning it in a calyx that is distant from the initial nephrostomy tract prevents its dislodgment during dilatation. Some urologists advocate the use of a second, safety guidewire in addition to the initial working guidewire.

This safety wire is inserted adjacent to the working wire, its goal being to maintain access to the nephrostomy tract if the working wire is kinked or displaced. This safety wire is retained until the entire surgical procedure is finished.

A variety of techniques can be utilized to perform the tract dilatation. The most commonly used dilation techniques are the Amplatz dilator set or the 10-cm, 30 Fr dilating balloon catheter and sheath set. Balloon dilation catheters of 9 Fr size can dilate a nephrostomy tract to a diameter of 30 Fr under pressure up to 10–12 atm in a one-step procedure. This dilation may prove difficult or impossible if perirenal scar tissue from a previous surgery prevents complete expansion of the balloon over its entire length. Sequential plastic dilators allow stepwise dilation of the tract under fluoroscopic control; however, on withdrawal for insertion of the next larger dilator, compression of the tract is lost intermittently and bleeding occurs into the collecting system, sometimes hindering subsequent endoscopy. Coaxial metal dilators (each dilator slides over the next smaller one) allow stepwise tract dilation even in the presence of severe scarring with continuous nephrostomy tract compression for improved hemostasis. With any dilation technique, the last step is insertion of a working sheath, which may be either the 24–26 Fr metal working sheath of the nephroscope or a larger plastic sheath. A 28–30 Fr plastic working sheath is preferable to a metal nephroscope sheath in all cases in which extensive, prolonged instrumentation is anticipated (e.g., staghorn stones). Larger plastic sheaths not only provide better irrigation with lower intrapelvic pressures than do continuous-flow nephroscope sheaths but also allow easier extraction of large stone fragments. The stone can be fragmented with intracorporeal lithotriptors and removed with various kind of forceps and baskets.

Percutaneous drainage of the pelvicalyceal system is routine after most endourological approaches to the upper urinary tract. Some authors argue that there is no need for a drainage tube after certain percutaneous procedures [6]. Nevertheless, there seems to be a concurrence in the literature regarding the need for postoperative drainage with a nephrostomy tube after percutaneous procedures. The desired function of the nephrostomy tube greatly influences the choice of which drainage method to adopt. The main function of a nephrostomy tube is the drainage of urine and possibly the tamponade of bleeding originating from the structures acutely expanded during dilatation.

Complications

Bleeding is the most significant complication of PNL, with transfusion rates varying from less than 1% to 10%. Bleeding from an arteriovenous fistula or pseudoaneurysm requiring emergency embolization is seen in less than 0.5% of patients (Fig. 1) [7]. Most bleeding is venous in nature, and placement of a nephrostomy tube is usually adequate to control the bleeding. Clamping the nephrostomy tube for 10 min is helpful in tamponading any persistent bleeding [8]. PNL can lead to some absorption of irrigation fluid; therefore, the use of physiological irrigating solutions is essential. The amount of absorbed fluid

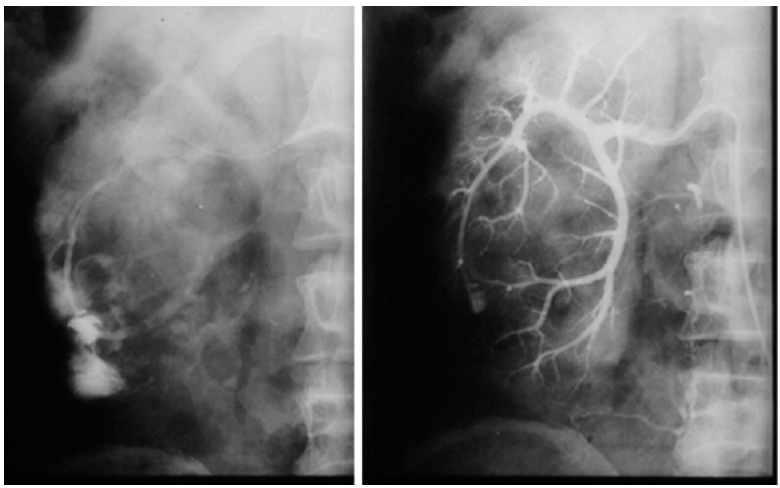


FIG. 1. Arteriovenous fistula from percutaneous nephrolithotomy (PNL). **a** Angiographic appearance. **b** After successful selective arterial embolization

depends mostly on the irrigant pressure and the length of procedure. Intraoperative administration of diuretics (e.g., mannitol 12.5 g) is advisable and also has proved effective in preventing intrarenal reflux [9,10].

When a supracostal puncture is performed, extravasation of irrigant into the pleural cavity may occur. The use of a working sheath tends to minimize extravasation into the pleura because intrarenal pressure is low. The chest should be examined at the end of PNL procedures in which a supracostal puncture is used. When a supracostal puncture is performed, the risk of pneumothorax or pleural effusion requiring drainage is 4%–12% [9,11]. Punctures above the 11th rib resulted in a tremendously higher intrathoracic complication rate (34.6%) compared to the supra-12th rib access (1.4%) [12]. These facts corroborate the strategy of avoiding this high approach as far as possible. If the clinical findings suggest either of these complications, placement of a chest tube is mandatory. Immediate aspiration is performed, and the tube is removed within 24 h. If the hemothorax is extensive, a large chest tube is advisable. Pardalidis and Smith suggested that in the case of nephrostomy access between the 11th and 12th rib, approximately 10% of patients present with fluid accumulation within the pleural space [13].

Colonic injury is an unusual complication often diagnosed on postoperative nephrostogram (Fig. 2). It tends to occur in severely lean or reterorenal colon patients, so one should be careful not to injure the colon during puncture and tract dilation in these patients. Typically, the injury is retroperitoneal; thus, signs and symptoms of peritonitis are infrequent. If the perforation is extraperitoneal, management may be expectant, with placement of a ureteral catheter or double-J stent to decompress the collecting system and withdrawal of the nephrostomy

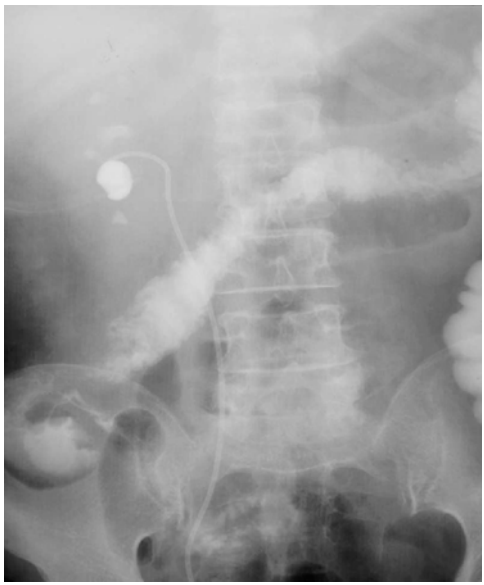


Fig. 2. Ascending colon injury of PNL performed in patient with retrorenal colon. Extravasated contrast medium is seen in transverse and descending colon

tube from an intrarenal position to an intracolonic position to serve as a colostomy tube. The colostomy tube is left in place for a minimum of 7 days and is removed after a nephrostogram or a retrograde pyelogram showing no communication between the colon and the kidney [14,15].

Effects on Renal Function

The effect of PNL on short-term differential renal function was examined with nuclear renography by Chatham et al. [16]. 99m-Tc-Mercaptoacetyl triglycine (MAG3) nuclear scans were performed preoperatively and postoperatively in 19 PNL patients. Nuclear renography at a median of 22 days revealed stable differential function in the treated kidney (37% preoperatively, 39% postoperatively). Renal function was previously assessed in anatrophic nephrolithotomy patients with 99m-Tc-dimercapto-succinic acid, and a decrease from 42.0% preoperatively to 37.6% postoperatively was noted [17]. Liou and Streem assessed long-term renal function in patients with a solitary kidney after shockwave lithotripsy (SWL), PNL, or combined PNL/SWL therapy [18]. Using sCr (serum creatinine) and calculated glomerular filtration rate (GFR), follow-up renal function revealed no statistically significant change for all chosen therapeutic modalities. The sCr (serum creatinine) and calculated GFR were used to evaluate follow-up changes in renal function. Although no significant differences in postoperative renal function was found among the different therapy options, the PNL and combined therapy group had an average postprocedural increase in Cr by 0.5 mg/dl, as compared to a 0.1 mg/dl decrease in the SWL-only group.

Although PNL was not introduced until the 1980s, the role of PNL is firmly entrenched. Kerbl et al. noted that the number of percutaneous stone procedures had steadily increased from 2068 cases to 2678 over the time period from 1988 to 2000 [19]. Not surprisingly, the number of percutaneous procedures performed for stone burden greater than 2 cm rose by 123%. These data confirm the recommendation of the NIH consensus conference for primary percutaneous therapy for larger stone burdens. PNL continues to play an important role in treating lower pole calculi. Although many lower pole stones are treated initially with SWL or even ureteroscopy, the Lower Pole Study Group revealed a clear advantage for PNL in stones larger than 1.0 cm [20]. The role of PNL as primary therapy for lower pole calculi may accordingly increase. Although PNL is safe and effective, future studies may further refine the technique of PNL, help to minimize adverse effects, and thereby help to deliver better patient care.

Percutaneous Endopyelotomy

Endourological management of ureteropelvic junction (UPJ) obstruction was introduced by Whitfield and Wickham in 1983 as a "percutaneous pyelolysis" and popularized shortly thereafter by Smith et al., who coined the term "endopyelotomy" [21]. Despite various nuances in the name of the procedure and in the technique performed, the basic concept is constant and involves a full-thickness incision through the obstructing proximal ureter from the ureteral lumen out to the peripelvic and periureteral fat. The incision is stented and left to heal, based on the early work of Davis, who used an "intubated ureterotomy" in the course of an open operative procedure for UPJ obstruction [22]. Contraindications to a percutaneous endopyelotomy are similar to the contraindications to any endourological approach and include a long segment (>2 cm) of obstruction, active infection, or untreated coagulopathy. The impact of crossing vessels is controversial [23–26].

Compared with the retrograde techniques of endopyelotomy (incision with a cold knife, Acucise catheter, Greenwald electrode, or laser), the antegrade technique offers the advantage of an incision under direct vision. The incision must be extended into the perirenal fat and into healthy ureter. Although several clinicians suggest that the incision should always be made laterally, in fact, the ureter may be inserting into the renal pelvis on the anterior or posterior wall. In such cases, the incision should instead marsupialize the proximal ureter into the renal pelvis such that an anterior or posterior incision may be required [22]. Percutaneous endopyeloplasty, horizontal percutaneous suturing of a conventional longitudinal endopyelotomy incision, was recently developed with good clinical results. The technical simplicity and shorter operative time are advantages compared with laparoscopic pyeloplasty [27,28].

Once the incision is complete, stenting is accomplished. A 14/7 Fr endopyelotomy stent can be used, passed in an antegrade fashion with the large-diameter end of the stent positioned across the UPJ. There was a trend for better results

Table 1. Contemporary results and follow-up of percutaneous endopyelotomy for primary and secondary UPJ obstruction

Authors	Patients (*n*)	Method of incision	Year published	Success rate (%)	Mean F/U (months)
Knudsen et al. [31]	80 (61/19)	Cold knife	2004	67 (65/74)	55
Shalhav et al. [32]	63 (40/23)	Hot knife	1998	85 (89/77)	15
Danuser et al. [23]	80 (80/0)	Cold knife	1998	81 (81/NA)	26
Gupta et al. [24]	401 (235/166)	Cold knife	1997	85 (82/89)	51

Data presented as overall value with data for primary/secondary UPJ obstruction in parentheses
UPJ, ureteropelvic junction; NA, not available; F/U, follow-up

with the use of 14/7 Fr stent in patients with secondary stricture, although the difference in success rates between 6 Fr and 14/7 Fr stent was not significant statistically [29].

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 [22,30]. Currently, success rates approaching 85%–90% are reported at experienced centers (Table 1). It is noted there is little difference in outcome between primary and secondary UPJ obstruction but no difference in methods of incision.

Laparoscopic pyeloplasty has been recently reported, with success rates in excess of 95% [33]. Moreover, laparoscopy can be applied in patients with severe hydronephrosis requiring pelvic reduction and in patients with crossing vessels that may require ureteral–vascular transposition. However, the steep learning curve inherent to laparoscopic intracorporeal suturing may limit laparoscopic pyeloplasty to select centers proficient in reconstructive laparoscopy.

Calyceal Diverticulum

A calyceal diverticulum is a smooth-walled, nonsecretory cavity in the renal parenchyma that is lined with transitional cell epithelium. It receives urine by passive retrograde filling from the adjacent collecting system, usually through a narrow forniceal channel or infundibulum. Calyceal diverticula are believed to be congenital in origin, likely from failed degeneration of small ureteral buds. They are typically less than 1 cm in diameter, with no predilection for sex or kidney side. Uncomplicated, asymptomatic calyceal diverticula may be managed conservatively without routine follow-up imaging. However, because of their cystic, urine-containing nature, they are frequently associated with stone formation and infection and become symptomatic in up to one-third of patients [34].

Treatment of calyceal diverticulum has evolved from open surgical excision to SWL to percutaneous and ureteroscopic ablative technique. The preferred

technique continues to be debated. Percutaneous management of the calyceal diverticulum is challenging because the cavity is often small, making localization for direct access is difficult. Cystoscopy and ureteral balloon catheter placement is performed in the renal pelvis. A balloon catheter is helpful to opacify the diverticulum with injection of contrast through the ureteral catheter to guide the percutaneous access, especially when the neck of diverticulum is narrow. Direct puncture of the diverticulum is then made under fluoroscopic guidance, and a guidewire is coiled within it. Ideally, a polytetrafluoroethylene-coated or hydrophilic safety wire is placed through the diverticular neck into the renal pelvis, but it may be coiled in the diverticular cavity if the neck cannot be cannulated.

Canales and Monga advocate dilation of the tract into the diverticulum, although not through the diverticular neck as the goal of the procedure is to ablate the cavity and the connection to the collecting system [34]. Dilation of the diverticular infundibulum could be viewed as counterproductive. Auge et al. described an alternative approach if guidewire passage into the main collecting system was unsuccessful after several attempts [35]. Once inside the cavity, they advance an 18-gauge percutaneous access needle directly through the inner or medial diverticulum wall into the renal colleting system and subsequently dilate to 30 Fr with a dilating balloon, creating a large "neoinfundibulotomy" tract. This maneuver prevents the safety wire from being inadvertently withdrawn. With this technique, the connection between the diverticulum and the collecting system is enlarged rather than ablated. Lining urothelium of the calyceal diverticulum was usually fulgurated with electrocautery or holmium laser if greater than 4 cm in diameter. If electrocautery is utilized, the safety wire should be insulated with an open-ended catheter to prevent inadvertent transmission of current down the ureter. The nephrostomy catheter was placed through the calyceal diverticulum and neoinfundibulotomy and secured in the renal pelvis. There are controversies about the duration of a nephrostomy catheter, but it tends to shorter because there is no difference in success rates according to nephrostomy catheter duration [34–36].

The results of percutaneous management of calyceal diverticula from the literature are presented in Table 2. In the cases reviewed, stone-free and

Table 2. Results of percutaneous management of calyceal diverticular calculi from the literature

Authors	Patients (*n*)	Year published	Stone free (%)	Symptom free (%)	Diverticular obliteration (%)	Major complication (%)
Auge et al. [35]	22	2002	78	86	61	9.1
Landry et al. [36]	31	2002	84	88	68	0
Monga et al. [37]	14	2000	100	NA	100	7.1
Shalhav et al. [38]	26	1998	93	85	76	7.7

Data presented as overall value
NA, not available

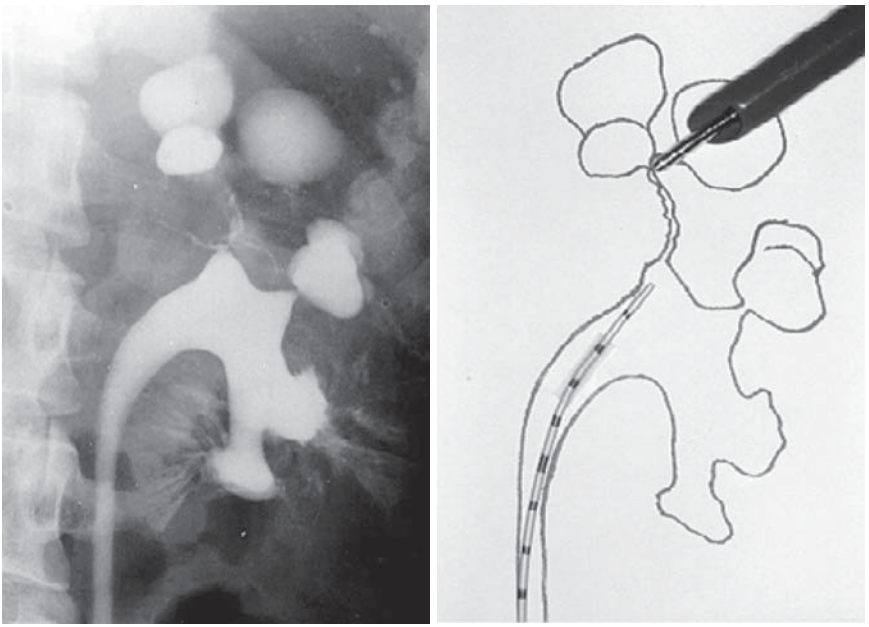
symptom-free rates for percutaneous management are consistently 80% or greater. Minor complications during percutaneous ablation and calculus removal include hemorrhage, pneumothorax, persistent urinary extravasation, and mild extravasation of irrigant. Major complications include renal pelvis perforation with urinoma formation, pneumothorax or hemothorax requiring tube thoracostomy, and massive hemorrhage requiring balloon tamponade. As Table 2 demonstrates, major complications are relatively uncommon.

Limitations exist primarily for an anteriorly located diverticulum. In this situation, if the diverticulum is in a superior anterior calyx, a ureteroscopic approach is recommended whereas if the diverticulum is in a middle or lower anterior calyx, a laparoscopic approach is recommended [34]. Ureteroscopic approach may be an appropriate initial treatment option for patients with small stone burden (<1.5 cm) or patients with comorbidities who are poor candidates for PNL.

Infundibular Stenosis

Infundibular stenosis and hydrocalyx are usually an acquired condition associated with inflammation, renal tuberculosis, obstructive calculus, or prior renal surgery [9,39]. The hydrocalyx should be differentiated from a calyceal diverticulum because the treatments are different. At times, this distinction can be made only by a nephroscopy because the presence (hydrocalyx) or absence (calyceal diverticulum) of a renal papilla is diagnostic. The infundibular narrowing can be resolved in several ways. The least difficult approach is to dilate the infundibulum to 8 mm with an 8-mm ureteral dilating balloon passed over the working guidewire. Alternatively, the infundibulum can be cut under endoscopic control with a cold knife through a direct vision ureterotome. When the guidewire cannot be passed through the stricture, a round-tipped rigid ureteroscope could be pushed in an antegrade fashion to traverse the stricture with injection of indigo carmine through the retrograde ureteral catheter (Fig. 3). According to anatomical studies by Sampaio, the incision should be made along the less-vascular superior and inferior aspects of the middle calyceal infundibulum or the medial and lateral aspects of the upper calyceal infundibulum [40].

Reported series of endourologically treated infundibular stenosis are few. Lang reported a 50% success rate in 6 patients with infundibular stenosis and caliceal diverticuli containing stones [41]. Hwang and Park reported an 80% success rate in 10 patients with tuberculous infundibular strictures who had undergone a cold knife incision; follow-up was greater than 1 year [39]. Hwang et al. reported long-term (more than 2 years follow-up) results with a success rate of 76% in 21 patients and better results in strictures with stone than in strictures with tuberculosis [42]. It appears that in contrast to the calyceal diverticulum, in which a successful outcome is obtainable in nearly 90%, the infundibular stenosis is a more difficult entity to treat endourologically, with only a 50%–76% success rate (Table 3).



a **b**

FIG. 3. Tuberculous infundibular stenosis. **a** Retrograde pyelography shows dilated upper calyces and severely narrowed infundibular neck. **b** Schematic diagram of percutaneous endoinfundibulotomy. When the guidewire could not be passed through the stricture, a round-tipped rigid ureteroscope could be pushed in an antegrade fashion to traverse the stricture with injection of indigo carmine through the retrograde ureteral catheter

TABLE 3. Results of percutaneous endoscopic therapy for infundibular stenosis

Author	Patients (*n*)	Stent duration (weeks)	Success rate (%)	Follow-up (months)
Schneider et al. [43]	9	3–6	67	7–45
Lang [41]	6	4–8	50	24–48
Hwang et al. [42]	21	6–8	76	24–90
Overall	36	3–8	68	7–90

References

1. Payne SR, Webb DR (1988) Imaging techniques and antegrade access to the collecting system. In: Percutaneous renal surgery. Churchill Livingstone, New York, pp 23–37
2. Fernstrom I, Johansson B (1976) Percutaneous pyelolithotomy: a new extraction technique. Scand J Urol Nephrol 10:257–259
3. Payne SR, Webb DR (1988) Anatomy for percutaneous renal surgery. In: Percutaneous renal surgery. Churchill Livingstone, New York, pp 3–14

4. Rupel E, Brown R (1941) Nephroscopy with removal of stone following nephrostomy for obstructive calculous anuria. J Urol 46:177–182
5. Lingeman JE, Newmark JR, Wong MYC (1995) Classification and management of staghorn calculi. In: Smith AD (ed) Controversies in endourology. Saunders, Philadelphia, pp 136–144
6. Goh M, Wolf JS Jr (1999) Almost totally tubeless percutaneous nephrolithotomy: further evolution of the technique. J Endourol 13:177–180
7. Kessaris DN, Bellman GC, Pardalidis NP, Smith AD (1995) Management of hemorrhage after percutaneous renal surgery. J Urol 153:604–608
8. Carson CC (1986) Complications of percutaneous stone extraction: prevention and treatment. Semin Urol 4:161–169
9. McDougall EM, Liatsikos EN, Dinlenc CZ, Smith AD (2002) Percutaneous approaches to the upper urinary tract. In: Walsh PC, Retik AB, Vaughan ED Jr, Wein AJ (eds) Campbell's urology. Saunders, Philadelphia, pp 3320–3360
10. Thuroff JW, Gilfrich CP (2004) Percutaneous endourology & ureteroscopy. In: Tanago EA, McAninch JW (eds) Smith's general urology. McGraw-Hill, New York, pp 121–139
11. Golijanin D, Katz R, Verstandig A, Sasson T, Landau EH, Meretyk S (1998) The supracostal percutaneous nephrostomy for treatment of staghorn and complex kidney stones. J Endourol 12:403–405
12. Munver R, Delvechio F, Newman G, Preminger G (2001) Critical analyses of supracostal access for percutaneous renal surgery. J Urol 166:1242–1246
13. Pardalidis N, Smith AD (1995) Complications of stone treatment. In: Smith AD (ed) Controversies in endourology. Saunders, Philadelphia, pp 179–185
14. Wolf JS (1998) Management of intra-operatively diagnosed colonic injury during percutaneous nephrostolithotomy. Tech Urol 4:160–164
15. Lingeman JE, Lifshitz DA, Evan AP (2002) Surgical management of urinary lithiasis. In: Walsh PC, Retik AB, Vaughan ED Jr, Wein AJ (eds) Campbell's urology. Saunders, Philadelphia, pp 3361–3451
16. Chatham JR, Dykes TE, Kennon WG, Schwartz BF (2002) Effect of percutaneous nephrolithotomy on differential renal function as measured by mercaptoacetyl triglycine nuclear renography. Urology 59:522–525
17. Morey AF, Nitahara KS, McAninch JW (1999) Modified anatrophic nephrolithotomy for management of staghorn calculi: is renal function preserved? J Urol 162:670–673
18. Liou LS, Streem SB (2001) Long-term renal functional effects of shock wave lithotripsy, percutaneous nephrolithotomy and combination therapy: a comparative study of patients with solitary kidney. J Urol 166:33–37
19. Kerbl K, Rehman J, Landman J, Lee D, Sundaram C, Clayman RV (2002) Current management of urolithiasis: progress or regress? J Endourol 16:281–288
20. Albara DM, Assimos DG, Clayman RV, Denstedt JD, Grasso M, Gutierrez-Aceves J, Kahn RI, Leveillee RJ, Lingeman JE, Macaluso JN Jr, Munch LC, Nakada SY, Newman RC, Pearle MS, Preminger GM, Teichman J, Woods JR (2001) Lower pole I: a prospective randomized trial of extracorporeal shock wave lithotripsy and percutaneous nephrostolithotomy for lower pole nephrolithiasis: initial results. J Urol 167:2072–2080
21. Badlani G, Eshghi M, Smith AD (1986) Percutaneous surgery for ureteropelvic junction obstruction (endopyelotomy): technique and early results. J Urol 135:26–28
22. Streem SB (2000) Minimal invasive surgery of the kidney: a problem oriented approach. Urol Clin N Am 27:685–693

23. Danuser H, Ackermann DK, Bohlen D, Studer UE (1998) Endopyelotomy for primary ureteropelvic junction obstruction: risk factors determine the success rate. J Urol 159:56–61
24. Gupta M, Tuncay OL, Smith AD (1997) Open surgical exploration after failed endopyelotomy: a 12-year perspective. J Urol 157:1613–1618
25. Sampaio FJB (1998) Vascular anatomy at the ureteropelvic junction. Urol Clin N Am 25:251–258
26. Van Cangh PJ, Wilmart JF, Opsomer RJ, Abi-Aad A, Wese FX, Lorge F (1994) Long-term results and late recurrence after endoureteropyelotomy: a critical analysis of prognostic factors. J Urol 151:934–937
27. Gill IS, Desai MM, Kaouk JH, Wani K, Desai MR (2002) Percutaneous endopyeloplasty: description of new technique. J Urol 168:2097–2102
28. Desai MM, Desai MR, Gill IS (2004) Endopyeloplasty versus endopyelotomy versus laparoscopic pyeloplasty for primary ureteropelvic junction. Urology 64:16–21
29. Hwang TK, Yoon JY, Ahn JH, Park YH (1996) Percutaneous endoscopic management of upper ureteral stricture: size of stent. J Urol 155:882–884
30. Brooks JD, Kavoussi LR, Preminger GM, Schuessler WW, Moore RG (1995) Comparison of open and endourologic approaches to the obstructed ureteropelvic junction. Urology 46:791–795
31. Knudsen BE, Cook AJ, Watterson CD, Beiko DT, Nott L, Razvi H, Denstedt JD (2004) Percutaneous antegrade endopyelotomy: long-term results from one institution. Urology 63:230–234
32. Shalhav AL, Giusti G, Elbahnasy AM, Hoenig DM, McDougall EM, Smith DS, Maxwell KL, Clayman RV (1998) Adult endopyelotomy: impact of etiology and antegrade versus retrograde approach on outcome. J Urol 160:685–689
33. Ost MC, Kaye JD, Guttman MJ, Lee BR, Smith AD (2005) Laparoscopic pyeloplasty versus antegrade endopyelotomy: comparison in 100 patients and a new algorithm for the minimally invasive treatment of ureteropelvic junction obstruction. Urology 66: 47–51
34. Canales B, Monga M (2003) Surgical management of the calyceal diverticulum. Curr Opin Urol 13:255–260
35. Auge BK, Munver R, Kourambas J, Newman GE, Wu NZ, Preminger GM (2002) Neoinfundibulotomy for the management of symptomatic caliceal diverticula. J Urol 167:1616–1620
36. Landry JL, Colombel M, Rouviere O, Lezrek M, Gelet A, Dubernard JM, Martin X (2002) Long term results of percutaneous treatment of caliceal diverticular calculi. Eur Urol 41:474–477
37. Monga M, Smith R, Ferral H, Thomas R (2000) Percutaneous ablation of caliceal diverticulum: long-term followup. J Urol 163:28–32
38. Shalhav AL, Soble JJ, Nakada SY, Wolf JS Jr, McClennan BL, Clayman RV (1998) Long-term outcome of caliceal diverticula following percutaneous endosurgical management. J Urol 160:1635–1639
39. Hwang T, Park Y (1994) Endoscopic infundibulotomy in tuberculous renal infundibular stricture. J Urol 151:852–854
40. Sampaio FJB (1996) Surgical anatomy of the kidney. In: Smith AD, Badlani GH, Bagley DH, Clayman RV, Jordan GH, Kavoussi LR, Lingerman JE, Preminger GM, Segura JW (eds) Smith's textbook of endourology. Quality Medical, St. Louis, pp 153–184

41. Lang EK (1991) Percutaneous infundibuloplasty: management of calyceal diverticula and infundibular stenosis. Radiology 181:871–877
42. Hwang T, Seo S, Kim J, Yoon J, Park Y, Yoon M (1999) Long-term results of percutaneous endourologic management of renal infundibular stricture. J Endourol 13: 495–498
43. Schneider AW, Conrad S, Busch R, Otto U (1991) The cold-knife technique for endourological management of stenoses in the upper urinary tract. J Urol 146: 961–965

Minimally Invasive Percutaneous Nephrolithotomy (MPCNL) According to the Chinese Method

Shu Keung Li, Dominic Tai, Lysander Chau, and Berry Fung

Summary. Standard percutaneous nephrolithotomy (PCNL) with a 28–30 Fr tract size is an established method for renal stone removal. PCNL using a small tract (12–20 Fr) has been reported but was considered applicable in specific conditions only. We review the experience of small-tract PCNL in the literature with particular reference to the experience in China by the Guangzhou group. The technique according to the Chinese method is described. We then report our initial experience of minimally invasive PCNL (MPCNL) using the same technique and discuss how MPCNL should have a greater role in upper tract stone management.

Keywords. Kidney, Renal stone, Ureter, Percutaneous nephrolithotomy, Minimally invasive

Introduction

Percutaneous nephrolithotomy (PCNL) is an important treatment option for upper tract renal stone. It was first described by Fernstrom and Johansson in 1976 in removal of renal calculi via a dilated nephrostomy tract under radiological control [1]. The technique was further improved by early workers such as Alken, Marberger, Segura, Wickham, and Smith and is now a standardized and routinely performed procedure [2–6]. PCNL is indicated for a large stone load greater than 2.5 cm, lower calyx stone, and stone in the calyceal diverticulum where shock wave lithotripsy (SWL) or the ureteroscopic approach do not achieve good stone clearance [7]. PCNL-based management is also the recommended treatment for staghorn stones [8].

However, PCNL can still be associated with significant morbidity, such as sepsis, bleeding, injury to surrounding viscera, or even loss of the kidney unit [9].

Division of Urology, Department of Surgery, Pamela Youde Nethersole Eastern Hospital, Hong Kong, China

Also, in real-life practice, the usual 26–30 Fr tract size of PCNL may be too large in the pediatric system and in some adult undilated systems, and this has brought the need of using a smaller-size tract and also the idea that a small tract may further enhance the minimal invasiveness of the procedure [10–13].

History of Minimally Invasive Percutaneous Nephrolithotomy (MPCNL)

PCNL using a small tract for stone management was first reported in 1997 for use in children by Helal et al. [14]. They described the use of a 15 Fr Hickman peel-away sheath as the working sheath in the removal of three stones of 5–7 mm in a 2-year-old child weighting 10 kg. A 10 Fr pediatric cystoscopy and grasping forcep was used to remove the stone with success.

Several small case series were then reported and various terms were used to describe the procedure. Jackman et al. used a 7 Fr pediatric cystoscope and a 9.8 Fr flexible ureteroscope through an 11 Fr tract in 11 children and called this the mini-perc [11]. Monga and Oglevie used a 20 Fr tract in 21 adults, reporting a 90% success rate, and called the procedure "mini-PCNL" [15]. Lahme et al. used a specially designed miniature nephroscope of 12 Fr through a 19 Fr tract in 19 patients and achieved a 100% success rate and termed this minimally invasive PCNL, or MPCNL [13]. For simplicity, MPCNL is used in the rest of this chapter for any PCNL procedure that uses a small tract. Table 1 summarizes the results of all the reported MPCNL series to date.

Despite the use of various sheath sizes and instruments and the different names for the procedure, all the authors believe that using a small tract will potentially cause less bleeding and less trauma to the renal parenchyma. All the authors also concluded that while the procedure was technically feasible, there was a suboptimal design for the working sheath, endoscope, lithotripsy device, and stone removal method. The general consensus was that it is only indicated in patients with a small stone load ($<2\,cm^2$), as a secondary tract for inaccessible or residual fragments to supplement standard PCNL, or in pediatric patients [10,13,15,18] (Table 2). However, in China, the technique of MPCNL had evolved and become standardized and popular. It is used to treat adult renal stones of all sizes including staghorn, stone in transplanted kidney, difficult upper ureteric stone, and stone in solitary kidney [16,19–24]. In some centres, MPCNL is routinely performed to treat all upper tract stones but it was rarely reported in the Western literature database until recently [25,26].

Chinese MPCNL

Li et al. of Guangzhou Medical College, China, reported their 20 years experience of 4014 cases of PCNL [16]. There were 358 cases of traditional PCNL, a two-stage "mini-perc" procedure in 520 patients, and minimally invasive PCNL

Table 1. Outcome of minimally invasive percutaneous nephrolithotomy (MPCNL) series reported

Author	Patient type	No. of patients	Stone size	Sheath size (Fr)	Mean LOS (days)	Mean OT (min)	Success rate (%)	Major complication (%)	Remarks
Helal 1997 [14]	P	1	7 mm	15	N/A	N/A	100	0	Transfusion: 0
Jackman 1998 (mini-perc) [11]	P	11	1.2 cm^2	11	6	203	85	0	Transfusion: 0
Jackman 1998 [10]	A	9	1.5 cm^2	13	1.7	176	89	0	Transfusion: 0
Monga 2000 (mini-PCNL) [15]	A	21	2.8 cm^2	20	1.1	54	90	4	Fever due to atelectasis: 1 Transfusion: 0
Chan 2000 [12]	A	17	1.4 cm^2	13	2.3	160	94	23	Conversion to PCNL: 2 Transfusion: 1 Urinary ascites: 1
Lahme 2001 (MPCNL) [13]	A	19	2.4 cm^2	15/18	N/A	99	100	5.3	Transfusion: 0 Pyelonephritis: 1
Li 2004 [16]	A	3136	N/A (includes 1283 staghorn)	16–18	13	75	91	0.5	Transfusion: 6 Pnenmothorax: 4 Delay hemorrhage: 2 Other: 5
de la Torre 2005 [17]	A	42	1.5–3.5 cm	14	<1	75.2	95.2	0	Transfusion: 0

Los, length of stay; OT, operating time; P/A, pediatric/adult; PCNL, percutaneous lithotomy

Table 2. Current indications for MPCNL[a]

1. Pelvic stone load of 1–2 cm^{2}[b]
2. Stone in calyceal diverticulum
3. Lower pole calyceal stone
4. Stone-associated special anatomy feature, e.g., infundibular stenosis or unfavourable angle
5. As secondary tract for standard PCNL
6. Total stone area >6 cm^{2} in case of multiple stones[b]
7. Case in maximal chance of renal parenchymal preservation (solitary/transplant kidney)[c]

[a]According to various authors
[b]Monga et al. suggest a large stone load up to 6 cm^{2} but they use a Fr 20 sheath
[c]Controversial

Table 3. Summary of results of 20 years experience of PCNL and MPCNL by the Guangzhou Group in China according to different time periods [16]

Year	1984–1992	1992–1994	1998–2003
Treatment	PCNL	Two-stage MPCNL	MPCNL
Number of patients	358	520	3136
Total procedure number	421	848	4302
Stone type			
Upper ureteric stone	—	34	257
Staghorn	37	314	1283
Nonstaghorn	310	85	746
Residual stone after open surgery/ESWL	11	87	850
Multiple tract, *n* (%)	—	45 (8.6)	942 (30)
Success rate (%)	90	95	98
Stone-free rate (%)	82	86	91
Mean OR time (min)	120	89	75
Mean LOS (day)	15	21	13
Number of transfusions	16	3	6
Major complication rate (%)	5.3	1.2	0.5

(MPCNL) using a 16–18 Fr tract in 3136 patients, including 1283 staghorn. They achieved a stone-free rate of 82%, 86%, and 91%, respectively, in the three groups. The complication rates were 5.3%, 1.2%, and 0.5% among the three groups (Table 3). They reported on their development on MPCNL with maturation of technique and standardization of the equipment and setup. Although we cannot conclude MPCNL was superior to traditional PCNL from their report because their MPCNL group was a more recent cohort, nevertheless their MPCNL outcome was impressive. It demonstrated that MPCNL can achieve much more than we had expected.

Recently, their centre reported their updated results on treatment of staghorn stone using MPCNL [27]. A total of 949 procedures was performed in 633 patients with a mean stone size of 1277 mm^{2}. The overall success rate was 90.8%. Sixty-five percent of patients required one procedure, and 34% required two

procedures, and 24% required multiple tracking. The mean operating time (OT) was 150 min, and only 2 patients required transfusion.

Surgical Technique of MPCNL According to the Chinese Method

The technique is based on that described by Li of First Affiliated Hospital of Guangzhou Medical College because their group was the main developer and had the greatest experience with MPCNL in China [28].

The operation was performed under general anesthesia with endotracheal intubation. It can also be performed using epidural anesthesia with the patient awake. A 7 Fr ureteric catheter was preliminarily inserted, anchored, and maintained sterile. This catheter is brought into the operating field without any connecting tubing so as to allow injection of contrast to opacify the system, to distend the system during puncture, and most importantly to allow forceful retrograde normal saline flushing for stone fragment removal later on. The patient is then turned prone and the abdomen supported to minimize lumbar lordosis. The chest is padded to allow good ventilatory movement, and pressure points are protected.

The preoperative imaging was reviewed, and a three-dimensional mental picture was constructed as to the site of the needle entry point, the needle angle in relation to the sagital plane, and how deep the needle should go. After distension of the system by normal saline via the ureteric catheter, free-hand puncture was performed with an 18-gauge needle, and emphasis was put on tactile feedback via the needle on going through the tissue. There will be a feel of a giving on entry to the system, or one will feel a grinding sensation when the needle hits on the stone. According to their experience, the usual puncture site would be in the 11th rib space bounded laterally by the posterior axillary line and medially by a line projected caudally from the lower tip of the scapula, which is essentially medial to the midpoint of the 12th rib (Fig. 1). The usual angle of puncture is 45° to the sagittal plane and perpendicular to the axis of the vertebral column. The track should take the shortest route through the abdominal wall and the renal parenchyma to the stone or the destination calyx, usually the middle calyx [29], but the actual selected calyx is tailored to the stone location and calyceal configuration. An oblique track should be avoided. The role of fluoroscopy is to confirm the puncture, monitor the passage of a guidewire, or to guide a puncture into a specific calyx in difficult cases.

Once entry into the system is confirmed with fluid efflux, a 0.035 in straight floppy tip, Zebra urological guidewire (Boston Scientific, USA) was passed down the ureter or coiled up in a dilated calyx. The needle is then removed and the tract serially dilated to 16–18 Fr with fascial dilators on the same guidewire.

A 16 Fr peel-away introducer set (Cook Urological, USA) is inserted, and its 15-cm-long peel-away sheath serves as the working sheath. In patients with a large stone load and dilated calyx, an 18-Fr sheath is used. A second Zebra

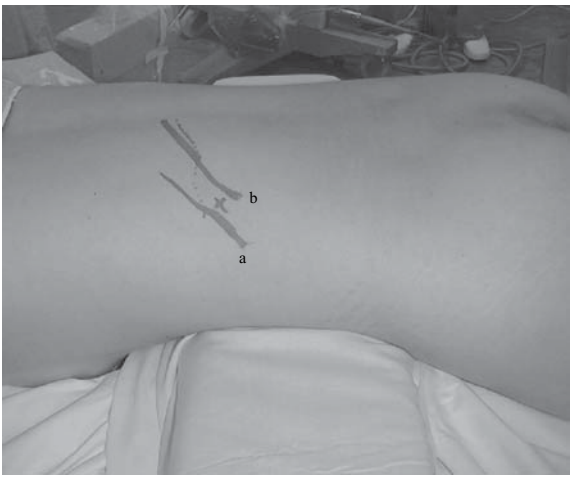


FIG. 1. Puncture site (*X*) is at the 11th intercostal space near the posterior axillary line. *Dotted line* shows the limit of parietal pleura. Note the abdomen is padded to reduce lumbar lordosis. *a*, 11th rib; *b*, 12th rib

guidewire can then be inserted through the sheath into the system; the sheath is then removed and backloaded with the introducer into the system on one of the guidewires. Once the sheath is back into the system, the introducer together with the guidewire can be removed, and now we have the sheath in situ together with a guidewire outside the sheath to serve as the safety wire. In a straightforward case, the initial guidewire can just be left in place through the sheath as a safety, but a properly placed safety is recommended.

A 8/9.8 Fr semirigid ureteroscope (Richard Wolf Knittlingen) is used as the working endoscope. It has a working length of 410 mm, a working channel of 6 Fr, and can accommodate a 5 Fr rigid grasping forceps. Stone fragmentation is exclusively by use of ballistic lithotriptor with a 1–1.5 mm probe. Laser was considered too slow and inconvenient to use (Li 2005, personal communication). Intraoperatively the small size of the ureteroscope, together with a straight short tract through the abdominal wall allow access to most calyces, PUJ (pelvic ureteric junction), and upper ureter as far down as the L4 level (Fig. 2). Only the parallel calyx with an acute angle to the puncture calyx may be inaccessible, and if necessary, an additional tract can be inserted as required. A flexible instrument is seldom used as it is considered suboptimal in terms of image quality, ease of use, and stone removal efficiency.

Pressurized pulsatile irrigation generated by a rotary pump (MMC, Guangzhou, China) was used through the ureteroscope to ensure a clear view. The pump generated pressure up to 350 mmHg for about 3 s, then stopped for 2 s, and then repeated the cycle. Stone fragment removal was by a combination of forceful retrograde saline flushing through the ureteric catheter by the assistant, the flushing effect of pulsatile irrigation through the endoscope, and the rapid removal of the ureteroscope from the sheath; this was further supplemented by use of 5 Fr rigid grasping forcep. Rapid removal of the ureteroscope out of the sheath synchronized with the low-flow irrigation period was considered impor-

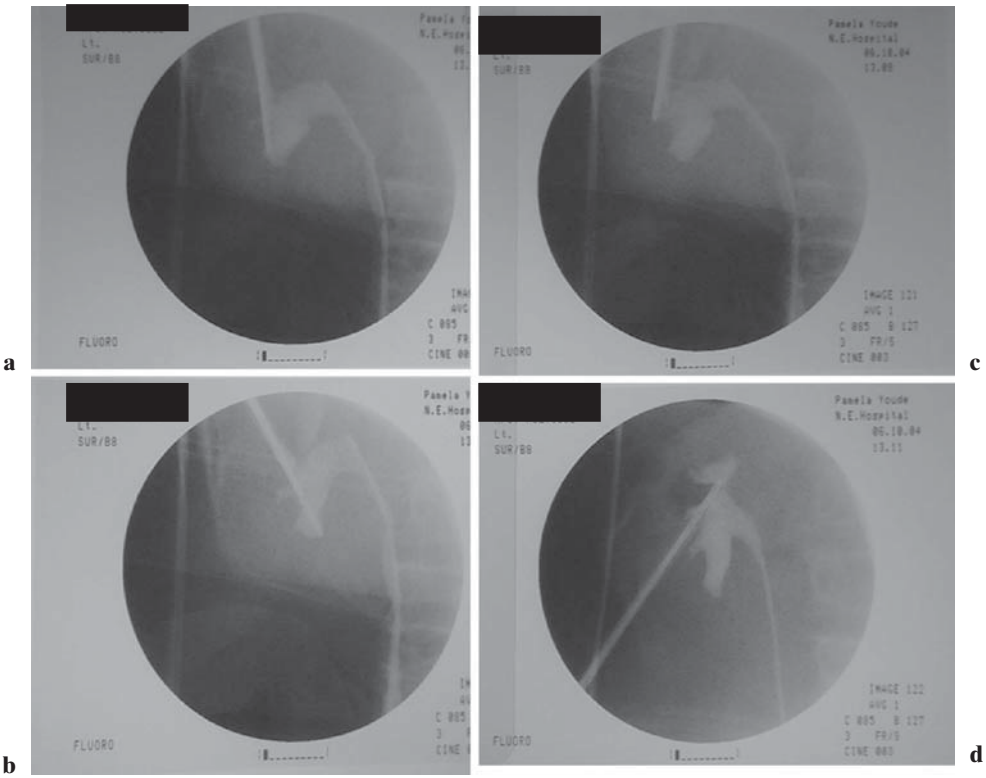


FIG. 2. Intraoperative X-ray shows good calyceal access. **a,b** lower calyx; **c** lower middle calyx; **d** upper calyx. Note the great range of movement of the ureteroscope via a middle calyceal puncture

tant as this would create a relative vacuum within the sheath and, together with the recoil of the system from the transient high pressure from the irrigant, would "push and pull" the stone fragment out (Li 2005, personal communication).

Postoperatively, as judged by the surgeon, a double J stent may be inserted under endoscopic guidance. A 14 Fr silicon drain was inserted as nephrostomy routinely. It was spigoted on postoperative day 1 and removed on day 2 if uneventful. If a second-look procedure is needed, it is performed on the next OT list, usually within a week, with the semirigid ureteroscope. If the residual stone burden is large, separate tracking is done. A flexible endoscope usually is not used.

Local Experience in Hong Kong

The technique of the Chinese MPCNL method was introduced to Hong Kong in 2004. It was adopted as a treatment option for upper tract stones with minimal modifications.

Initially, we also used the standard 8/9.8 Fr ureteroscope and the 1-mm lithoclast (EMS, Switzerland) probe for the MPCNL procedure. We later identified the semirigid slim compact cystoscope (Olympus, Tokyo, Japan) as a better alternative because it has a slim outer diameter of 11 Fr and a working channel of 7.2 Fr to admit 6 Fr instruments. It has a working length of 310 cm and thus is more easy to use compared to the long ureteroscope. It can also accommodate the 5 Fr short rigid grasping forcep (Richard Wolf Knittlingen) (Fig. 3).

The high-pressure pulsatile pump is not marketed outside China, so we replaced it with another pressured irrigation system (Niagara irrigator; Cabot Medical, USA) to provide a pressurized continuous irrigation of 300 mmHg. We also used a special warming tubing (Hotline; Level 1, USA) to prevent hypothermia consequent to the high-volume irrigation. Normally about 12–14 l normal saline is required for a 1-h procedure. Stone fragment removal was mainly by irrigant flushing and the use of a tipless basket. The rigid 5 Fr grasping forcep was available for the latter case.

We retrospectively review a prospectively collected database on MPCNL for staghorn and compare to that of the last 20 cases by traditional PCNL using a 24–28 Fr sheath. The stones were categorized as borderline if they involved the renal pelvis and one calyx, as partial if two calyces were involved, and as complete if three or more calyces were involved. Stone size was measured by tracing the stone outline in plain (KUB) film on graph paper [30]. Assessment of clearance of the stones was based on postoperative plain (KUB) film. Fragments of 4 mm or less were considered clinically insignificant fragments. Operating time was measured from initiation of puncture to the end of placement of the nephrostomy. Time for ureteric catheter insertion and positioning was excluded.

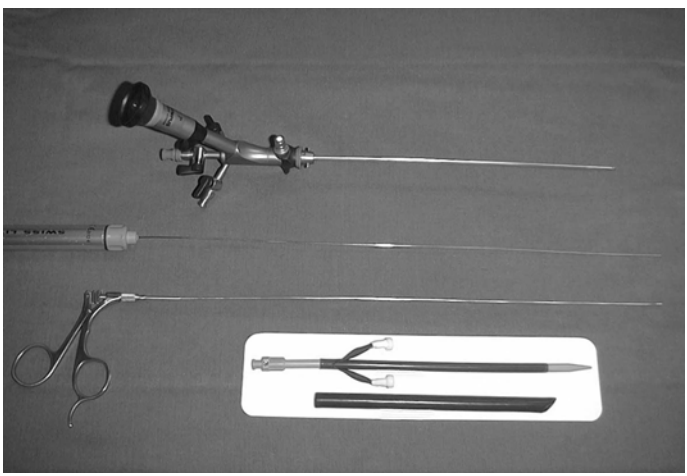


Fig. 3. Instrument and sheath used in minimally invasive percutaneous nephrolithotomy (MPCNL): slim compact cystoscope (Olympus), lithoclast with 1-mm probe, 5 Fr rigid grasping forceps (Richard Wolf), and the 18 Fr peel-away introducer set (Cook Urological). A 24 Fr amplatz sheath is placed alongside for comparison

Between July 2004 and March 2005, 12 consecutive cases of staghorn stone were treated with MPCNL (Table 4). There were 7 right and 5 left units. Six were borderline, 5 were partial, and 1 was a complete staghorn, with a mean stone size of 948.2 mm^2. Mean OT was 139.2 min, and in all cases, a single tract was developed and no second look was necessary. There were no major complications. Mean length of stay was 5.6 days. Complete stone-free rate on discharge was 33%, while 33% had a CIRF (Clinical Insignificant Residual Fragment) <4 mm. Three patients required auxiliary treatment.

These results were compared to those of the last 20 patients of staghorn treated with traditional PCNL (Table 5). The two groups were comparable in stone size and stone type. There was no difference in operating time and length of hospital stay. Complete stone clearance rate was higher with traditional PCNL. MPCNL was associated with more small residual fragments, ≤4 mm, whereas those fragments >4 mm were comparable in both groups. There was no difference in auxiliary procedure rate. Although statistically not significant, there was a trend for higher transfusion rate in the traditional PCNL while the infection rate was comparable.

In our initial experience, we found the fragmentation very effective even with the use of the long lithoclast probe via the long ureteroscope. Subsequent adoption of the short miniaturized endoscope further enhanced the ease of the process.

We noticed that the stone removal process by flushing was not very effective if the kidney had a very baggy system, in which case the pressure will be absorbed with very little recoil to push the stone out. Similarly, in patients with severe hydrocalyx, the stone fragments may be retained inside one of these "diverticulum-like" side chambers. Thus, removal of fragments by a suitable grasping forceps is still important. We prefer the rigid 5 Fr forceps (Richard Wolf Knittlingen), which provide a secure grip of the stone without blocking the view. Compared to the basket, the forceps can be completely controlled by one of the surgeon's hands. The other hand, holding the endoscope, controls the tape to slow down the irrigation temporarily so as not to flush the stone away. It is unclear whether pulsatile irrigation is superior than continuous irrigation in stone clearance, but we believe that using pressurized irrigation to flush out the stone is a significant improvement in the technique of MPCNL.

Equipment for MPCNL

For the traditional PCNL, a regular nephroscope of 24–26 Fr is used within a amplatz sheath of 26–30 Fr. The smallest amplatz sheath commercially available has an internal size of 24 Fr and an outer size of 28 Fr. There is also a small-caliber percutaneous nephroscope of 18.5 Fr outer diameter available, but it can only accommodate 2.4-mm accessories. None of these regular nephroscopes can be used for MPCNL, which normally uses a 13–20 Fr tract in adults, with a 15–18 Fr tract size being most common. In fact, the lack of suitable equipment tailored for MPCNL purposes is a major obstacle for its development. A critical

Table 4. Details of staghorn patients undergoing MPCNL (Hong Kong experience)

Patient no.	Sex	Age (years)	LOS (days)	Stone size (mm^2)	Side	Staghorn type	Calyx punctured	OT (min)	Stone Clearance	Auxillary procedure	Complication
1	M	41	4	875	L	Partial	Lower	100	Complete	—	—
2	F	77	4	1050	L	Partial	Middle	120	Complete	—	—
3	M	66	5	738	R	Borderline	Middle	105	Complete	—	—
4	F	48	9	770	R	Borderline	Lower	165	>4 mm	ESWL	Transfusion
5	M	58	6	1450	R	Partial	Upper	175	>4 mm	PCNL	Transfusion
6	M	58	6	1200	R	Partial	Upper Lower	195	≤4 mm	—	—
7	M	32	4	500	L	Borderline	Middle	135	≤4 mm	—	—
8	F	61	9	176	L	Partial	Lower	120	≤4 mm	—	Postoperative fever
9	M	66	6	360	R	Borderline	Lower	150	>4 mm	Observe	—
10	F	53	5	720	R	Borderline	Middle	135	>4 mm	ESWL	—
11	F	51	5	1200	R	Complete	Upper	180	≤4 mm	—	—
12	M	46	5	750	L	Borderline	Upper	90	Complete	—	—

L, left; R, right

Table 5. Outcome comparison between MPCNL and traditional PCNL (Hong Kong experience)

	MPCNL	Traditional PCNL	*P* value
n	12	20	
Stone diameter (cm)	3.82 ± 1.3	3.36 ± 0.94	NS[a]
Stone area (mm^2)	948.2	926.3	NS[a]
Type *n* (%)			
Borderline	6 (50)	13 (65)	
Partial	5 (40)	5 (25)	
Complete	1 (10)	2 (10)	
OR time (min)	139 ± 34	122 ± 34	NS[a]
Hospital stay (days)	5.6 ± 1.72	7.6 ± 6.3	NS[a]
Stone clearance *n* (%)			NS[b]
Complete	4 (33)	12 (60)	
Residual ≤4 mm	4 (33.3)	2 (10)	
Residual >4 mm	4 (33)	6 (30)	
Auxiliary treatment	4	6	NS[b]
Complication	3 (25%)	7 (35%)	NS[b]
Transfusion	2 (17%)	5 (25%)	
UTI	1 (8%)	2 (10%)	

NS; not significant; UTI, urmary tract infection
[a]Mann–Whitney *U* test
[b]Pearson chi-square test

comparison of the equipment used and technical details reported by various authors is listed in Table 6.

The Working Sheath

The lack of a suitable working sheath is the first hurdle that one needs to overcome. Use of a 15 Fr Hickman peel-away sheath [14], the 13 Fr ureterscopy access sheath [12], the 11 Fr peel-away vascular access sheath [11], and the 15 Fr specially made metal sheath [13] has been reported. The ideal sheath should be of correct size and length with a thin wall to allow a maximal internal diameter and minimal outer diameter, yet strong enough to maintain the function of a conduit and resist buckling on bending. We find the peel-away introducer set (Cook Urological) quite suitable. It is made of thin-walled, radiopaque TFE (polytetrafluoroethylene) with a smooth beveled edge for easy insertion with the introducer. It is 15 cm long with a size range from 8 to 18 Fr. There is also a commercially available mini-perc entry set (Cook Urological) with its special fascial incising needle, but only one size (13 Fr) is available, and its 11.5-cm-long sheath may be too short for adult use. Interestingly, on a few occasions, when the usual sheath was not available, our colleagues from China found a large plastic sucking straw to be a reasonable temporary alternative (X Li, 2005, personal communication).

Table 6. MPCNL: comparison of instruments, equipment, and technical details by various authors

Authors	Sheath size and type	Dilatation	Endoscope	Fragmentation	Removal	Nephrostomy drainage
Helal [14]	15 Fr Hickman Peel-away sheath	Sequentially dilated	10 Fr pediatric cystoscope	None	Grasping forceps	12 Fr
Jackman [11]	11 Fr peel-away vascular access sheath	Step dilatation	7 Fr pediatric cystoscope 9.5 Fr flexible ureteroscope	Electrohydraulic	Irrigation Three-prong forceps	6 Fr nephroureteric stent
Jackman [10]	13 Fr ureteroscopic access sheath	Step dilatation (cut with fascial incision needle)	6.9 Fr rigid ureteroscope 7.2 Fr flexible ureteroscope 7.7 Fr rigid pediatric cystoscope	Laser, Ultrasonic	Suction Tipless basket Three-prong forceps	8 Fr and J stent
Monga [15]	20 Fr nephrostomy sheath	Balloon	8/9.5 Fr ureteroscope 15.5 Fr flexible nephroscope 7.5 Fr flexible ureteroscope	Laser, Ultrasonic	Tipless basket Irrigation	16 Fr Nephrostomy
Chan [12]	13 Fr ureteroscopy access sheath	Sequentialn dilatatio	Pediatric cystoscope Adult ureteroscope	Laser	Basket, grasper Washout	8 Fr 7 Fr J stent
Lahme [13]	15 Fr metallic amplatz sheath	Single-step metal dilator	12 Fr rigid nephroscope	Ballistic, Ultrasonic, laser	Not mentioned	12 Fr
Li and Wu [16]	16–18 Fr peel-away sheath	Sequential	8/9.8 Fr ureteroscope	Ballistic	Retrograde flushing Intermittent High pressure Irrigation, grasper	14 Fr
de la Torre G [17]	14 Fr Amplatz sheath	N/A	N/A	Ballistic	N/A	None
Current series	18 Fr peel-away sheath	Sequential	8/9.8 Fr ureteroscope 11 Fr slim compact cystoscope	Ballistic	Continuous high-pressure irrigation grasper, basket	16 Fr

The Endoscope

When MPCNL was initially reported, there was no purposely designed endoscope. A pediatric rigid cystoscope, adult semirigid, and flexible ureteroscope had all been used. Lahme [13] reported the use of a specially designed miniaturize nephroscope (Richard Wolf Knittlingen) in 2001. It is 15 Fr when used with a sheath, 12 Fr without a sheath, and has a 12° angle of view and a straight 6 Fr working channel. Because of its 50 000-pixel image guide, it gives an excellent image (size and resolution) comparable to the nephroscope available at that time. This concept of miniaturization represents great progress.

Again, the ideal endoscope should have an optimal length of about 200–300 mm, with a small outer diameter to go through a 13–18 Fr sheath, while the working channel allows the use of grasping forceps and other accessories as large and as strong as possible. A straight working channel is preferred because the whole range of rigid accessories can be used. Among them, the grasping forceps probably is most important. A flexible forceps is usually too frail and inconvenient to use. We prefer the rigid 5 Fr stone-grasping forceps. It is strong enough to grasp the stone firmly without breakage but slim enough not to obstruct the view or the flow of irrigant. Therefore, it is essential for the endoscope to have a working channel able to accommodate 5 Fr rigid instruments.

We think the short semirigid ureteroscope is very suitable for this purpose because of its small size yet comes with its full set of rigid accessories. The image quality is good and can be further enhanced by high-flow irrigation. The field of view is more limited but adequate for ballistic lithotripsy. In our experience, its view is as good, if not better, than that with the large nephroscope. A paediatric cystoscope, while of suitable size, is too short and not robust enough for routine usage. Its smaller working channel also limits the use of accessories.

Recently, there has been the development of a miniaturized endoscope with a more suitable size range (8.5–12 Fr) and a large instrument channel, which greatly facilitates the procedure. Because of the use of pressurized irrigation through the endoscope, we consider the new membrane-sealing mechanism for the instrument channel an important feature, as it prevents leakage of irrigant from the nipple of the instrument channel and makes the operation neat and tidy. Although a flexible scope is always an option, it does not afford the same range of grasping forceps or ballistic lithotripsy device or the same image quality as the rigid scope, especially if bleeding is encountered.

A comparison of the currently available endoscopes and forceps that the author considers useful for MPCNL is given in Table 7.

Options of Lithotripsy Devices in MPCNL

The initial report of MPCNL by Helal did not require any fragmentation, and the stone was removed by grasping forceps. However, lithotripsy is inevitable in MPCNL. Laser had been a primary choice for its smallness and can be used through a flexible URS (ureterorenoscope). The 1.9 and 3.0 Fr electrohydraulic

Table 7. Comparison of current instruments that may be useful for MPCNL

	Manufacturer	Name/code no.	Nature	Size (tip/shaft), Fr	Working length (mm)	Maximum instrument size	Angle of view	Special feature	Suggested grasping forceps
1	Wolf	Mini compact nephroscope by Li Xun (8968.403)	Short ureterscope	8.5/11.5	315	1 × 6 F	12°	Membrane valve seal for instrument port, special notch for ergonomic len holding Beak at tip Angle eye piece	5 Fr rigid Wolf forceps
2	Wolf	Miniature nephroscope by Lahme (8968.421)	Nephroscope	12	225	1 × 6 F	12°	15 Fr, 18 Fr sheath available, angle eyepiece Membrane valve seal for instrument port, angle eyepiece	Wolf rigid grasping forceps 2 mm, WL (working length) 265 mm
3	Wolf	Compact ureterorenoscope by Bichler (8719.401)	Short ureteroscope	8/9.8	310	1 × 5 F	10°	Membrane valve seal for instrument port	5 Fr rigid Wolf forceps, WL (working length) 415 mm
4	Olympus	Slim compact cystoscope (A37025A)	Cystoscope	11	220	1 × 6 F	7°	15.9 Fr outer sheath available, beak at tip, angle eyepiece	5 Fr rigid Wolf forceps
5	Olympus	(A37026A)	Cystoscope	7.9	160	1 × 3.5 F	7°		
6	Storz	Ureteroscope (27002 K)	Short ureteroscope	9.5/13.5	340	1 × 5 F	6°	Instrument port with sealing system, angle eyepiece, beak at tip	5 Fr Storz rigid grasping forceps
7	Storz	Miniature nephroscope[a]	Nephroscope	12	220	1 × 6 F	N/A	15 Fr sheath available, angle eyepiece	

[a]Marketed later this year (2006)

(EHL) probes were also used, as was lithoclasts and ultrasound. Most authors reported a combination of different modalities, and there did not seem to be a "best" way (see Table 6). The reason may be there is no standardized endoscope for this purpose in the first place. Experience from China shows that the use of the semirigid ureteroscope together with the use of ballistic lithotripsy forms the best combination. Laser may be considered too slow, and EHL has a narrow safety margin [31]. Ultrasound is a very useful lithotripsy option in standard PCNL, but it is not suitable for MPCNL because the solid 2.5 Fr probe is slow to fragment the stone, and inadvertent slight bending of the probe will dissipate the energy as heat rather than fragmenting the stone. In contrast, the lithoclast probe is robust, effective, and can break the hardest stone. A 1- to 1.2-mm probe is preferred to a large probe because one wants to break the stone into finer fragments to be flushed out. The semirigid probe also provides a direct tactile feedback on touching the stone and greatly facilitates safe firing of the probe even when the stone view is suboptimal, either because of bleeding or because the view is partially obscured by a mucosal flap.

Unique Features of Chinese MPCNL

The Use of Pressurized Pulsatile Irrigation Through the Endoscope and the Use of Irrigant Flushing for Stone Fragment Removal

Although most authors use gravity drainage through their endoscope, the use of pulsatile pressurized irrigation through the endoscope is unique in the Chinese method, particularly with a pressure as high as 350 mmHg. The advantage is to provide a clear view and to allow flushing out of the small stone fragments after disintegration. The endoscope is withdrawn quickly out of the peel-away working sheath when the pulsatile fluid current stops. This rapid removal of the endoscope is postulated to create a negative pressure within the sheath, together with the recoil pressure generated by the distended system from the immediate pressurized pulsatile influx, and together with forceful retrograde irrigation through the ureteric catheter by the assistant, this creates a strong current to wash the stone fragment out.

There is concern about the safety of the use of this pressurized irrigation. Although a previous study for standard PCNL using a 34 Fr amplatz sheath and gravity drainage up to 75 cm H_2O showed that it was safe [32], no similar study is available for the use of a small sheath and high irrigation pressure of such an extent. We have conducted a pressure measurement study in five patients who underwent MPCNL to answer this question. During the procedure, a 8 Fr pigtail catheter was inserted into the renal pelvis through the lower pole and connected to a central venous pressure (CVP) manometer set (Allegiance Healthcare, USA). If a lower pole puncture is also used, the pigtail would share the same tract but be placed outside the sheath. The procedure was carried out with the

8/9.8 Fr ureteroscope connected to a pressurized continuous irrigation of 300 mmHg. No accessory was placed in the working channel, which was used solely for irrigation.

Pressure readings were recorded with the tip of the ureteroscope in the following positions: in the calyx, in the pelvis, in the proximal ureter, inside the working sheath, and with the endoscope in the pelvis plus forceful retrograde injection via a 7 Fr ureteric catheter. Toward the end of the operation, while withdrawing the working sheath with the scope in situ at the pelvis, a pressure measurement was taken for simulation of sheath dislodgement. A pressure of 30 mmHg (40.8 cmH_2O) is used as the threshold of safety because a previous study showed that intrapelvic pressure above that was associated with pyelovenous and pyelolymphatic backflow, which may be the route for systemic entry of bacteria or endotoxins [33], and this reading is also that which was used in another similar study [34].

We found that pressure readings taken in these five patients in the study were all below the threshold (mean, 11.7 cm H_2O; range, 5.5–18 cm H_2O), except during simulation of sheath dislodgement when there was a sustained elevated pressure above threshold (mean, 47 cm H_2O; range, 38–58 cm H_2O). Forceful irrigation via ureteric catheter only gave rise to a transient surge of intrapelvic pressure close to the threshold (mean, 30 cm H_2O; range, 26–34 cm H_2O). Thus, we concluded that pressurized continuous irrigation through the working channel of a 8/9.8 Fr ureteroscope was safe so long as the sheath is in situ. Pressurized irrigation translated to a high-flow irrigation only and not high intrarenal pelvic pressure. Clinically, we did not notice a high septic rate in our study. Similarly, the complication rate from sepsis reported from the Guangzhou group was only 1% [21].

Access Site and the Preference for Middle Calyceal Puncture

In the Chinese method, the preferred puncture site was at the 11th intercostal space, bounded laterally by the posterior axillary line and medially by a line projected caudially from the tip of the scapula. It is in fact a supracostal puncture, but avoiding the parietal pleura edge, which typically crosses the middle of the 12th rib and goes to the level of the 10th rib at the midaxillary line, so that the lateral half of the 12th rib is always inferior to the parietal plura limit [35]. Using this puncture site has the advantage of hitting the middle calyx without resorting to an oblique tract while having minimal risk of injury to the pleura. There is also no risk of puncturing the spleen or liver so long as the puncture is done during expiration [36].

The skin puncture site is close to but not lateral to the posterior axillary line. This position is usually 2–3 cm more lateral to the entry site when the "down the barrel" method as described by Kassaris and Smith is used [37]. In that case, the calyx/kidney is usually hit at about a 25°–30° angle from the sagittal plane compared to the 45° angle using the Chinese method. One advantage of a more-lateral approach at 45° is the avoidance of the thick muscle of the back so that

the tract transgresses the thinner part of the abdominal wall; this contributes significantly to the subsequent improved manuverability of the endoscope as there is minimal impingement of endoscope movement by the abdominal wall. In fact, a more lateral approach at the posterior axillary line and 45° puncture angle is also favoured by others [38,39].

The choice of calyceal puncture will be determined by stone location, stone size, calyceal anatomy, and the surgeon's experience. In standard PCNL, usually a subcostal lower pole puncture or a supracostal upper pole approach is preferred [9]. A lower pole puncture is safe because in 80% of right kidneys and 78% of left kidneys the lower pole calyx lies below the 12th rib [40], and through this access one can avoid pleural complication and can tackle stones in the lower pole calyx, pelvis, and upper calyx [39]. A supracostal upper pole puncture is preferred by some authors because it provides a straight tract along the longitudal axis of the kidney to access the superior calyx, pelvic ureteric function, proximal ureter, and lower calyx, and it is recommended particularly for staghorn stones [41,42]. Recent data show that supracostal puncture above the 12th rib is safe, with thoracic complications of only 0%–1.7%. Only puncture above the 11th rib is associated with a greater incidence of intrathoracic complication [42].

In standard PCNL, the middle calyx is only selected for direct attack of a middle calyx stone or a stone the at renal pelvis because access to other parts of the calyx is poor if not impossible [37,39,40]. However, interestingly, a middle calyceal puncture is still being used either alone or as part of a multitract approach in 30%–80% of cases in reported series [41,43]. The argument to support a middle calyx puncture is that it may be associated with fewer complications compared to upper or lower calyx puncture [44]. From the blood supply aspect, the lower pole puncture may have a narrow safety margin as it is supplied by a single segmental artery from the anterior branch, and if injury to this vessel occurs, it will result in whole lower pole segment being infarcted [45]. Also, puncture of the upper pole posterior portion has a greater chance of significant vascular injury because of the position of the posterior segmental renal artery [46]. This artery crosses the posterior surface of the upper infundibulum in 57% of cases and may supply as much as 50% of the renal parenchyma [47].

In the Chinese method, a middle calyx puncture is preferred. Maximal intrarenal access can be achieved via the "neutral position" of the midcalyceal puncture as the endoscope can swing a full arc (see Fig. 2). With the small sheath and miniaturized endoscope, it is normally possible to inspect the renal pelvis, proximal ureter up to L4, and upper and lower calyx in MPCNL, which would be impossible using the large rigid renoscope as it will place severe torque on the tissue, risking parenchymal tear. The merit of a middle calyceal approach was exemplified by the impressive results from China. They reported a series of 152 patients, including 58 staghorn, undergoing MPCNL using solely a posterior middle calyx puncture, and achieved an 86.2% success rate. Fifteen patients required additional ESWL (Extracorporeal Shook Wave Lithotrispy) and only 6 needed a second puncture for a parallel calyx [29]. We also find good intrarenal access through the middle calyx puncture using the miniaturized endoscope. It

can negotiate the narrow calyceal neck and turn corners that would be impossible to do by the standard renoscope.

In summary, a supra-12th middle calyceal approach may be the best balance of all. It avoids the high risk of supra-11th puncture while allowing a good perpendicular approach through the abdominal wall and renal parenchyma into the middle calyx, thereby minimizing impairment of endoscope movement, allowing the endoscope to swing a full arc and set the best angle for maximal intrarenal access to all calyx and PUJ as well as to the ureter.

Summary of Advantages of the Chinese Method of MPCNL

Current reported MPCNL series showed that there was a lack of suitable equipment and that it took a long time to fragment and remove the stone. The MPCNL by the Chinese method solved these problems by standardization of the use of equipment and simplification of the surgical technique. Only one type of guidewire, a peelaway sheath, is used. The routine use of the semirigid ureteroscope, ballistic lithotripsy, and stone removal by irrigation supplemented by a rigid 5 Fr forcep represents the optimal solution to all problems of MPCNL. This equipment is readily available in all units providing stone service. The routine use of ballistic lithotripsy through the semirigid miniaturized endoscope avoids the need for interchange to other lithotripsy devices and provides a superior quality of image not matched by use of a flexible endoscope. The great range of intrarenal manuverability also makes flexible endoscopy obsolete. In fact, if the stone is located in an calyx inaccessible to the rigid miniaturized endoscope, it would also be difficult to reach by flexible endoscopy (Li 2005, personal communication).

The strategy of stone fragment removal by irrigant flushing is an important concept. It avoids the tedious process of picking up every fragment by forceps. The process of stone fragment removal occurs concurrently with stone fragmentation and saves time, explaining why operating time in Chinese MPCNL can be much shortened. Although it is a random process, as long as the fragment is small enough to pass through the sheath and this process of irrigation and flushing is repeated many times, then it should have a good chance of complete stone clearance. For a 16 Fr sheath, the theoretical maximum stone diameter that it can accommodate is $16/\pi = 5$ mm. The size of fragment can be judged with reference to the size of probe. This fragment removal process can be further enhanced by irrigation via secondary tracts [23,29].

Is MPCNL a Less Invasive Procedure than PCNL?

Clinical Outcome, Bleeding, and Complication Rate

Standard PCNL is already a well-recognized minimally invasive surgery compared to that of open surgery with shorter operative time, less intraoperative

complication, shorter hospital stay, and earlier return to work, while achieving similar stone clearance rate [48].

From a practical point of view, a 28–30 Fr sheath (outer diameter, 32–34 Fr) may be too large to be accommodated in a pediatric patient and adult patients with an undilated system, risking rupture of the calyceal neck. Indeed, there were reports of similar or greater renal damage by PCNL compared to open surgery in pediatric patients [49], and some would even not recommend PCNL in children younger than 8 years for fear of renal damage resulting from the relatively large endourological equipment [50]. This size awareness and use of a smaller sheath to fit calyceal size is also noted in adults. Kukreja et al. use a 20–22 Fr tract in patients with a nondilated system or narrow infundibulum [38].

The access tract is an important cause of haemorrhage and other complications [9]. It is now clear that bleeding is associated with increased number of tracts and also increased size of tract [38]. In contrast to the 3%–25% transfusion rate reported in standard PCNL [8,51–53], most of the available MPCNL series reported minimal bleeding and a very low transfusion rate. In most adult series, patients can return home in 2 days' time. In our series, the transfusion rate is 16%, lower than the 25% in the standard PCNL arm. The length of stay is also shortened by 2 days in the MPCNL group. The largest reported series of MPCNL from China on 3136 patients also showed a short operating time, a low transfusion rate of 0.2%, and only 2 patients required embolization for bleeding complication. The overall major complication rate is only 0.5% [16]. In conclusion, available evidence strongly suggested that MPCNL can further reduce the invasiveness of PCNL, although a larger-scale prospective randomized study is needed to confirm this.

Issue of Renal Function Preservation

As to tissue injury, it is unclear whether there is a direct relationship between tract size and degree of parenchymal trauma. All being equal, a small tract will cause less tissue compression/disruption compared to a large tract. In case of any mishap related to the tracking, a small tract stands a better chance of causing less damage compared to larger tract [10].

Previous studies on the effect of standard PCNL on renal parenchymal injury show that it is negligible [54–56]. However, one must appreciate the difficulty in assessment because any change in global renal function measurement will be masked by compensation by the contralateral kidney, and individual kidney functional change measurement is limited by the sensitivity of the available differential functional scan and compensation by correction of adverse factors to that kidney by the procedure.

Previous anatomical studies based on scar tissue calculation in the pig kidney model showed that the volume of parenchymal fibrosis is only 0.16%–0.63% of the total renal volume even with a 36 Fr tract, thus leading to the conclusion that the degree of tissue trauma is negligible [57,58]. A similar anatomical study by

Webb and Fitzpatrick on dog kidney showed a 22 Fr track wound healed to a fine hairline scar [59]. However, it is unclear whether scar size so measured truly reflected the degree of injury. With healing, even a big wound will shrink to a small scar. The other potential problem associated with these studies is that we tend to overestimate the total cortical volume because we include the volume occupied by the collecting system as functional renal volume; thus, the calculated percentage of cortical scar is an underestimation, and the degree of error can be significant because of the relatively small number of the numerator. There is also emerging evidence that standard PCNL using a large tract results in renal functional damage to an extent greater than we previously appreciated.

Hegarty reported the result of PCNL in 90 solitary kidneys. There was statistically significant deterioration of serum creatinine by 11% and creatinine clearance by 9% in the immediate postoperative period, although both parameters returned to the preoperative level on longer-term follow-up [60]. This result shows that there is a definite insult on renal function by PCNL although it is compensated later, possibly due to relief of obstruction or clearance of sepsis.

Morskovitz et al., in a study on global and regional renal function using quantative single photoemission computerized tomography (SPECT) measurement of Tc-dimercaptosuccinic acid (DMSA) uptake in kidney (QDMSA) in 79 patients undergoing standard PCNL, found that there was statistically significant decrease of total renal functional volume of the kidney that undergoes the procedure. Furthermore, regional renal function analysis revealed statistically significant decrease in functional renal volume at the part that underwent the PCNL procedure. The functional volume loss represented 4.5% of the whole kidney and 10% of that region [61], which is a direct measurement of the functional change in humans and represents a closer picture to the truth than the indirect scar measurement study. These new data show that large tracking in standard PCNL does cause significant renal function damage, much greater than we had previously appreciated.

Conclusions

Modern instrumentation and technical improvement have revitalized MPCNL. The previous difficulty in stone fragmentation and stone removal has been solved. Now, MPCNL has a much wider application. Our initial experience echoes that reported in the Chinese literature that it can be applied to large stone loads, including staghorns, with comparable operating time and clinical stone clearance rate as standard PCNL. While there is a trend toward less blood loss, whether MPCNL is a less invasive procedure than standard PCNL in terms of functional preservation remains controversial. However, MPCNL is still a preferable option because of the standardization and simplificity of technique and equipment, excellent surgical view, and unparalleled intrarenal maneuverability, which may render large-tract PCNL no longer necessary.

References

1. Fernstrom I, Johansson B (1976) Percutaneous pyelolithotomy: a new extraction technique. Scand J Urol Nephrol 10:257–259
2. Alken P, Hutschenreiter G, Gunther R, et al (1981) Percutaneous stone manipulation. J Urol 125:463–466
3. Marberger M, Steckl W, Hruby W (1982) Percutaneous litho-lapaxy of renal calculi with ultrasound. Eur Urol 8:236–242
4. Segura JW, Patterson DE, LeRoy AJ, et al (1982) Percutaneous removal of kidney stones: preliminary report. Mayo Clin Proc 57:615–619
5. Wickham JE, Kellett MJ (1981) Percutaneous nephrolithotomy. Br J Urol 53:297–299
6. Smith AD, Reinke DB, Miller RP, et al (1979) Percutaneous nephrostomy in the management of ureteral and renal calculi. Radiology 133:49–54
7. Ramakumar S, Segura JW (2000) Renal calculi: percutaneous management. In: Streem SB, Gill ES (eds) Urol Clin N Am 27:617–622
8. Preminger GM, Assimos DG, Lingeman JE, et al (2005) AUA guideline on management of staghorn calculi: diagnosis and treatment recommendations. J Urol 173:1991–2000
9. Clayman RV, McDougall EM, Nakada SY (1998) Endourology of upper tract: percutaneous renal and ureteral procedures. In: Walsh PC, Retik AB, Vaughan ED, Wein AJ (eds) Campbell's urology, 7th edn, vol 3. Saunders, Philadelphia, p 2799
10. Jackman SV, Docimo SG, Cadeddu JA, Bishoff JT, Kavoussi LR, Jarrett TW (1998) The 'mini-perc' technique: a less invasive alternative to percutaneous nephrolithotomy. World J Urol 16:371–374
11. Jackman SV, Hedican SP, Peters CA, Docimo SG (1998) Percutaneous nephrolithotomy in infants and preschool age children: experience with a new technique. Urology 52:697–701
12. Chan DY, Jarrett TW (2000) Mini-percutaneous nephrolithotomy. J Endourol 14:269–273
13. Lahme S, Bichler KH, Strohmaier WL, Gotz T (2001) Minimally invasive PCNL in patients with renal pelvic and calyceal stones. Eur Urol 40:619–624
14. Helal M, Black T, Lockhart J, Figueroa TE (1997) The Hickman peel-away sheath: alternative for pediatric percutaneous nephrolithotomy. J Endourol 11:171–172
15. Monga M, Oglevie S (2000) Minipercutaneous nephrolithotomy. J Endourol 14: 419–421
16. Li X, Zeng GH, Yuan J, Wu KJ, et al (2004) Treatment of upper urinary calculi with the PCNL technique (experience of 20 years) (in Chinese). J Peking Univ Health Sci 36(2):124–126
17. de la Torre G, De Bonis W, Rey H, et al (2005) Percutaneous renal surgery with minimal access: miniperc (in Spanish). Arch Esp Urol 58(2):145–150
18. Fernandez Gonzalez I, Santos Arrontes D, Llanes Gonzalez L, et al (2005) "Mini-percutaneous" percutaneous nephrolithotmy: technique and indications (in Spanish). Arch Esp Urol 58(1):55–60
19. Li X, Wu KJ, Shan CC (1995) Percutaneous ureteroscopic lithotripsy for upper tract urinary stone (in Chinese). Chin J Urol 16:426–427
20. Li X, Lei M, Yuan J, et al (2004) The comparison of minimally invasive percutaneous nephrolithotomy and trans-urethral ureteroscope lithotripsy for impacted upper ureteric calculi (in Chinese). J Clin Urol 19(7):388–390

21. Shan CC, Guo B, Lu XG, et al (2004) Effect of mini-percutaneous nephrostomy by ureteroscopy in treatment of complex upper urinary stone (in Chinese). J Postgrad Med (Surg Ed) 27(7):17–19
22. Zeng GH, Li X, Wu KJ, et al (2003) Treatment of solitary kidney calculi with minimally invasive percutaneous nephrolithotomy (in Chinese). China J Endosc 9(9):4–5
23. Li X, Wu KJ (1998) Multiple channel percutaneous nephrolithotomy in the treatment of complex renal calculi (in Chinese). Chin J Urol 19(8):469–470
24. Li X, Lu W, Wu KJ, et al (2005) Endoscopic treatment of urinary calculi in allograft kidneys (in Chinese). Chin J Urol 26(5):318–320
25. Wu KJ, Li X (2005) PCNL techniques for treatment of upper urinary stone (18 years & clinical report). J Endourol 19(suppl 1):A73
26. Li SK, Tai CK, Fung TC (2005) Early experience of minimally invasive PCNL (MPCNL) according to the Chinese method for staghorn stone. J Endourol 19(suppl 1):A241
27. Wu KJ, Li X (2005) Mini nephrostomy with ureteroscopic lithotripsy (mini-PCNL) for the treatment of staghorn stone. J Endourol 19(suppl 1):A132
28. Li X (2003) MPCNL. Chin J Mod Operat Surg 7(5):338–344
29. Li X, Zeng GH, Liu JH, et al (2005) Minimally invasive percutaneous nephrolithotomy in the management of complex urinary calculi: a middle calyx puncture approach. J Clin Urol 20(3):147–149
30. Lam HS, Lingeman JE, Russo R, et al (1992) Stone surface area determination technique: a unifying concept of staghorn stone burden assessment. J Urol 148:1026–1029
31. Grocela JA, Dretler SP (1997) Intracorporeal lithotripsy: instrumentation and development. In: Resnick MI (ed) Urol Clin N Am. 24:13–23
32. Saltzman B, Khasidy LR, Smith AD (1987) Measurement of renal pelvic pressures during endourological procedures. Urology 30:472–474
33. Hinman F, Redewill FH (1926) Pyelovenous backflow. JAMA 87:1287
34. Troxel SA, Low RK (2002) Renal intrapelvic pressure during percutaneous nephrolithotomy and its correlation with the development of postoperative fever. J Urol 168:1348–1351
35. Williams PL, Warwick R (eds) (1980) Gray's anatomy, 36th edn. Churchill Livingstone, London, pp 1248
36. Hopper KD, Yakes WF (1989) The posterior intercostal approach for percutaneous renal procedures: risk of puncturing the lung, spleen, and liver as determined by CT. AJR 154:115–117
37. Kassaris DN, Smith AD (1995) Fluoroscopic access in prone position—with C-arm. In: Smith AD (ed) Controversies in endourology. Saunders, Philadelphia, pp 10–17
38. Kukreja R, Desai M, Patal S, Bapat S, Desai M (2004) Factors affecting blood loss during percutaneous nephrolithotomy: prospective study. J Endourol 18:715–722
39. Marberger M (1994) Percutaneous renal surgery: its role in stone management. In: Krane RJ, Siroky MB, Fitzpatrick JM (eds) Clinical urology. Lippincott, Philadelphia, pp 254–265
40. Wickham JEA, Miller RA (1983) Percutaneous renal surgery. Churchill Livingstone, Edinburgh, p 5
41. Netto NR, Ikonomidis J, Ikari O, Claro JA (2005) Comparative study of percutaneous access for staghorn calculi. Urology 65:659–663
42. Munver R, Delvecchio FC, Newman GE, Preminger GM (2001) Critical analysis of supracostal access for percutaneous renal surgery. J Urol 166:1242–1246

43. Gupta R, Kumar A, Kapoor R, Srivastava A, Mandhani A (2002) Prospective evaluation of safety and efficancy of the supracostal approach for percutaneous nephrolithotomy. BJU Int 90:809–813
44. Atallah N, Slaba S, Karam R, Salem C, Merhej S (1999) Complications of percutaneous nephrostomy apropos of 481 procedures: the value of puncture of the median calices (in French). Leban Med J 47:92–94
45. Wickham JEA, Miller RA (1983) Percutaneous renal surgery. Churchill Livingstone, Edinburgh, p 12
46. Winfield HW, Clayman RV (1986) Percutaneous nephrostolithotomy: complication of premature nephrostomy tube removal. J Urol 136:77–79
47. Sampaio FJB, Aragao AHM (1990) Anatomical relationship between the intrarenal arteries and the collecting system. J Urol 143:679–681
48. Al-Kohlany KM, Sholreir AA, Mosbah A, et al (2005) Treatment of complete staghorn stones: a prospective randomized comparison of open surgery versus percutaneous nephrolithotomy. J Urol 173:469–473
49. Wilson WT, Hussman AD, Morris JS, Miller GL, Alexander M, Preminger GM (1993) A comparison of the bioeffects of 4 different modes of stone therapy on renal function and morphology. J Urol 150:1267–1270
50. Hulbert JC, Reddy PK, Gonzalez R, Young AD, Cardella J, Amplatz K, et al (1985) Percutaneous nephrostolithotomy: an alternative approach in the management of pediatric calculus disease. Pediatrics 76:610
51. Lingeman JE, Coury TA, Newman DM, et al (1987) Comparison of results and morbidity of percutaneous nephrostolithotomy and extracorporeal shock wave lithotripsy. J Urol 138:485–490
52. Stoller ML, Wolf JS Jr, St. Lezin MA (1994) Estimated blood loss and transfusion rates associated with percutaneous nephrolithotomy. J Urol 152:1977
53. Davidoff R, Bellman GC (1997) Influence of technique of percutaneous tract creation on incidence of renal hemorrhage. J Urol 157:1229–1231
54. Chatham JR, Dykes TE, Kennon WG, Schwartz BF (2002) Effect of percutaneous nephrolithotomy on differential renal function as measured by mercaptoacetyl triglycine nuclear renography. Urology 59(4):522–525
55. Liou LS, Streem SB (2001) Long-term renal functional effects of shock wave lithotripsy, percutaneous nephrolithotomy and combination therapy: a comparative study of patients with solitary kidney. J Urol 166(1):33–37
56. Jones DJ, Kellett MJ, Wickham JE (1991) Percutaneous nephrolithotomy and the solitary kidney. J Urol 145:477–479
57. Clayman RV, Elbers J, Miller RP, et al (1987) Percutaneous nephrostomy: assessment of renal damage associated with semi-rigid (24 F) and balloon (36 F) dilatation. J Urol 138:203–206
58. Traxer O, Smith TG (2001) Renal parenchymal injury after standard and mini percutaneous nephrostolithotomy. J Urol 165:1693–1695
59. Webb DR, Fitzpatrick JM (1985) Percutaneous nephrolithotripsy: a functional and morphological study. J Urol 134:587–591
60. Hegarty NJ (2005) Percutaneous surgery in solitary kidney: impact on renal function. J Urol 173(suppl):25
61. Morskovitz B, Halachmi S, Mullerad M, Sopov V, et al (2005) Does renal function change following percutaneous nephrolithotripsy (PCNL)? Assessment with quantitative spect of Tc-99M-DMSA (QDMSA) renal scintigraphy. Eur Urol 47(suppl 4) (3):198

Cryoablation for Renal Cell Carcinoma

Osamu Ukimura and Inderbir S. Gill

Summary. The aim of energy-based tissue ablative procedures for renal cell carcinoma is to achieve complete destruction of the cancer cells, targeting the entire visualized tumor with a surrounding margin of healthy renal parenchyma. Based on recent technological advances of cryodelivery systems and imaging technology, cryoablation has now been performed via open, laparoscopic, and percutaneous approaches worldwide. Because immediate pathological confirmation of complete cancer cell death with negative surgical margin is impossible in cryoablation of renal tumor, clinical long-term follow-up with meticulous imaging assessment and needle biopsy data is necessary to determine the oncological efficacy of cryoablation for renal cell carcinoma. Recently, the authors reported intermediate-term oncological follow-up data on 56 patients, of whom each completed a 3-year follow-up after laparoscopic renal cryoablation. Overall 3-year cancer-specific survival was 98%. The intermediate-term oncological data are encouraging for continued performance of renal cryoablation for renal cell carcinoma in carefully selected older patients with a small renal mass. Technically, the authors routinely attempt to extend the iceball at least 1 cm beyond the edge of the tumor to achieve the tumoricidal temperature within the entire extent of the tumor.

Keywords. Renal tumor, Renal cell carcinoma, Cryoablation, Nephron-sparing surgery, Minimally invasive surgery

Introduction

Nephron-sparing surgery (NSS) is now the established treatment for small renal cell carcinoma (RCC) [1]. With the aim of decreasing pain, morbidity, hospital stay, and operative time, various minimally invasive modalities for NSS have

Section of Laparoscopic and Robotic Surgery, Urological Institute, A-100, Cleveland Clinic Foundation, 9500 Euclid Ave., Cleveland, OH 44195, USA

been evaluated [2–5]. The goal of energy-based tissue ablative procedures for RCC is to achieve complete destruction of a predetermined volume of target tissue (including the RCC tumor and a surrounding margin of healthy renal parenchyma) that would otherwise be excised during a traditional partial nephrectomy.

Cryoablation is an energy-based tissue ablation technique inducing tissue destruction by cryoinjury. Based on recent technological advances of a cryodelivery system (cryoprobe) and a real-time imaging system, cryoablation has now been performed via open, laparoscopic, and percutaneous approaches in academic centers worldwide. However, during cryosurgery the ablated renal tumor remains in situ. As such, pathological confirmation of complete cancer cell death with negative surgical margin is impossible. Therefore, clinical long-term follow-up with meticulous imaging assessment and needle biopsy data is necessary to determine the oncological efficacy of cryoablation for RCC.

Cryoinjury occurs through two sequential synergic immediate and delayed mechanisms that involve rapid intracellular ice formation and delayed microcirculatory failure. Intracellular ice formation requires a temperature of –40°C [6]. Freezing sustained in the range of –20°C to –40°C is more damaging than shorter-term freezing. The established essential steps of renal cryoablation treatment include rapid freezing, slow thawing, and repetition of the second freeze–thaw cycle [6]. The optimal duration of freezing is not known; however, the enhanced lethal effect of repeated freeze–thaw cycles is well seen at the freezing temperature range –20° to –30°C.

Although intraoperative monitoring images could suggest the cryolesion as iceball formation, the temperature at the margin of the iceball is 0°C, and the iceball needs to extend at least several millimeters beyond the visible margin of the tumor to achieve uniform destruction of all viable RCC [7]. Therefore, the authors routinely attempt to extend the iceball at least 1 cm beyond the edge of the tumor to achieve the tumoricidal temperature within the entire extent of the tumor.

Cryoablation Technology and Cryobiology

A double freeze–thaw cycle creates a larger lesion of necrotic tissue compared to a single freeze–thaw cycle [8]. An essential requisite for reliable cryoablation is a double freeze–thaw cycle, involving rapid freezing and slow thaw [6]. Campbell et al. confirmed that the critical temperature of –19.4°C was uniformly achieved at a distance of 3.1 mm inside the visible margin of the iceball [7], suggesting the iceball should extend at least 3.1 mm beyond the visible margin of the tumor to achieve uniform destruction of all viable RCC. Moreover, the critical threshold to achieve complete, reliable cytoreduction is assured between –19.4° and –40°C [9]. Therefore, our policy has been to extend the iceball 1 cm beyond the margin of the tumor under dual laparoscopic and sonographic mon-

itoring during laparoscopic cryablation. Transient clamping of the renal artery does not improve the efficacy of renal cryoablation [7]. Involvement of the renal collecting system by the cryolesion appears to be healed in a watertight manner without urinary extravasation or leak [10].

The introduction of a liquid-nitrogen- or liquid argon-based cryosystem allows creating a cryolesion with a core temperature of –175° to –190°C at the tip of the cryoprobe. Liquid-nitrogen-based cryoprobes are available in 3-mm, 4.8-mm, and 8-mm-diameter sizes and allow creating lesions ranging from 1 to 5 cm in diameter. At the author's center, the 4.8-mm-diameter argon-based probe has routinely been employed for clinical laparoscopic renal cryoablation. A recent argon-based cryosystem introduced three types of probes—1.7, 2.4, and 3.8 mm in diameter (Endocare, Irvine, CA, USA). At the author's center, 2.4-mm-diameter probes are currently selected for a percutaneous procedure. However, the temperature within the cryolesion is not uniform, increasing exponentially as a function of the distance from the cryoprobe. Estimated dimensions (diameter×length) of the isotherm for a 24-mm probe at 10 min 100% freezing in gel, which approximates soft tissue, are 16×36 mm for a –40°C isotherm, 23×42 mm for a –20°C isotherm, and 36×55 mm for a 0°C isotherm (the edge of the actual visible iceball). Therefore, when percutaneously targeting, multiple probes are necessary to extend the iceball at least 1 cm beyond the edge of the tumor to achieve tumoricidal temperature within the entire extent of the tumor.

Uchida et al. reported the first clinical application of percutaneous renal cryoablation in 1995 in two patients with metastatic RCC [11]. The authors described shrinkage in size on the cryolesion and symptomatic improvement in 5–10 months follow-up. Since we began our renal cryoablation program in September 1997, sequential radiographic follow-up has been performed to determine the natural history of cryoablated RCC [2,12]. In 3 years, the cryoablated RCC had decreased a mean of 75% compared to the dimension of the cryolesion on postoperative day 1, and complete disappearance of the cryoablated tumor was observed in 38% of patients [13]. Sequential cryolesion size on postoperative 1 day, 3 and 6 months, and 1, 2, and 3 years was 3.7, 2.8, 2.3, 1.7, 1.2, and 0.9 cm, respectively. A cryolesion typically contracts with time, resulting in a fibrotic scar [13].

Remer et al. characterized the magnetic resonance imaging (MRI) findings of a successful cryolesion: shrinkage in size, isointensity on T_1-weighted images, and hypo- or isointensity on T_2-weighted images [14]. In the radiologic follow-up assessment of ablated renal tumor, the authors preferred MRI with and without gadolinium enhancement over computed tomography (CT) because of its superior contrast resolution and safety for renal function. The current consensus of the clinical imaging definition of successful cryoablation is lack of enhancement of the cryoablated tumor on gadolinium-enhanced MRI. Occasionally, rim enhancement of the cryolesion was found in short-term follow-up studies. Because this rim enhancement typically disappeared on subsequent assessment,

such rim enhancement may represent reactive changes in the sublethal cryoinjury and interstitial hemorrhage in the peripheral area. However, persistent enhanced lesion, nodular enhancement, or an increase in the size of the cryolesion must be considered suspicious for residual or recurrent RCC.

Clinical Cryoablation Series

Since our initial clinical series of laparoscopic renal cryoablation, renal cryoablation has now been performed in select patients with a small clinically organ-confined renal tumor at many academic centers via open, laparoscopic, and percutaneous approaches (Table 1). Cryoablation has been shown to not adversely effect long-term renal function. The essential technical requirement of renal cryoablation is the same among open, laparoscopic, and percutaneous approaches. The procedures include (1) real-time imaging of the tumor, (2) preplanning of the angle and depth of cyroprobe entry, (3) needle core biopsy to obtain a tissue specimen, (4) insertion of the cryoprobe perpendicularly through the center of the tumor and advancement of the probe tip just beyond the deep margin of the tumor, (5) confirming that the active cryolesion should not locate in physical proximity to any adjacent viscera or structure, (6) performing a double freeze–thaw cycle, (7) creating a cryolesion to completely engulf the renal tumor with the iceball 1 cm beyond the margin of the tumor, and (8) achieving and confirming hemostasis [2,5].

Laparoscopic Renal Cryoablation

Currently, laparoscopic renal cryoablation is the most studied among all energy-based ablative techniques for RCC. The advantages of a laparoscopic approach include first, the ability to mobilize the kidney away from adjacent bowel and the ueter, thereby avoiding risk of inadvertent cryoinjury; second, dural control of direct laparoscopic visualization as well as ultrasonographic monitoring of the iceball to target the tumor; and third, the ability to achieve hemostasis at the site of cryoprobe puncture if necessary.

Recently, the authors reported intermediate-term oncological follow-up data on 56 patients, each of whom completed a 3-year follow-up after laparoscopic renal cryoablation [13]. According to tumor location, the transperitoneal or retroperitoneal approach was used in 25% and 75% of patients, respectively.

Postoperative imaging assessment comprised serial MRI at postoperative day 1, months 1, 3, 6, 12, 18, and 24, and yearly thereafter for 5 years. The CT-guided needle biopsy of the cryoablated lesion was performed 6 months postoperatively and repeated if MRI findings were abnormal. For a mean renal tumor size of 2.3 cm, mean intraoperative size of the iceball was 3.6 cm. Postoperative needle biopsy identified locally residual/recurrent renal tumor in two patients. Overall 3-year cancer-specific survival was 98% [13].

Table 1. Renal cryoablation: clinical series

First author (year)	Approach	Number of patients	T (cm)	Follow-up (months)	Prognosis/functional data	Comments
Uchida (1995) [11]	Percutaneous	2	—	5–10	Both died of metastatic RCC	First report of renal cryoablation in human
Delworth (1996) [18]	Open	2	6.5	1–3	Minimal loss of renal function	Feasibility in solitary kidney
Gill (1998) [2]	Laparoscopic	10	2	5.5 (3–9)	No enhance in MRI in all 11	Initial series of laparoscopic approach
Bishoff (1999) [19]	Laparoscopic	8	2	7.7 (1–18)	No recurrence/stable serum-Cr	No urinoma, no major complication
Gill (2000) [12]	Laparoscopic	32	2	16.2 (6–23)	1/34 enhanced with pos. biopsy	Largest series, mean 3.2-cm iceball made
Rodriguez (2000) [20]	Open/laparoscopic	7	2.2	14.2	Lesions show partial resolution	Feasibility with minimal morbidity
Rukstalis (2001) [21]	Open	29	2	1–43 (16)	One biopsy-proven local recurrence	Inadequate freezing caused local recurrence
Shingleton (2001) [22]	Percutaneous	20	3	9.1 (3–14)	No MRI enhancement in all	Percutaneous cryoablation under MRI guidance
Carvalhal (2001) [23]	Laparoscopic	22	—	20.6	Stable blood pressure/serum-Cr	Renal function/blood pressure unchanged
Harada (2001) [24]	Percutaneous	4	2.5	—	No major complication	Feasibility of MRI monitoring iceball
Shingleton (2002) [25]	Percutaneous	4	3.3	2–23	Two patients required retreatment	Feasibility in von Hippel–Lindau patients
Lee (2003) [26]	Laparoscopic	20	2.6	14.2 (1–40)	No local and no port site recurrence	No evidence of disease in 14.2 months
Shingleton (2003) [27]	Percutaneous	14	3.1	17 (2–30)	Three patients required retreatment	Percutaneous cryoablation feasibility for solitary kidney

Table 1. *Continued*

First author (year)	Approach	Number of patients	T (cm)	Follow-up (months)	Prognosis/functional data	Comments
Nadler (2003) [28]	Laparoscopic	15	2.2	15 (5–27)	Incomplete in 3.2-cm tumor	Select tumor <3 cm/monitor iceball
Bassignari (2004) [16]	Percutaneous	3	2.8	2	No enhancement in all 4 tumors	Feasibility of US-guided percutaneous cryoablation
Moon (2004) [29]	Laparoscopic	16	2.6	9.6	All remain nonenhanced	Duplicating previous laparoscopic cryoablation report
Cestari (2004) [30]	Laparoscopic	37	2.6	6 or longer	All negative at 6 months bx in 25	Patients duplicating previous laparoscopic cryoablation report
Tuncali (2004) [31]	Percutaneous	27	2.2	—	37% benign preprocedural bx	Preprocedural bx may change decision
Silverman (2005) [15]	Percutaneous	23	2.6	14 (4–30)	One abscess and one bleeding	MRI used for guidance and monitoring
Bachmann (2005) [32]	Laparoscopic	7	2.6	13.6	No residual and no recurrence	Small 1.5-mm ablative probe available
Gore (2005) [33]	Laparoscopic	4	2	—	One residual enhancement	Feasibility of laparoscopy-assisted percutaneous cryoablation
Gill (2005) [13]	Laparoscopic	56	2.3	36 in each	Two postoperative biopsy was positive	Largest and longest follow-up series
Gupta (2006) [17]	Percutaneous	20	2.4	6	One enhanced one major bleeding	CT-guided cryoablation for noncentral tumor

RCC, renal cell carcinoma; T, tumor; Cr, creatinine; bx, biopsy; US, ultrasound

Percutaneous Cryoablation

Although limited data are currently available for assessing the role of percutaneous renal cryoablation, Silverman et al. reported the largest percutaneous series of renal cryoablation under general anesthesia with MRI guidance in 23 patients with a mean tumor size of 2.6 cm [15]. Image guidance for percutaneous renal cryoablation alternated between MRI, CT, and ultrasound (US). Although an interventional MRI system is expensive and limited in use, the ability of real-time guidance and visualization of the iceball in multiple planes are the advantage of MRI guidance, allowing the operator to achieve the safety margins of the cryolesion. Bassignari et al. described the feasibility of real-time US-guided percutaneous renal cryoablation to aim for future performance of this treatment by a urologist alone without the assistance of an interventional radiologist because urologists have extensive experience in ultrasound intervention [16]. Gupta et al. recently reported an attempt of percutaneous renal cryoablation under conscious sedation with local anesthesia in 20 patients. Under sedation, voluntary respiratory movement of a kidney may impact on the accuracy in angle and depth of cryoprobe entry into the tumor [17]. These initial technical feasibility studies suggest that percutaneous renal cryoablation is promising; however, longer-term meticulous clinical follow-up data are needed to determine treatment success.

The indication for percutaneous renal cryoablation appears more limited by size and location of the renal tumor compared to laparoscopic renal cryoablation because, for percutaneous approach, insertion of the smaller cryoprobe (2.4 mm in diameter) is preferable because of consideration of the size of the skin incision. The smaller cryoprobe limits creating a smaller cryolesion with tumoricidal temperature. An anterior or central renal tumor is difficult to target by the percutaneous approach, as it may locate in the proximity of critical vascular structures of the bowel, pelvis, or ureter that should not be damaged by the iceball. As such, the current indication of percutaneous renal cryoablation is restricted to older patients with a posterior peripheral small renal tumor (Table 2).

Conclusion

We recently reported the outcome of 3 years' follow-up of laparoscopic cryoablation in a clinically large number of patients. These ongoing intermediate-term oncological data are encouraging for continued performance of renal cryoablation for RCC in carefully selected older patients with a small renal mass. Five-year follow-up data are necessary to determine the appropriate place of renal cryoablation among treatment options for nephron-sparing surgery.

Table 2. Characteristics of cryosurgical approach

	Advantage	Disadvantage	Comment
Open approach	Direct visualization of iceball No need for laparoscopic expertise	Most invasive Need general anesthesia	Highly controversial procedure with ethical concerns
Laparoscopic approach	Less invasive Monitor by both laparoscopy (direct visualization) and contact laparoscopic US Ability to mobilize the kidney Any tumor location indicated (alternative, transperitoneal/retraoperitoneal approach)	Need general anesthesia	Currently most widespread approach Available follow-up data up to 3 years compatible with partial nephrectomy
MRI-guided percutaneous approach	Real-time guidance Real-time monitoring efficacy Minimally invasive Able to confirm accurate needle placement	Need expensive open MRI facility and MRI-specific equipment Need interventional radiologist Select small, peripheral, posterior tumor Under general anesthesia (by current reports)	Need development of less expensive facility and equipment
CT-guided percutaneous approach	Able to confirm accurate needle placement Under local anesthesia plus sedation (by a current report)	Not real-time guidance Radiation exposure by fluoro/spinal CT Need interventional radiologist and CT facility Select small, peripheral, posterior tumor	Need avoidance of extensive radiation exposure
US-guided percutaneous approach	Real-time guidance Real-time monitoring iceball Minimally invasive Feasible by urologist with familiarity in US intervention	Lower-resolution image than CT or MRI Need expertise of US Select small, peripheral, posterior tumor 12- and 11-rib bones interface US image (difficulty to target upper pole tumor)	Contrast enhanced US, three-dimensional US and/or real-time virtual sonography (RVS, fusion system with pre-operative CT) [34] may compensate for disadvantages of US

References

1. Uzzo RG, Novick AC (2001) Nephron sparing surgery for renal tumors: indications, techniques and outcomes. J Urol 166:6–18
2. Gill IS, Novick AC, Sobble JJ, et al (1998) Laparoscopic renal cryoablation: initial clinical series. Urology 52:543–551
3. Gill IS, Desai MM, Kaouk JH, et al (2002) Laparoscopic partial nephrectomy for renal tumor: duplicating open surgical techniques. J Urol 167:469–477
4. Ukimura O, Kawauchi A, Fujito A, et al (2004) Radio-frequency ablation of renal cell carcinoma in patients who were at significant risk. Int J Urol 11:1051–1057
5. Gill IS (2003) Minimally invasive nephron-sparing surgery. Urol Clin N Am 30:551–579
6. Gage AA, Baust J (1998) Mechanisms of tissue injury in cryosurgery. Cryobiology 37:171–186
7. Campbell SC, Krishnamurthi V, Chow G, Hale J, Myles J, Novick AC (1998) Renal cryosurgery: experimental evaluation of treatment parameters. Urology 52:29–33
8. Woolley ML, Sclsinger DA, Durand DB, et al (2002) Effect of freezing parameters (freeze cycle and thaw process) on tissue destruction following renal cryoablation. J Endourol 16:519–522
9. Chosy SG, Nakada SY, Lee FT Jr, et al (1998) Monitoring renal cryosurgery: predictors of tissue necrosis in swine. J Urol 159:1370–1374
10. Sung GT, Gill IS, Hsu TH, et al (2003) Effect of intentional cryo-injury to the renal collecting system. J Urol 170:619–622
11. Uchida M, Imaide Y, Sugimoto K, et al (1995) Percutaneous cryosurgery for renal tumours. Br J Urol 75:132–136
12. Gill IS, Novick AC, Meraney AM, et al (2000) Laparoscopic renal cryoablation in 32 patients. Urology 56:748–753
13. Gill IS, Remer EM, Hasan WA, et al (2005) Renal cryoablation: outcome at 3 years. J Urol. 173:1903–1907
14. Remer EM, Weinberg EJ, Oto A, et al (2000) MR imaging of the kidneys after laparoscopic cryoablation. AJR Am J Roentgenol 174:635–640
15. Silverman SG, Tuncali K, vanSonnenberg E, et al (2005) Renal tumors: MR imaging-guided percutaneous cryotherapy—initial experience in 23 patients. Radiology 236:716–724
16. Bassignari MJ, Moore Y, Watson L, et al (2004) Pilot experience with real-time ultrasound guided percutaneous renal mass cryoablation. J Urol 171:1620–1623
17. Gupta A, Allaf ME, Kavoussi LR, et al (2006) Computerized tomography guided percutaneous renal cryoablation with the patient under conscious sedation: initial clinical experience. J Urol 175:447–452
18. Delworth MG, Pisters LL, Fornage BD, von Eschenvach AC (1996) Cryotherapy for renal cell carcinoma and angiomyolipoma. J Urol 155:252–254
19. Bishoff JT, Chen RB, Lee BR, et al (1999) Laparoscopic renal cryoablation: acute and long-term clinical, radiographic, and pathologic effects in an animal model and application in a clinical trial.J Endourol 13:233–239
20. Rodriguez R, Chan DY, Bishoff JT, et al (2000) Renal ablative cryosurgery in selected patients with peripheral renal masses. Urology 55:25–30
21. Rukstalis DB, Khorsandi M, Garcia FU, et al (2001) Clinical experience with open renal cryoablation. Urology 57:34–39

22. Shingleton WB, Sewell PE Jr (2001) Percutaneous renal tumor cryoablation with magnetic resonance imaging guidance. J Urol 165:773–776
23. Carvalhal EF, Gill IS, Meraney AM, et al (2001) Laparoscopic renal cryoablation: impact on renal function and blood pressure. Urology 258:357–361
24. Harada J, Dohi J, Mogami T, et al (2001) Initial experience of percutaneous renal cryosurgery under the guidance of a horizontal open MRI system. Radiat Med 19:291–296
25. Shingleton WB, Sewell PE Jr (2002) Percutaneous renal cryoablation of renal tumors in patients with von Hippel-Lindau disease. J Urol. 167:1268–1270
26. Lee DI, McGinnis De, Feld R, et al (2003) Retroperitoneal laparoscopic cryoablation of small renal tumors: intermediate results. Urology 61:83–88
27. Shingleton WB, Sewell PE Jr (2003) Cryoablation of renal tumours in patients with solitary kidneys. BJU Int 92:237–239
28. Nadler RB, Kim SC, Rubenstein JN, et al (2003) Laparoscopic renal cryosurgery: the Northwestern experience. J Urol 170:1121–1125
29. Moon TD, Lee FT Jr, Hedican SP, et al (2004) Laparoscopic cryoablation under sonographic guidance for the treatment of small renal tumors. J Endourol 18:436–440
30. Cestari A, Guazzoni G, Dell'Acqua V, et al (2004) Laparoscopic cryoablation of solid renal masses: intermediate term followup. J Urol 172:1267–1270
31. Tuncali K, vanSonnenberg E, Shankar S, et al (2004) Evaluation of patients referred for percutaneous ablation of renal tumors: importance of a preprocedural diagnosis. AJR Am J Roentgenol 183:575–582
32. Bachmann A, Sulser T, Jayet C, et al (2005) Retroperitoneoscopy-assisted cryoablation of renal tumors using multiple 1.5 mm ultrathin cryoprobes: a preliminary report. Eur Urol 47:474–479
33. Gore JL, Kim HL, Schulam P (2005) Initial experience with laparoscopically assisted percutaneous cryotherapy of renal tumors. J Endourol 19:480–483
34. Ukimura O, Kaouk J, Remer EM, et al (2006) Real-time virtual sonography guided percutaneous radiofrequency-ablation of renal tumor: initial experience. J Urol (Suppl) AUA (abstract) (in press)

Ureteral Stent for Ureteral Stricture

James F. Borin and Elspeth M. McDougall

Summary. Advances in minimally invasive treatment of ureteral stricture have been facilitated by the development of small-caliber, flexible ureteroscopes and the holmium laser; however, most patients will require a stent at some point during management. A ureteral stent can be employed for a variety of reasons: (1) to provide a scaffold for healing after endoureterotomy; (2) to maintain urinary flow in the case of chronic obstruction that is not amenable to repair; and (3) as a prophylactic measure to guard against the development of ureteral stricture after ureteroscopy, ureteroneocystostomy, ureteroureterostomy, or ureteroenteric anastomosis. Since Finney originated the double-J stent in 1978, minor modifications in design and biomaterials have improved on the original concept with the aim of increasing durability and decreasing discomfort and encrustation. Currently, there are no perfectly biocompatible materials available for ureteral stents; silicone remains the gold standard, although various proprietary compounds have been developed based on silicone or polyurethane. Metal stents present a promising, long-term option for the management of recalcitrant ureteral strictures. The optimal stent size after endoureterotomy or endopyelotomy is controversial; however, there may be an advantage to larger-caliber stents, generally >12–14 Fr. Similarly, there is no consensus on the duration of stinting after stricture repair. Most studies suggest that there is no benefit to stinting beyond 2–3 weeks, and there may even be a detriment in the form of fibrosis and increased risk of urinary tract infection.

Keywords. Ureteral stricture, Stent, Ureteropelvic junction obstruction, Biomaterials

University of California Irvine Medical Center, Department of Urology, 101 The City Drive, Orange, CA 92868, U.S.A.

Introduction

Successful treatment of ureteral stricture disease requires patience and creativity on the part of the urologist. There are numerous options available to repair a ureteral stricture, but factors such as comorbidities, age, prior surgery, patient compliance, and the surgeon's own skill and familiarity with various techniques all factor into the treatment algorithm. What is certain is that regardless of the treatment selected, the majority of ureteral strictures will require a stent at some point during management. Depending on the etiology of the stricture, a stent may be a temporary or permanent solution.

The etiology and, to a lesser extent, location of a ureteral stricture will dictate the most appropriate approach to management. Table 1 lists the common causes of ureteral stricture disease. The factors underlying each of these can be further narrowed to malignancy or ischemia, whether iatrogenic due to ureteroscopy, pelvic surgery, or radiation, or traumatic due to passage of a calculus.

Intrinsic strictures are generally more amenable to endourological procedures, especially when shorter than 2 cm (Fig. 1). Extrinsic strictures tend to be longer and thus require more invasive repairs or else long-term stents. Of paramount importance in treating a ureteral stricture is to perform a biopsy to rule out malignancy if the cause is unclear. Stricture repair may be performed either antegrade or retrograde, or even laparoscopically in the case of pyeloplasty for ureteropelvic junction (UPJ) obstruction, ureteroureterostomy for midureteral strictures, or ureteral reimplant for a distal stricture.

A ureteral stent can be employed for a variety of reasons: (1) to provide a scaffold for healing after endoureterotomy; (2) to maintain urinary flow in the case of chronic obstruction that is not amenable to repair; or (3) as a prophylactic measure to guard against the development of ureteral stricture after ureteroscopy, ureteroneocystostomy, ureteroureterostomy, or ureteroenteric anastomosis.

Davis et al. popularized the use of a ureteral catheter as a scaffold for healing when they performed an intubated ureterotomy during open repair of a UPJ obstruction in 1943 [1,2]. Subsequently, Oppenheimer and Hinman showed, in a dog model, that smooth muscle regeneration and not fibrotic contracture is responsible for ureteral healing after a stinted ureterotomy [3].

In patients with long or recalcitrant ureteral strictures or extrinsic compression due to malignancy, definitive repair may not be feasible or desirable because of comorbidities or short life expectancy. In fact, patients with malignant extrin-

Table 1. Etiology of ureteral strictures requiring a stent

Intrinsic	Extrinsic
Iatrogenic	Metastatic tumor disease
Infection (tuberculosis)	Radiation
Inflammation (ureteral calculus)	Retroperitoneal fibrosis
Ureteropelvic junction obstruction (congenital)	

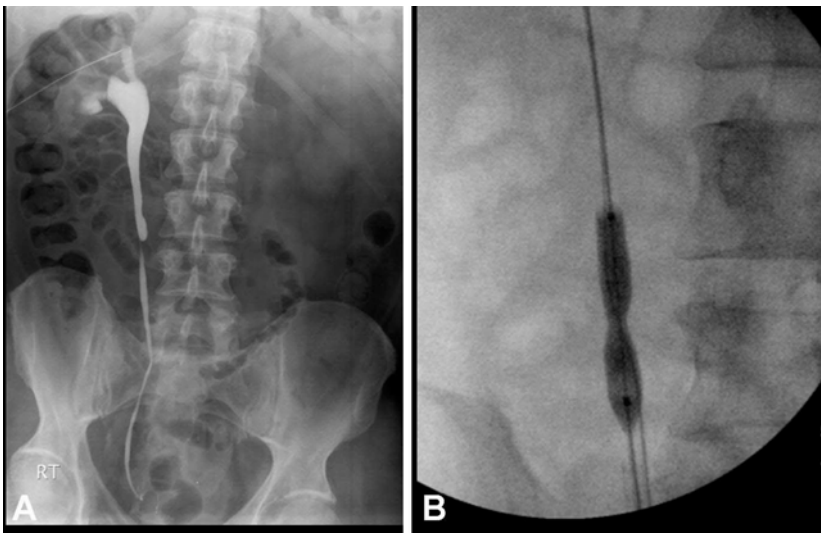


Fig. 1. A 52-year-old man developed a ureteral stricture after multiple ureteroscopies for recurrent nephrolithiasis. **A** Antegrade nephrostogram demonstrates a short ureteral stricture at L3–L4. **B** Balloon dilatation performed after laser incision. A persistent waist eventually disappeared after applying 7 atmospheres of pressure to the balloon

sic compression have an estimated stent failure rate of 36%–42%, and many will require percutaneous nephrostomy tubes [4,5]. Further, the median survival time of patients with metastatic cancer causing ureteral obstruction is reported to be less than 7 months; thus, surgical procedures beyond simple internal or external drainage are generally not warranted [6].

Although the placement of either double-J or diversion stents after ureterointestinal anastomosis is the current standard of care, prophylactic stinting to prevent a ureteral stricture after ureteroscopy or renal transplant is controversial. The incidence of ureteral stricture after ureteroscopy with small-caliber semirigid or flexible ureteroscopes is low, generally 0%–2% in most large series [7,8]. There are no randomized, controlled trials demonstrating the ability of a stent to prevent ureteral strictures. In fact, the routine use of a ureteral stent following uncomplicated ureteroscopy has been questioned. Denstedt et al. performed the first randomized trial to compare stinted versus unstinted ureteroscopy in 58 patients [9]. There was no difference in the complication rate, which was low, although there was significantly less pain, dysuria, and urinary frequency among the unstinted group during the first postoperative week. All patients were assessed with a renal ultrasound at 3 months, and there was no evidence of hydronephrosis or ureteral stricture in either group.

Urological complications are encountered in 1.5%–13% of renal transplants, with ureteral obstruction the most common [10–12]. Approximately 60% of all urological complications are ureterovesical anastomotic strictures, which usually

occur early but can manifest as late as 5 years posttransplant [13]. Because transplanted kidneys lack renal innervation, ureteral obstruction is usually asymptomatic, which can delay diagnosis. In nontransplanted patients, placing a stent across a ureteral repair has been demonstrated to reduce or eliminate stricture formation [14]. However, the routine use of double-J stents during renal transplant is still controversial, with randomized controlled trials demonstrating conflicting results. For example, Osman et al. found no strictures in either group of stinted or unstinted patients ($n=50$) with a mean follow-up of 11 months, whereas the rate of urinary tract infection was double in the stinted group (40% vs 18%; $P=0.02$) [15]. However, a recent meta-analysis of 49 studies, including 5 randomized controlled trials, found fewer urological complications with stinted versus nonstinted extravesical ureteroneocystostomy [16].

Treatment of Ureteral Stricture

The history of endourological approaches to ureteral stricture begins with the first balloon dilatation by Nitze in 1907 [17]. Grüntzig improved the design of small balloon catheters with the first percutaneous transluminal coronary angioplasty in 1978 [18]. Wickam and Kellett first reported "percutaneous pyelolysis" in three patients in 1983 [19], which was then modified by Badlani et al. as an "endopyelotomy" [20]. Further advances in minimally invasive treatment of ureteral stricture have been facilitated by the development of small-caliber flexible ureteroscopes and the holmium laser. It is our practice to address virtually all ureteral strictures in either a retrograde, antegrade, or combined manner. However, UPJ obstructions due to crossing vessels are repaired with a laparoscopic pyeloplasty (Fig. 2).

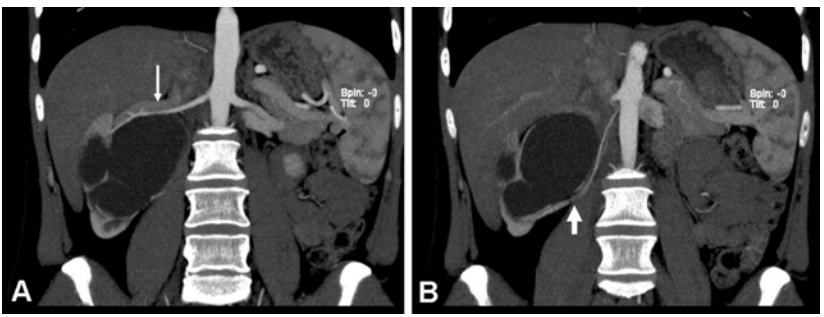


Fig. 2. Computed tomography (CT) angiogram with reconstructed coronal images demonstrating a ureteropelvic junction obstruction in a 33-year-old woman. **A** Markedly dilated calyces and renal pelvis. The main (superior) renal artery is marked by a *thin arrow*. **B** An anterior crossing artery (*thick arrow*) with an accompanying vein is the cause of the obstruction at the level of the uteropelvic junction (UPJ). This patient was successfully treated with a laparoscopic dismembered pyeloplasty with transposition of the crossing vessels. A 6 Fr stent was left in situ for 3 weeks postoperatively

Stent History and Etymology

The term stent, as applied to the field of medicine, originated with the English dentist Charles T. Stent, who, with his two sons, fabricated a more durable substance for making dental impressions in 1859 [21]. During World War I, a Dutch plastic surgeon subsequently described the use of "stents mould" as an aid in skin grafting and hypospadias repair [22]. The term "stent" did not reach the urological literature for another half-century. Two manuscripts from the early 1970s helped to solidify modern usage. Goodwin's editorial *Splint, Stent, Stint* first applied "stent" to what had been previously referred to as a catheter, tube, or splint [21]: "Urologists are always talking about putting a tube in a ureter or urethra. When they do this, it is not a splint. It may be a stent. It probably is never a stint. Perhaps the process is most properly described as leaving a tube or stent in an organ." [23]. Building upon Goodwin's initial efforts, Montie et al. concluded "When referring to an intralumenal device to maintain patency until healing has taken place, the word stent is most appropriate." [24].

The concept of a tube designed to maintain ureteral patency originated with Albarran who made the first ureteral catheter in 1909 [25]. It was not until 1976 that Gibbons crafted a new version; this stent was made of silicone and contained barbs along the shaft and a distal flange to prevent migration, a significant problem of the earlier design [26]. However, the barbs resulted in a larger outer diameter and thus the stent was difficult to place [27]. The modern design of the double-J stent was reported by Finney in 1978 [28]. Since then, minor modifications in design and biomaterials have improved on the original concept with the aim of increasing durability and decreasing discomfort and encrustation [27].

Stent Biomaterials

A biomaterial may be defined as any substance—either natural or derived from synthetic polymers—used in the treatment of a patient that interfaces with tissue [29]. An ideal biomaterial for the urinary tract would be biocompatible, have adequate tensile strength, reduced coefficient of friction, stability after placement, resistance to encrustation and infection, and excellent flow [29]. A completely biocompatible material would not adversely affect or be affected by the environment in which it was placed [29]. Currently, there are no perfectly biocompatible materials available for ureteral stents. Ureteral catheters were initially crafted from fabric coated with varnish [30]. Because they did not have sufficient rigidity for easy placement, they were later constructed of plastic [31]. Today, a variety of synthetic polymers is employed in ureteral stent design.

Silicone is the current gold standard for ureteral stents due to its high degree of tissue compatibility and resistance to encrustation [32]. However, the extreme flexibility of silicone can make stent passage more difficult [27]. Polyurethane is

more rigid than silicone yet still flexible, but demonstrates more urothelial erosion and ulceration than other materials and may even result in cytotoxic degradation products if left in situ for extended periods [33,34]. Several proprietary biomaterials have also been developed with the goal of retaining the flexibility and inert nature of silicone but with more rigidity: Silitek (Surgitek, Racine, WI, USA), C-Flex (Consolidated Polymer Technologies, Clearwater, FL, USA), and Percuflex (Boston Scientific, Natick, MA, USA) [27].

Hydrogel coatings are currently employed for most stent materials; they improve biocompatibility by reducing irritation and cell adhesion [27]. Heparin-like polysaccharide coatings have shown promise in reducing encrustation by resisting biofilm formation [35]. Finally, in a clever attempt to employ an inert substance, Amiel et al. developed stents from bovine and mouse chondrocytes in vitro and in vivo; although these have yet to be placed in in vivo models, this type of bioengineering holds great promise for the future [36].

Stent Flow

Luminal and extraluminal flow characteristics have been studied in in vitro and in vivo models of the stinted and unstinted ureter. [37–40]. The flow of urine through a normal ureter is based on the principles of Poiseuille's law, which describes laminar streamlined viscous flow through a horizontal tube [37]. In a porcine model, Brewer et al. demonstrated that luminal, but not extraluminal, flow is proportional to internal stent diameter [40]. The same group subsequently evaluated the pattern of flow in stinted and unstinted ureters and compared these results to Poiseuille flow in vitro [41]. They demonstrated that in vitro flow did not accurately predict in vivo flow patterns. In their animal model, there was a nonsignificant trend for better flow through stinted versus unstinted ureters. In contrast to Ramsay et al. [39], who reported that stent flow is primarily extraluminal and can therefore be compromised by external compression of the ureter, the authors noted that luminal flow comprised 67%, 50%, and 33% of the total flow for a tail stent (7 Fr tapering to a lumen-less 3 Fr tail), a standard 7 Fr double-pigtail stent, and a 7/14 Fr endopyelotomy stent, respectively. Thus, drainage will be both around and through a stent. External compression will first compromise extraluminal flow; in severe cases, however, even a stinted ureter can become obstructed in a matter of days.

Metal Stents

Various designs of short metal stents have been used in clinical practice over the past 15 years, but none of these has been in the style of an indwelling ureteral stent. In 1991, Lugmayr and Pauer first reported their experience with self-expanding metallic stents of a defined length (3–10 cm); these stents consisted of an elastic mesh woven from stainless cobalt-based alloy filaments [42]. The stent was mounted on a 7 Fr delivery catheter. A follow-up report of 40 patients with

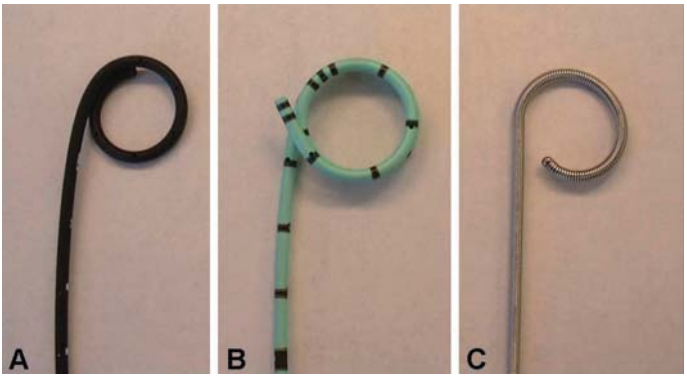


FIG. 3. Representative double-pigtail stents. **A** Silicone. **B** Polyurethane. **C** Metal (Resonance)

54 ureters obstructed due to malignancy demonstrated a 49% reintervention rate with Kaplan–Meier estimation of only a 31% patency at 12 months [43]. Much of the problem with these stents was due to ingrowth of hyperplastic urothelium and subsequent obstruction. Mean follow-up was 10.5 months, and survival rate at 12 and 24 months was 40% and 22%, respectively. Concerns with metal ureteral stents include biocompatibility, hyperplastic tissue response, and encrustation. Newer versions of expandable stents constructed of nitinol may be more biocompatible than their predecessors [44].

The Resonance metal stent (Cook Ireland, Limerick, Ireland) is a continuous unfenestrated metal coil with a 6Fr lumen and an inner safety wire welded to both closed, tapered ends (Fig. 3C). It is constructed of MP35N alloy, a composite of nonmagnetic nickel-cobalt-chromium-molybdenum possessing a unique combination of ultrahigh tensile strength and excellent resistance to corrosion, high-temperature oxidation, and hydrogen embrittlement. This alloy is used in the manufacture of other medical devices, including cardiac stents. Its superelastic properties allow for tremendous strength as well as flexibility, and it is compatible with a 1.5-Tesla field strength magnetic resonance imaging scan.

We compared the encrustation potential of the Resonance metal stent versus silicone and polyurethane stents in an in vivo rabbit model and found no increased risk of encrustation in the severe environment of the hypercalciuric rabbit bladder [45]. We are uncertain of the means of drainage for this closed-ended stent; however, we hypothesize that drainage occurs solely by capillary action along the metal coils of the stent. Studies in this regard are planned for the near future.

The acceptable stent indwell time has yet to be determined. In Europe, Resonance stents are approved to remain in situ for 12 months. In England, these stents have been left in place for as long as 11 months without complications. To date, there have been no reports of stent fracture or inability to remove the stent due to encrustation.

Stent Types: Indwelling and External

Early ureteral stents had to be measured to fit each patient; as there was no mechanism for self-retention, these stents often migrated [46]. Modern stents have retention coils and shape memory, which helps to prevent migration (Fig. 3). There are four basic designs: pigtail, J, cross-coil, and double-pigtail (or double-J) [46]; the latter is the most popular design in use today.

Common stent sizes include 6, 7, and 8 Fr. For recalcitrant ureteral obstruction, particularly due to extrinsic compression, two 6 or 7 Fr stents may be placed simultaneously in the same ureter [47]. For endopyelotomy, tapered stents are often employed, typically 7/10 Fr or 7/14 Fr. In some cases, large-caliber stents may be desired throughout the ureter. Single pigtail ureteral stents of 10 Fr or biliary urinary drainage (BUD) catheters of 10, 12, or 14 Fr may be employed with drainage to an external appliance. The silicone Universal stent is a 10 Fr soft catheter with multiple fenestrations that is placed in a percutaneous antegrade approach. It can be capped to provide internal drainage. Similarly, a nephroureteral stent can facilitate antegrade stent changes and allow for easy access to the collecting system.

The ideal size for a stent placed after repair of a ureteral stricture has been studied but is still somewhat controversial. In his initial report, Davis empirically advocated large-bore stents of 12–16 Fr [1]. In a porcine model, Moon et al. compared healing after endoureterotomy of an iatrogenically induced midureteral stricture in groups receiving 7/14 Fr endopyelotomy stents or standard 7 Fr stents [48]. Stents were removed after 1 week; at 3 months, there was no difference in the rate of stricture recurrence (20%) between both groups, demonstrating no advantage for the larger stent. Conversely, a retrospective review by Wolf et al. found that benign ureteral strictures of any length benefited from the use of a stent ≥12 Fr [49].

Optimal stent size after endopyelotomy may favor larger-caliber models. Hwang et al. retrospectively compared 6 Fr versus 7/14 Fr stents in 40 patients with both primary and secondary stricture of the UPJ or upper ureter [50]. Stents were left in situ for 6–8 weeks after percutaneous endopyelotomy and endoureterotomy; mean follow-up was 3 years. Due to the small number of patients, there was only a nonsignificant trend favoring the larger-bore stents, with success rates of 93% versus 84% for the 6 Fr group. Danuser and colleagues, however, demonstrated the superiority of a 27 Fr percutaneous endopyelotomy catheter they created by adding a 27 Fr wound drain to a standard 8.2/14 Fr stent versus the unmodified 8.2/14 Fr stent after antegrade cold-knife endopyelotomy [51,52]; 113 of 196 patients had a follow-up greater than 5 years, which consisted of a urogram and diuretic renography at 2 years, then a questionnaire and ultrasound every 2–3 years. The success rate was 83% for the 27 Fr group versus 65% for the 14 Fr group ($P<0.05$). Patients with primary UPJ obstruction had long-term success rates of 88% (28/32) with 27 Fr versus 64% (42/66) with 14 Fr ($P<0.05$). The authors concluded that large-caliber stinting after antegrade endopyelotomy results in better, sustainable success rates.

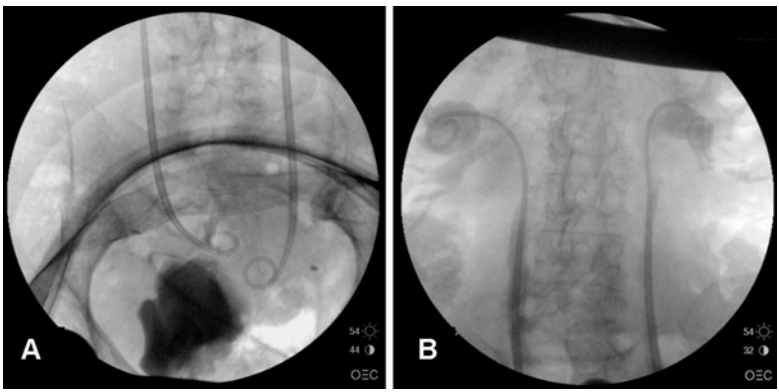


FIG. 4. Postoperative cystogram in a 79-year-old woman who developed ureterointestinal strictures 1 year after augmentation cystoplasty with ureteral reimplantation. The strictures were treated with antegrade balloon dilatation and incision with a holmium laser. **A** Inverted 7/14 Fr stents were passed antegrade such that the 14 Fr portion crossed the ureterointestinal junction. **B** Postoperatively, free retrograde reflux of contrast ensures the stents are patent. Note the tapering of the stent proximally to 7 Fr

It is our current practice to use 7/14 Fr stents after endopyelotomy and to invert these same stents after endoureterotomy of ureteroenteric stricture (Fig. 4). For a benign, midureteric stricture, we will use a 7 Fr stent or two 6 Fr stents.

Stent Duration

In determining the length of stent indwell time following minimally invasive treatment of a ureteral stricture, one must balance two objectives: (1) allowing the stent to act as a scaffold to facilitate healing; and (2) avoiding infection and inflammation, which will lead to fibrosis [53]. Much of the dogma about the duration of stinting is based on Davis' original work in dogs wherein he found 90% replacement of the ureteral smooth muscle 6 weeks following intubated ureterotomy [2]. McDonald and Calams also studied ureteral regeneration after injury in a dog model [54]. Similar to Davis, they noted near-complete muscular continuity by 7 weeks. However, once the epithelium had been reestablished, the stent began to induce a fibrotic response, which increased over time.

There are several arguments against prolonged stinting. There is an increased risk of infection as well as the possibility of an increased inflammatory response at the site of repair; these alone or in concert may result in fibrosis and restricturing [33]. Kerbl et al. induced ureteral strictures in a pig model, then treated them with Acucise endoureterotomy [55]. All pigs received 7 Fr stents, which were then removed at 1, 3, or 6 weeks following the endoureterotomy. At 12 weeks, pigs were killed and the degree of ureteral healing was assessed by a pathologist. There was no statistically significant difference in healing across the three groups, although there was a trend favoring the 1-week group. Moreover,

for strictures >2 cm, there was a statistically significant difference favoring the 1-week group versus the 6-week group. A recent animal study sought to determine optimal stent size and duration [56]. After balloon endoureterotomy of an experimentally induced stricture, pigs were maintained with 7 Fr or 7/14 Fr stents for either 3 or 6 weeks. One month after stent removal, there was no difference in ureteral diameter or histopathological changes at the stricture site. However, there was a significant relationship between urinary tract infection (UTI) and stricture recurrence, with UTI prevalence directly related to a larger stent with a longer indwell time.

This issue has been examined in human subjects as well. A retrospective review of 135 patients who underwent endopyelotomy noted a 78% success rate for those stinted for 3 weeks versus only 60% for the 6-week group [57]. There are two randomized, prospective trials, performed by the same group, which have attempted to address this controversy. The first compared two groups of 13 patients who had nephroureteral stents placed for 2 or 4 weeks, following endopyelotomy [58]. At a mean follow-up of 18 months, diuretic renogram curves showed objective improvement in 69% (9/13) for the 2-week group versus 54% (7/13) for the 4-week group. The second trial randomized 52 patients after endopyelotomy; 7/14 Fr internal stents were placed for either 2 or 4 weeks [59]. At a mean follow-up of 22 months, diuretic renography showed improved drainage in 93% (2-week) versus 90% (4-week), a difference that was not statistically significant. However, there was a significantly increased incidence of UTI in the 4-week group versus the 2-week group (38% vs 11.5%, $P=0.04$).

These studies suggest that there is no benefit to stinting beyond 2–3 weeks, and there may even be a detriment in the form of fibrosis and increased risk of UTI. Therefore, we favor early removal of stents following endoureterotomy or endopyelotomy, generally after 2 or 3 weeks.

Conclusion

Ureteral stents represent an integral component in the treatment of ureteral stricture. New materials that are more biocompatible may help to prevent stent complications such as encrustation, infection, discomfort, and inflammation leading to fibrosis. In terms of prophylactic use of stents to prevent strictures, they are probably not necessary following routine ureteroscopy but may be beneficial in renal transplants. After treatment of ureteral stricture or UPJ obstruction, there is some evidence that large stents (>12–14 Fr) placed for short periods of time (2–3 weeks) will result in better long-term success rates and fewer UTIs.

References

1. Davis DM (1943) Intubated ureterostomy: a new operation for ureteral and ureteropelvic strictures. Surg Gynecol Obstet 76:513

2. Davis DM, Strong GH, Drake WM (1948) Intubated ureterotomy: experimental work and clinical results. J Urol 59:851–862
3. Oppenheimer R, Hinman F Jr (1955) Ureteral regeneration: contracture vs. hyperplasia of smooth muscle. J Urol 74:476–484
4. Ganatra AM, Loughlin KR (2005) The management of malignant ureteral obstruction treated with ureteral stents. J Urol 174:2125–2128
5. Chung SY, Stein RJ, Landsittel D, Davies BJ, Cuellar DC, Hrebinko RL, Tarin T, Averch TD (2004) 15-year experience with the management of extrinsic ureteral obstruction with indwelling ureteral stents. J Urol 172:592–595
6. Russo P (2000) Urologic emergencies in the cancer patient. Semin Oncol 27:284–298
7. Elashry OM, Elbahnasy AM, Rao GS, Nakada SY, Clayman RV (1997) Flexible ureteroscopy: Washington University experience with the 9.3 F and 7.5 F flexible ureteroscopes. J Urol 157:2074–2080
8. Francesca F, Scatloni V, Nava L, Pompa P, Grasso M, Rigatti P (1995) Failures and complications of transurethral ureteroscopy in 297 cases: conventional rigid instruments vs. small caliber semirigid ureteroscopes. Eur Urol 28:112–115
9. Denstedt JD, Wollin TA, Sofer M, Nott L, Weir M, D'A Honey RJ (2001) A prospective randomized controlled trial comparing nonstented versus stented ureteroscopic lithotripsy J Urol 165:1419–1422
10. Gettman MT, Levy JB, Engen DE, Nehra A (1998) Urological complications after kidney pancreas transplantation. J Urol 159:38–43
11. Butterworth PC, Horsburgh T, Vietch PS, Bell PR, Nicholson ML (1997) Urological complications in renal transplantation: impact of change in technique. Br J Urol 79: 499–502
12. Faenza A, Nardo B, Catena F, Scolari MP, d'Arcangelo GL, Buscaroli A, Rossi C, Zompatori M (1999) Ureteral stenosis after kidney transplantation: a study on 869 consecutive transplants. Transplant Int 12:334–340
13. Thiounn N, Benoit G, Osphal C, Charpentier B, Bensadoun H, Hiesse C, Moukarzel M, Neyrat N, Bellamy J, Lantz O (1991) Urological complications in renal transplantation. Prog Urol 1:531–538
14. Finney RP (1982) Double-J and diversion stents. Urol Clin North Am 9:89–94
15. Osman Y, Ali-El-Dein B, Shokeir AA, Kamal M, El-Din AB (2005) Routine insertion of ureteral stent in live-donor renal transplantation: is it worthwhile? Urology 65:867–871
16. Mangus RS, Haag BW (2004) Stented versus nonstented extravesical ureteroneocystostomy in renal transplantation: a metaanalysis. Am J Transplant 4:1889–1896
17. Nitze M (1907) In: Lehrbuch der Kystoskopie. Wiesbaden, pp 410
18. Grüntzig A (1978) Transluminal dilatation of coronary artery stenosis. Lancet 1:263
19. Wickam JEA, Kellett MJ (1983) Percutaneous pyelolysis. Eur Urol 9:122–124
20. Badlani G, Eshghi M, Smith AS (1986) Percutaneous surgery for ureteropelvic junction obstruction (endopyelotomy): technique and early results. J Urol 135:26–28
21. Bloom DA, Clayman RV, McDougall EM (1999) Stents and related terms: a brief history. Urology 54:767–771
22. Esser JF (1917) Studies in plastic surgery of the face. Ann Surg 65:297–315
23. Goodwin WE (1972) Splint, stent, stint. Urol Dig 11:13–14
24. Montie JE, Stewart BH, Levin HS (1973) Intravasal stents for vasovasostomy in canine subjects. Fertil Steril 24:877–883
25. Herman JR (1973) Urology: a view through the resectoscope. Harper & Row, New York

26. Gibbons RP, Correa RJ Jr, Cummings KB, Mason JT (1976) Experience with indwelling ureteral stent catheters. J Urol 115:22–26
27. Watterson JD, Dadieux P, Denstedt JD (2002) Ureteral stents: which, when, and why? AUA Update Ser 21:122–127
28. Finney RP (1978) Experience with a new double-J ureteral catheter stent. J Urol 120: 678–681
29. Mardis HK, Kroeger RM (1988) Ureteral stents: materials. Urol Clin N Am 15: 471–479
30. Mattelaer JJ (2004) History of ureteral and urethral stenting: 1870–1990. In: Yacchia D, Paterson PJ (eds) Stenting the urinary system. Martin Dunitz, New York, pp 17
31. Beiko DT, Knudsen BE, Watterson JD, Denstedt JD (2003) Biomaterials in urology. Curr Urol Rep 4:51–55
32. Denstedt JD, Wollin TA, Reid G (1998) Biomaterials used in urology: current issues of biocompatibility, infection, and encrustation. J Endourol 12:493–500
33. Marx M, Bettmann MA, Bridge S, Brodsky G, Boxt LM, Richie JP (1988) The effects of various indwelling ureteral catheter materials on the normal canine ureter. Urology 139:180–185
34. Slepian MJ, Hossainy SFA (2004) Characteristics of materials used in implants: polymers. In: Yacchia D, Paterson PJ (eds) Stenting the urinary system. Martin Dunitz, New York, pp 77
35. Riedl CR, Witkowski M, Plas E, Pflueger H (2002) Heparin coating reduces encrustation of ureteral stents: a preliminary report. Int J Antimicrob Agents 19: 507–510
36. Amiel GE, Yoo JJ, Kim BS, Atala A (2001) Tissue engineered stents created from chondrocytes. J Urol 165:2091–2095
37. Boyarsky S, Labay P (1972) In: Ureteral dynamics. Williams & Wilkins, Baltimore, p 52
38. Mardis HK, Kroeger RM, Hepperlen TW, Mazer MJ, Kammandel H (1982) Polyethylene double-pigtail ureteral stents. Urol Clin N Am 9:95–101
39. Ramsay JW, Payne SR, Gosling PT, Whitfield HN, Wickham JE, Levison DA (1985) The effects of double J stenting on unobstructed ureters: an experimental and clinical study. Br J Urol 57:630–634
40. Brewer AV, Elbahnasy AM, Bercowsky E, Maxwell KL, Shalhav AL, Kahn SA, McDougall EM, Clayman RV (1999) Mechanism of ureteral stent flow: a comparative in vivo study. J Endourol 13:269–271
41. Olweny EO, Portis AJ, Afane JS, Brewer AV, Shalhav AL, Luszczynski K, McDougall EM, Clayman RV (2000) Flow characteristics of 3 unique ureteral stents: investigation of a Poiseuille flow pattern. J Urol 164:2099–2103
42. Lugmayr H, Pauer W (1991) Self-expanding metallic stents in malignant ureteral stenosis. Dtsch Med Wochenschr 116:573–576
43. Lugmayr HF, Pauer W (1996) Wallstents for the treatment of extrinsic malignant ureteral obstruction: midterm results. Radiology 198:105–108
44. Trueba Arguinarena FJ, Fernandez del Busto E (2004) Self-expanding polytetrafluoroethylene covered nitinol stents for the treatment of ureteral stenosis: preliminary report. J Urol 172:620–623
45. Borin JF, Tyson D, Sala LG, Abdelshehid CA, Le T, Nguyen A, McDougall EM, Clayman RV (2005) Encrustation of biomaterials in an in vivo rabbit model. J Endourol 19:A284

46. Lawrentschuk N, Russell JM (2004) Ureteric stenting 25 years on: routine or risky? ANZ J Surg 74:243–247
47. Liu JS, Hrebinko RL (1998) The use of 2 ipsilateral ureteral stents for relief of ureteral obstruction from extrinsic compression. J Urol 159:179–181
48. Moon YT, Kerbl K, Pearle MS, Gardner SM, McDougall EM, Humphrey P, Clayman RV (1995) Evaluation of optimal stent size after endourologic incision of ureteral strictures. J Endourol 9:15–22
49. Wolf JS Jr, Elashry OM, Clayman RV (1997) Long-term results of endoureterotomy for benign ureteral and ureteroenteric strictures. J Urol 158:759–764
50. Hwang TK, Yoon JY, Ahn JH, Park YH (1996) Percutaneous endoscopic management of upper ureteral stricture size of stent. J Urol 155:882–884
51. Danuser H, Hochreiter WW, Ackermann DK, Studer UE (2001) Influence of stent size on the success of antegrade endopyelotomy for primary ureteropelvic junction obstruction: results of 2 consecutive series. J Urol 166:902–909
52. Danuser H, Dobry E, Z'Brun S, Mattei A, Studer UE (2005) Better endopyelotomy results with larger stent size! Are they stable in the long term? J Urol 173:316
53. Razdan S, Silberstein IK, Bagley DH (2005) Ureteroscopic endoureterotomy. BJU Int 95:94–101
54. McDonald JH, Calams JA (1960) Experimental ureteral stricture: ureteral regrowth following ureterotomy with and without intubation. J Urol 84:52–59
55. Kerbl K, Chandhoke PS, Figenshau RS, Stone AM, Clayman RV (1993) Effect of stent duration on ureteral healing following endoureterotomy in an animal model. J Urol 150:1302–1305
56. Soria F, Sanchez FM, Sun F, Ezquerra J, Duran E, Uson J (2005) Comparative study of ureteral stents following endoureterotomy in the porcine model: 3 vs 6 weeks and 7 F vs 14 F. Cardiovasc Intervent Radiol 28:773–778
57. Kuenkel M, Korth K (1990) Endopyelotomy: results after long-term follow-up of 135 patients. J Endourol 4:109–116
58. Kumar R, Kapoor R, Mandhani A, Kumar A, Ahlawat R (1999) Optimum duration of stenting after endopyelotomy. J Endourol 13:89–92
59. Mandhani A, Kapoor R, Zaman W, Kumar A, Bhandari M, Gambhir S (2003) Is a 2-week duration sufficient for stenting in endopyelotomy? J Urol 169:886–889

Endoscopic Treatment of Vesicoureteral Reflux

Nicola Capozza and Daniela Zavaglia

Summary. Since its introduction in 1984, endoscopic treatment of vesicoureteral reflux (VUR) has gained popularity and has proved successful in an increasing number of patients. Continuous improvements in injectable materials and increased experience with the technique have led to a broadening of the indications for endoscopic treatment. The authors report their experience with 1732 patients and 2455 refluxing ureters, treated over the past 20 years. From January 1986 to June 2005, 1732 patients underwent endoscopic treatment for grades II to V VUR. Polytetrafluoroethylene was injected as the bulking material in the first 14 cases; after 1989 bovine collagen was used in 442 cases, and starting in 1995 dextranomer/hyaluronic acid copolymer was used in 1276 cases. The follow-up protocol also changed over the years. The main changes consisted of time and number of micturition cystourethrograms (MCUG): in the first years MCUG was performed 3 and 12 months after endoscopic treatment; after 1999 a single MCUG was performed 3–6 months postoperatively. Minimum follow-up was 6 months. After one injection the overall success rate was 79% of ureters, and 91%, 78%, and 62% for grades II, III, and IV-V VUR, respectively. After the second injection, the overall success rate increased to 91%. Voiding dysfunction was identified as a possible limiting factor in the success of endoscopic treatment. Our results confirm that endoscopic treatment of VUR is a valid alternative to both long-term antibiotic prophylaxis and open surgery. The short hospital stay, the absence of significant postoperative complications, the safety of new injectable materials, and the increasingly high success rate suggest that endoscopic treatment should be offered as a first-line option to all children with VUR.

Keywords. Vesicoureteral reflux, Endoscopy, Injection, Dextranomer

---

Department of Pediatric Urology, "Bambino Gesù" Children's Hospital, Piazza S. Onofrio, 4, Rome 00165, Italy

Introduction

Vesicoureteral reflux (VUR) is the most common urological malformation in the pediatric age group; however, consensus has yet to be reached regarding its optimal management. Until the early 1980s, treatment guidelines for VUR recommended the use of antibiotic prophylaxis as initial therapy, with surgical repair for patients with persistent VUR [1]. Over the past 20 years, endoscopic treatment (ET) of VUR has gained popularity and has proved successful in an increasing percentage of cases [2].

Endoscopic subureteral injection of polytetrafluoroethylene was first described by Matouschek in 1981 and further developed by O'Donnell and Puri, who reported successful results in pigs and humans in 1984 [3–5]. Since then, VUR has been treated endoscopically in thousands of children, using different injectable materials. The indications and results of endoscopic treatment of VUR have changed over time, and various modifications of the original technique have been proposed in the last 20 years.

Injection Technique

The technique of endoscopic treatment was originally described by Puri and O'Donnell for subureteral polytetrafluoroethylene injection (STING) [5].

The most common cystourethroscopes are the Wolf-O'Donnell 10 Ch (Richard Wolf, Khittlingen, Germany), the Storz 10 Ch (Storz, Tuttlingen, Germany), and the Wolf 14 Ch. Optic lens varies from 5° to 30°. We have recently started using a new cystoscope, the Wolf 8/9,8 Ch, which is particularly effective in young infants as it has a very thin distal section (8 Ch) (Fig. 1). The material

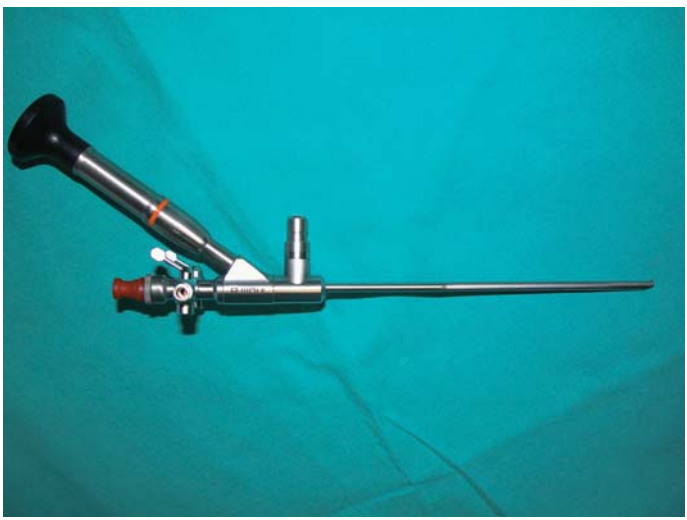


Fig. 1. Cystoscope 8/9,8 Ch, with a straight working channel

is injected through a 23-gauge endoscopic needle. The needle can be flexible, semirigid, or rigid. We recommend the rigid "all metal" needle (Q-Med, Uppsala, Sweden), which allows us to perform the injection very precisely, without the help of an assistant. When the metal needle is chosen, it is advisable to use a cystoscope with a straight working channel. According to the original technique, the needle is inserted a few millimeters below the ureteral orifice and the material is injected into the terminal submucosal tract of the ureter (Fig. 2). At the end of the procedure, a volcano-like projection with the ureteral orifice on top should be visible (Fig. 3).

Technical adjustments are necessary in some instances, particularly in cases of endoscopic treatment of VUR after failed surgery [6]. Specifically, a ureteral catheter should be inserted before the injection. In cases of previous transtrigonal ureteral reimplantation, gentle traction on the catheter toward the medial line helps to medialize the reimplanted orifice, to have it frontal and facilitate

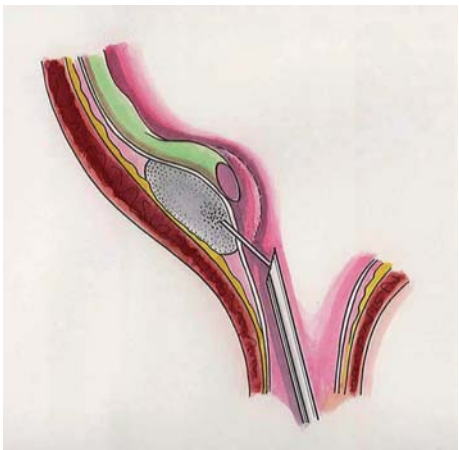


Fig. 2. Injection technique: bulking material is injected into the submucosal ureter

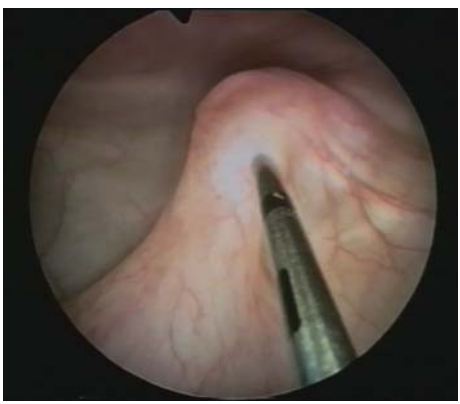


Fig. 3. Endoscopic view at the end of injection

the injection. If the final appearance is unsatisfactory, the injection can be performed also along the entire ureteral tunnel [7].

In 2005 Kirsch and Scherz presented a modification of the technique as an evolution of the STING procedure named the hydrodistension implantation technique (HIT). This modification is based on two concepts: hydrodistension of the ureteral orifice and submucosal intraureteral implantation of the material. With this technique, the needle is placed within the ureteral tunnel and the injection is performed into the submucosal intraureteral space along the entire length of the detrusor tunnel [7].

In our experience, this technique has proved useful in high-grade reflux with a short tunnel, when an intraureteral injection is feasible even without hydrodistension. In low-grade VUR, we give preference to the standard technique, which avoids hydrodistension and the consequent risk of seeding the kidney with bacteria. The amount of injectable material varies from 0.1 to 1.5 ml, depending also on the experience of the operators: with greater experience, less material can be used to achieve a satisfactory implant configuration.

Materials

Polytetrafluoroethylene (Teflon; Dupont, Wilmington, Delaware)

Teflon was first used in 1963 by Arnold for injection into vocal cords to treat dysphonia. In 1981, Matouschek introduced the concept of polytetrafluoroethylene paste implantation. In 1984, O'Donnell and Puri described the STING procedure as we know and use it today. Teflon is stable and remains visible by ultrasound at long-term follow-up. Nevertheless, in the late 1980s, experimental and clinical studies demonstrated that local and metastatic granuloma may form after Teflon injection [8–10]. Even though the results of these studies were strongly criticized by some authors [11,12], we decided to discontinue Teflon injections after our first 14 cases.

Bovine Collagen (Zyplast, Contigen; Collagen Corporation, Palo Alto, CA, USA)

Glutharaldehyde cross-linked bovine collagen (GAX collagen) has been widely used in cosmetic medicine. In 1986, a multicenter study was performed on bovine collagen for VUR treatment [13]. Since then, bovine collagen has been used in thousands of cases worldwide [14,15]. In our series, bovine collagen was used from 1989 to 1999 in 442 children. Unlike Teflon, bovine collagen is biodegradable, and histological findings have shown newly formed human collagen fibers [16]. Experimentally, collagen does not migrate to distant organs. Questions have been raised about possible cross-reactions between newly formed antibovine collagen antibodies and human collagen [17,18].

Polydimethysiloxane (Macroplastique; Uroplasty Ltd, Reading, UK)

Particles of polydimethylsiloxane are dispersed in a (povidone) gel. As in a foreign-body reaction, there is recruitment of macrophages and fibroblasts, with a resulting production of collagen [19]. The size of the particles ranges from 16 to 400 μm (30% are smaller than 100 μm and 7% smaller than 50 μm), and a small risk of distant migration still exists [20].

Chondrocytes

Atala et al. (1994) used chondrocytes in a biodegradable polymer solution for endoscopic treatment of VUR in an animal model, and Diamond and Caldamone (1998) used it clinically [21,22].

Calcium Hydroxylapatite (Coaptite; BioForm Medical, San Mateo, CA, USA)

It is a biocompatible and inert material, made of calcium hydroxylapatite spheres of 100 μm suspended in a water and glycerine gel. The main characteristic of this material is its X-ray opaqueness [23,24].

Dextranomer/Hyaluronic Acid Copolymer (Deflux; Q-Med, Uppsala, Sweden)

Dx/HA is a material composed of dextranomer microspheres and sodium hyaluronan (1%). These constituents form a viscous solution that is biodegradable, nonallergenic, nonmutagenic, and nonimmunogenic. These properties are highly favorable for endoscopic treatment [25]. The size of microspheres is 80–100 μm, and distant migration has never been reported [26]. We have used Dx/HA since 1995 as the material of choice for endoscopic treatment of VUR and, to June 2005, we treated 1276 patients (1811 refluxing ureters).

Our 20-Year Experience: Patients and Methods

From January 1986 to June 2005, 1732 patients (2455 refluxing ureteral units) of an age ranging from 5 months to 22 years (average, 28 months) underwent endoscopic treatment for grades II–V VUR. Grade I VUR was treated only when associated with contralateral higher-grade VUR. Grade V was initially not considered as eligible for endoscopic treatment; however, since 2001 we have also treated grade V VUR endoscopically, with few exceptions.

Of the total patients, 1608 (2293 ureters) had primary reflux, in 58 (62 ureters) reflux was secondary to a duplex system, 20 patients (37 ureters) had neurogenic

bladder, 18 (24 ureters) had posterior urethral valves, and in 28 (39 ureters) VUR was secondary to a failed reimplantation.

After 1994, all children with VUR who were older than 3 years of age were also evaluated using a micturition questionnaire, uroflowmetry, and measurement of postvoid residual urine. Voiding habits were classified as normal (group 1), mild–moderate voiding dysfunction (group 2), and severe voiding dysfunction (group 3).

Polytetrafluoroethylene was used in the initial 14 cases; after 1989, glutharaldehyde cross-linked bovine collagen was used in 442 cases, and since 1995 dextranomer/hyaluronic acid (Dx/HA) was used in 1276 cases (1811 ureters). The amount of material injected averaged 0.6 ml (0.2–2.2 ml). All the procedures were recorded on videotape and, when a second injection was required, the final appearance of the implant was compared with the one previously recorded.

Children were discharged 24 h after treatment. Antibiotic prophylaxis was continued for 1 month postoperatively. Follow-up consisted of periodic urinalysis, renal and bladder ultrasound 1 month after treatment, and, in our initial experience, micturition cystourethrogram (MCUG) 3 and 12 months after treatment. In the last 7 years, we have performed a single MCUG 3–6 months after treatment. In children having acquired urinary control and without urinary tract infection (UTI), a mercaptoacetyltriglycine-3 (MAG3) renal scan with indirect voiding cystogram has recently been preferred to traditional fluoroscopic MCUG. Long-term follow-up of cured patients included dimercaptosuccinic acid (DMSA) renal scan 12 months after treatment, and renal-bladder ultrasound once a year. In cases of febrile UTI or recurrent symptomatic UTI, a micturition diary was completed and another cystogram was performed. Patients with persistent or relapsing VUR of grade II or higher were considered for a second endoscopic treatment. A third treatment was performed in selected cases (18 patients). Open surgery was performed for persistent VUR, after two to three endoscopic attempts, only in the first years of our experience (10 patients). In the last 10 years, these patients have been managed with clinical follow-up with no antibiotic prophylaxis (AP) and with intermittent antibiotic treatment of UTI.

Results

After one injection, MCUG showed no or grade I VUR in 79% of ureters. The success rate was 91%, 78%, and 62% for grades II, III, and IV–V, respectively (Table 1). After a second injection, the success rate increased to 91%. A significant improvement in the success rate was noted in the most recent years, as compared to the previous years (Fig. 4). In endoscopic treatment after failed ureteral reimplantation, VUR was cured in 22 of 28 patients (78.5%), and in 30/39 ureters (76.9%). The results in secondary VUR treatment are described in Table 2.

Most relapses occurred during the first year of follow-up. No relapses were observed after 3 years, and the incidence of recurrence between 1 and 3 years

TABLE 1. Results of endoscopic treatment according to different materials and grade of vesicoureteral reflux (VUR) for 2455 ureters, 1986–2005

VUR Grade	Teflon			Collagen			Deflux			Overall success Rate
	Ureters	Success (%)		Ureters	Success (%)		Ureters	Success (%)		
II	7	6	85	258	209	81	858	806	94	91%
III	11	8	73	302	202	67	1099	890	83	78%
IV–V	4	2	50	62	25	40	498	324	65	62%
Total	22	16	73	622	436	70	1811	1485	82	79%
Number of patients		14			442			1276		

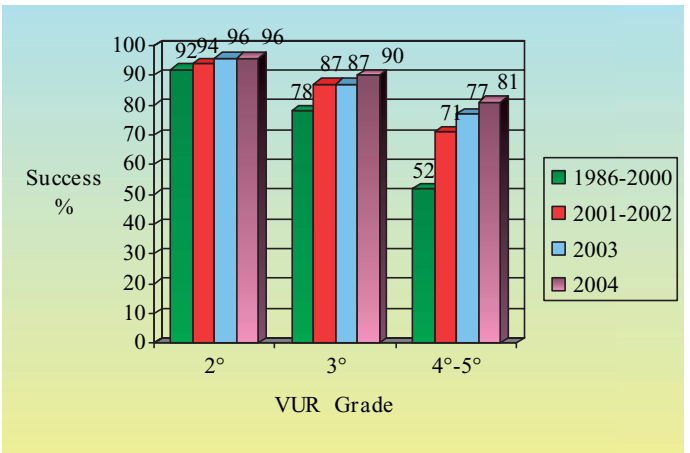


FIG. 4. Results of endoscopic treatment for vesicoureteral reflux according to different periods (indicated by *color*)

TABLE 2. Results of endoscopic treatment in secondary VUR

	Success
Failed Cohen	12/18 ureters
Double system	43/62 ureters
Neurogenic bladder	27/37 ureters
Posterior urethral valves	16/24 ureters

after treatment was 1%. The only major complications observed were prolonged and severe hematuria in one case and transient ureterovesical junction obstruction in eight cases (0.4%). This obstruction occurred in six cases after subureteral injection of bovine collagen and in two cases after injection of Dx/HA. Minor complications, such as dysuria and slight hematuria, should be considered as expected events in the circumstances. The comparison between DMSA scan

performed before treatment and 12 months after treatment showed no new scars. No significant variation in serum creatinine and glomerular filtration rate was found at 12-month follow-up.

In cases of VUR recurrence, the micturition questionnaire showed a significant number of cases of previously undetected voiding dysfunction (mainly in the groups of low and mild/moderate voiding dysfunction). Abnormal voiding habits were reported in 54% of the children in whom endoscopic treatment had failed versus 8% of those successfully treated. At the second treatment, the previously injected implant was often found displaced (usually medially and distally) from the original position, as confirmed by the videotape of the first treatment.

Discussion

Until the late 1990s, the overall success rate of endoscopic treatment was rather low compared to open surgery. In a recent meta-analysis of studies on endoscopic treatment of VUR, Elder and colleagues found an overall success rate (after one course of treatment) of 66.69%. The resolution rate of the second course of treatment was 54.39% [27].

In recent years, there have been major advances in endoscopic treatment, mainly regarding new injectable materials and improved endoscopic instruments and technique [2].

Materials

For about 15 years, endoscopic treatment has been performed using mainly polytetrafluoroethylene, silicone, and bovine collagen, but concerns about their safety and efficacy have precluded their widespread use. Dextranomer/hyaluronic acid (Dx/HA) copolymer has proved to be safe and much more effective than antibiotic prophylaxis [28].

In 2001, the FDA approved Dx/HA copolymer for VUR treatment. There is no doubt that the availability of a safe material has greatly contributed to the widespread use of endoscopic treatment and that this has fostered research into better instruments and techniques.

Instruments

The availability of the right endoscopic instruments is of primary importance to achieve good results. In our opinion, it is essential to use a straight operating channel cystoscope, 8 to 14 Fr, according to the patient's age. The cystoscopes we used in our series are the Wolf-O'Donnell 9.5 and 14 Fr and the Storz 10 Fr. Since 2004 we have used the Wolf 8/9.8 Fr cystoscope for very young patients. As mentioned previously, our preference is for an all-metal needle.

Technique

During the past 5 years, the results of endoscopic treatment of VUR have been constantly improving because of the above-described technical adjustments. The most recent series showed an overall success rate of about 90%, and the improvement was more evident in grade IV VUR [7]. As this success rate approaches that of open surgery, there may be a rationale for eliminating the standard postoperative micturition cystourethrogram.

Failure

Treatment outcome is known to be influenced by reflux grade and accuracy of injection technique [28–30]. In 2002, we investigated whether voiding dysfunction could affect the success of endoscopic treatment. Data from our study, in which Dx/HA was the only material used, suggest that uncontrolled voiding dysfunction may cause displacement of the implant, thus reducing treatment success. Endoscopic findings at the time of retreatment support this hypothesis because the displaced implant was found toward the bladder neck at medial and distal sites with respect to the ureteral orifice [31]. In about one-third of cases there was no evidence of the implanted material at the time of re-treatment, suggesting a poor implantation technique. Injection deep into the bladder wall, with secondary migration along the Waldeyer's sheath, accounts for the majority of early failures of endoscopic treatment. Alternative explanations, such as the distant migration or the biodegradation of the implant, are unlikely because of the large diameter of dextranomer microspheres.

Indications to ET

Although vesicoureteral reflux is a common disorder in pediatric patients, there is controversy over reflux management. As a result of the advances in endoscopic treatment, the 1997 American Urological Association (AUA) guidelines are being reevaluated to include this procedure in the management of VUR [27–32].

To date, the three main options are open surgery, antibiotic prophylaxis, and endoscopic treatment with injectable materials. Few randomized comparative studies have been performed in recent years to assess the optimal management of VUR.

If the goal is the prevention of renal damage, there is no evidence of better results with one treatment rather than another. However, if the goal is to cure VUR and to avoid daily antibiotics and yearly cystographies, there is no doubt that both surgery and endoscopic treatment are much more effective than antibiotic prophylaxis (AP) [28–32].

Many authors have suggested stopping antibiotic prophylaxis after a certain age, even though the reflux may not have been resolved [33–35]. Nevertheless, there is a well-documented risk of renal scarring when AP is stopped [36–41]. Moreover, there are no controlled, prospective studies to support this

recommendation, and antibiotics cannot be safely stopped in children with persistent reflux.

Some studies are ongoing to evaluate the safety of "no treatment" for VUR; this modality should be better defined as "intermittent antibiotic therapy for breakthrough UTI." In our opinion, this therapy can be proposed for children older than 3 years of age, with the informed consent of compliant parents. Other arguments against the overuse of antibiotics are related to the rise of bacterial resistance [42]. Concerns about antibiotics may be among the reasons of parental preferences for ET. In a parent survey that we published in 2003, parental preferences indicate that endoscopic treatment should be considered as first-line treatment for all VUR patients, rather than open surgery or prolonged antibiotic prophylaxis [43,44].

Cost-Effectiveness Considerations

Some studies have been performed to assess the cost and outcome of endoscopic treatment of VUR, as compared to antibiotics and surgery [45]. The conclusions of these studies are that endoscopic treatment of VUR appears to be cost-effective, when compared to open surgery; cost effectiveness is less obvious when comparing ET to antibiotic prophylaxis (or simple observation). Human costs are more difficult to measure. If we consider the invasiveness and disadvantages of the different options, ET requires about 10 min of general anesthesia, it is a 1-day procedure, and the possible complications are usually limited to a mild, temporary dysuria. Open surgery needs 60–90 min of general anesthesia; it entails an abdominal incision, about 5 days in hospital, 3 weeks for full recovery, postoperative pain, and possible major complications.

Conclusions

In our opinion, the advent of endoscopic treatment has changed the algorithm of reflux management in children. ET is minimally invasive, can be performed as 1-day surgery (or even as an outpatient procedure), and has very low morbidity.

Currently used injectable materials are safe and ensure long-term permanence at the site of injection. The success rate of ET is high if compared to long-term prophylaxis and, due to the continuous improvements of materials, instruments, and technique, it is approaching that of open surgery. ET results are satisfactory even in complex anatomical situations.

On the basis of the foregoing considerations, we propose endoscopic treatment as the first-line option for most cases of VUR. Long-term prophylaxis, intermittent antibiotic therapy, or open surgery can be reserved to selected cases, mainly after failure of endoscopic treatment.

References

1. Report of the International Reflux Study in Children (1981) Medical versus surgical treatment of primary vesicoureteral reflux: report of the International Reflux Study Committee. Pediatrics 67:392
2. Capozza N, Lais A, Nappo S, Caione P (2004) The role of endoscopic treatment of vesicoureteral reflux: a 17-year experience. J Urol 172:1626–1629
3. Matousceck E (1981) Die bahandlung des vesikorenalen refluxes durch transurethrale einspritzung von Teflon paste. Urologe A 20:263–264
4. Puri P, O'Donnell B (1984) Correction of experimentally produced vesicoureteric reflux in the piglet by intravesical injection of Teflon. Br Med J 289:5–7
5. O'Donnell B, Puri P (1984) Treatment of vesicoureteric reflux by endoscopic injection of Teflon. Br Med J 289:7–9
6. Capozza N, Caione P, Nappo S, De Gennaro M, Patricolo M (1995) Endoscopic treatment of vesico-ureteric reflux and urinary incontinence; technical problems in the pediatric patients. Br J Urol 75:538–563
7. Kirsch AJ, Perez-Brayfield MR, Smith EA (2004) The modified STING procedure to correct vesicoureteral reflux: improved results with submucosal implantation within the intramural ureter. J Urol 171(1):2413–2416
8. Mittleman RE, Maraccini JV (1983) Pulmonary Teflon granulomas following periurethral Teflon injection for urinary incontinence. Arch Pathol Lab Med 107:611–612
9. Malizia AA, Reiman HM, Myers RP, Sande JR, Barham SS, Benson RC (1984) Migration and granulomatous reaction after periurethral injection of polytef (Teflon). JAMA 251:3277–3281
10. Rames RA, Aaronson IA (1991) Migration of polytef paste to the lung and brain following intravesical injection for the correction of reflux. Pediatr Surg Int 6:239–240
11. Vandenbossche M, Delhove O, Dumortier P, Deneft F, Schulman CC (1993) Endoscopic treatment of reflux; experimental study and review of Teflon and collagen. Eur Urol 23:386–393
12. Miyakita H, Puri P (1994) Particles found in lung and brain following subureteral injection of polytetrafluoroethylene paste are not Teflon particles. J Urol 152:636–640
13. Peters CA, Jeffs RD (1987) Endoscopic correction of primary vesicoureteric reflux with bovine collagen injected submucosally at the ureteral orifice. J Urol 137(2):122A (abstract 76)
14. Cendron M, Leonard MP, Gearhart JP, Jeffs RD (1991) Endoscopic treatment of vesicoureteral reflux using cross-linked bovine dermal collagen. Pediatr Surg Int 6:295–300
15. Frey P, Jenny P, Herzog B (1991) Endoscopic subureteric collagen injection (SCIN): a new alternative treatment of vesicoureteric reflux in children. Experience in 82 refluxing ureters. Pediatr Surg Int 6:287–294
16. Frey P, Berger D, Jenny P, Herzog B (1992) Subureteral collagen injection for the endoscopic treatment of vesicoureteral reflux in children. Follow-up study of 97 treated ureters and histological analysis of collagen implants. J Urol 148:718–723
17. Ellingsworth LR, De Lustro F, Brennan JE, Sawamura S, McPherson J (1986) The human response to reconstituted bovine collagen. J Immunol 136:877–882
18. Cukier J, Beauchamp RA, Spindler JS, Sindler S, Lorenzo C, Trentham DE (1993) Association between bovine collagen dermal implants and dermatomyosistis or polymiositis-like syndrome. Ann Intern Med 118:920–928

19. Preston Smith D, Kaplan WE, Ryoichi O (1994) Evaluation of polymethylsiloxane as an alternative in the endoscopic treatment of vesicoureteral reflux. J Urol 152: 1221–1223
20. Henley DR, Barrett DM, Weiland TL, O'Connor MK, Malizia AA, Wein AJ (1995) Particulate silicone for use in periurethral injections: local tissue effects and search for migration. J Urol 153:2039–2043
21. Atala A, Kim W, Paige KT, Vacanti CA, Retik AB (1994) Endoscopic treatment of vesicoureteral reflux with a chondrocyte-alginate suspension. J Urol 152(2): 641–643
22. Caldamone AA, Diamond DA (2001) Long-term results of the endoscopic correction of vesicoureteral reflux in children using autologous chondrocytes. J Urol 165(2): 2224–2227
23. Mayer R, Chertin B, Velayudham M, Laxaman D, Colhoun E (2001) Preliminary evaluation of calcium hydroxylapatite as a transurethral bulking agent for stress urinary incontinence. Urology 57:434–438
24. Mevorach R, Rabinowitz R, Beck C, Hulbert W (2002) Endoscopic treatment of vesicoureteral reflux with Coaptite: the first 50 patients. J Urol 167:429 (abstract)
25. Stendberg A, Lackgren G (1995) A new bioimplant Deflux System for the endoscopic treatment for vesicoureteral reflux. Experimental and clinical results. J Urol 154: 800–803
26. Stendberg AM, Sundin A, Laarson E, Lackgren G, Stendberg A (1997) Lack of distant migration after injection of 25 iodine-labelled dextranomer based implant into rabbit bladder. J Urol 158:1937–1941
27. Elder JS, Diaz M, Caldamone AA (2004) Endoscopic therapy for vesicoureteral reflux. A meta-analysis. Presented at American Academy of Pediatrics 2004 National Conference and Exhibition, San Francisco, CA, October 10, 2004
28. Capozza N, Caione P (2002) Dextranomer/hyaluronic acid copolymer implantation for vesicoureteral reflux: a randomized comparison with antibiotic prophylaxis. J Pediatr 140(2):230–234
29. Lackgren G, Stendberg A, Wahlin N (2001) Long-term follow-up of children treated with dextranomer/hyaluronic acid copolymer for vesicoureteral reflux. J Urol 166(5): 1887–1892
30. Yucel S, Ucar M, Guntekin E, Kukul E, Melikoglu M, Baykara M (2005) The effect of location of the ureteric orifice on the efficacy of endoscopic injection to correct vesico-ureteric reflux. BJU Int 95(9):1314–1318
31. Capozza N, Lais A, Matarazzo E, Nappo S, Patricolo M, Caione P (2002) Influence of voiding dysfunction on the outcome of endoscopic treatment for vesicoureteral reflux. J Urol 168:1695–1698
32. Elder JS (1997) Pediatric vesicoureteral reflux guidelines panel summary: report on the management of primary vesicoureteral reflux in children. J Urol 157(5):1846–1851
33. Ditchfield MR, De Campo JF, Nolan TM (1994) Risk factors in the development of early renal cortical defects in children with urinary tract infection. Am J Roentgenol 162:1393–1397
34. Winberg J (1992) Progressive renal damage from infection with or without reflux. J Urol 148:1733–1734
35. Birmingham Reflux Study Group (1987) Prospective trial of operative versus non-operative treatment of severe vesicoureteric reflux in children: five years observation. Br Med J 295:237–241

36. Smellie JM, Poulton A, Prescod N (1994) Retrospective study of children with renal scarring associated with reflux and urinary tract infection. Br Med J 308:1193–1196
37. Shimada K, Matsui T, Ogino T (1988) Renal growth and progression of reflux nephropathy in children with vesicoureteral reflux. J Urol 140:1097–1100
38. Nasseer SR, Steinhardt GF (1997) New renal scars in children with urinary tract infections, vesicoureteral reflux and voiding dysfunction: a prospective evaluation. J Urol 158:566–568
39. Cooper CS, Chung BI, Kirsch AJ (2000) The outcome of stopping prophylactic antibiotics in older children with vesicoureteral reflux. J Urol 163:269–273
40. Thompson RH, Chen JJ, Pugatch J (2001) Cessation of prophylactic antibiotics for managing persistent vesicoureteral reflux. J Urol 166:1465–1469
41. Smellie JM, Jodal U, Mobius TT, Hirche H, Olbing H (2001) Outcome at 10 years of severe vesicoureteric reflux managed medically: report of the International Reflux Study in children. J Pediatr 139(5):656–663
42. Bollgren I (1999) Antibacterial prophylaxis in children with urinary tract infection. Acta Paediatr Suppl 88(431):48–52
43. Ogan K, Pohl HG, Carlson D, Belman AB, Rushton HG (2001) Parental preferences in the management of vesicoureteral reflux. J Urol 166:240–243
44. Capozza N, Lais A, Matarazzo E (2003) Treatment of vesicoureteral reflux: a new algorithm based on parental preference. BJU Int 92(3):285–288
45. Kobelt G, Canning DA, Hensle TW (2003) The cost effectiveness of endoscopic injection of dextranomer/hyaluronic acid copolymer for vesicoureteral reflux. J Urol 169:1480–1485

Photoselective KTP Laser Vaporization of Obstructive BPH (PVP)

Reza S. Malek

Summary. Exigencies of societal demands for alternatives to the not inconsiderable morbidity and significant and increasing cost of transurethral resection of the prostate (TURP) paved the way for development of a multitude of therapies for obstructive benign prostatic hyperplasia (BPH). Among them, laser prostatectomy (LP) attracted much attention. However, phenomenal appeal of earlier coagulative and later cutting (enucleative) or even some vaporizing LP techniques has vanished or waned largely due to some combination of mediocre outcomes, complications, or technical impediments. A recent breakthrough in technologic creation of high-power potassium-titanyl-phosphate (KTP) laser capped by its clinical development and application, pioneered by Malek at Mayo Clinic, paved the way for a new LP technique known as photoselective vaporization of the prostate (PVP). With this novel approach, high-power KTP laser is effectively utilized to vaporize obstructive BPH acutely and hemostatically. Multiple reports of experiences from Mayo Clinic and elsewhere, globally, have found uniformly that PVP is relatively bloodless even in hemostatically impaired patients and typically requires short-term catheterization or no catheterization at all. It is associated with minimal morbidity, even in the high-risk patients, little postoperative discomfort, rapid recovery, and durable long-term symptomatic, quality of life, and urodynamic outcomes that match those of TURP at significantly less cost for the health-care system. Indeed, PVP has evolved from a therapeutic curiosity at Mayo Clinic to a popular and dominant form of therapy for obstructive BPH in the United States. Current trends indicate that it is likely to achieve a similar status globally.

Keywords. Benign prostatic hyperplasia, KTP Laser, Laser surgery, Photoselective vaporization of the prostate, Prostatectomy

Department of Urology, Mayo Clinic, 200 First Street SW, Rochester, MN 55905, USA

Introduction

The prostate traces its etymologic ancestry to ancient Greece, where Herophilus named and described it as the organ standing in front of and, thus, guarding the bladder [1]. The prostate gland surrounds perhaps the most critical crossroad in the urogenital tract. Therefore, by virtue of its strategic location, benign prostatic hyperplasia (BPH) frequently chokes the tract, obstructs the flow of urine, and wreaks havoc with the lives of at least 50% of older men in whom untroubling microscopic BPH has progressed to bothersome macroscopic disease [1,2]. For nearly a century since its introduction, transurethral resection of the prostate (TURP) has been the globally dominant method of treatment for obstructive BPH and the de facto "gold standard" for all other similarly aspiring therapeutic measures [1,2]. However, societal demands for containment of health-care costs coupled with patients' desire for less invasive and less morbid remedies have led to the development of a multitude of newer approaches to treat obstructive BPH. Among the new surgical approaches, applications of various laser wavelengths have attracted much attention and some controversy since the birth of laser prostatectomy (LP) more than a decade ago [3]. A recent meta-analysis of multiple randomized clinical studies showed that, overall, TURP held little to no advantage over LP [4]. Expectedly, LP techniques were widely disparate, performed with different laser wavelengths, and accompanied by significantly different side effects and outcomes [4]. Nevertheless, collectively, LP proved less morbid than TURP with shorter length of hospital stay (LOS) but resulted in slightly less improvement in symptomatic and voiding outcomes and a somewhat higher reoperation rate than TURP [4]. Useful as it is to speak of LP as a collective term for an overview, it is axiomatic to recognize that different laser wavelengths have vastly different interactions with tissue. Consequently, LP techniques applied with different laser wavelengths and their outcomes are equally varied [5]. Of the three principal varieties of LP developed during the past nearly 15 years, the coagulative varieties, namely, noncontact technique with the neodymium:YAG (Nd:YAG) laser (visual laser ablation of the prostate, VLAP) or interstitial application with the diode laser (interstitial laser coagulation, ILC), have languished considerably due to prolonged postoperative obstruction by edematous necrotic tissue, protracted crippling dysuria, and a high rate of long-term failures [6–9]. Similarly, the cutting (enucleative) variety of LP with the holmium:YAG (Ho:YAG) laser, known as holmium laser enucleation of the prostate (HoLEP), despite its conceptual brilliance, completeness of removal of the offending prostatic tissue, and short-term outcomes as good as those of TURP [10], has found limited acceptance by urologists due to a significantly steep learning curve [11], long operative times [10], and a number of complications encountered both during the learning phase of the procedure [12] and even later when the operator was quite experienced [13,14]. Some attempts with the vaporization varieties of LP, however, have earned more success and acceptance. Despite disappointing experiences with the high-power (80–100 W)

Nd:YAG laser vaporization attempts, which also caused concomitant deep coagulation of the prostate [15] and subsequent high rate of dysuria [16], or with high-power holmium laser ablation of the prostate (HoLAP), which was found to be applicable but to small glands and had long-term outcomes described by the authors of the study as "between watchful waiting and TURP" [17], vaporization LP with high-power (60–80 W) potassium-titanyl-phospate (KTP) laser has met with substantial clinical success and acceptance by both patients and urologists worldwide [5]. Efficient vaporization of tissue by the KTP laser is due to release of substantial superficial thermal energy upon selective absorption of its photons by hemoglobin (chromophore). Therefore, prostatectomy with the KTP laser has been called photoselective vaporization of the prostate (PVP) [5].

Scientific Basis of Laser Prostatectomy

A comparative analysis of interactions of various lasers with prostatic tissue is essential to the understanding of rather unique features of PVP. LP is achieved by thermal (coagulation/vaporization) or thermomechanical (tearing/cutting action plus minimal coagulation/vaporization) properties specific to various laser wavelengths currently used in endourology. Thermal energy is focally released only when laser photons are absorbed by a certain component of the targeted tissue acting as chromophore for that specific wavelength. Otherwise, thermal energy is scattered diffusely by inhomogeneities within tissue [5]. Absorption and scattering of laser energy in tissue define the depth to which each laser wavelength penetrates tissue (optical penetration depth) [5]. Water and hemoglobin govern the absorption pattern of each specific laser wavelength, which varies from that of other wavelengths [3,5].

The Nd:YAG laser at a wavelength of 1064 nm undergoes little absorption in hemoglobin or water. Therefore, its invisible continuous beam, irrespective of its noncontact (VLAP) or contact application to tissue in LP, scatters slowly and deeply (up to 10 mm) into a relatively large volume of prostatic tissue; principal pathophysiologic outcome is tissue coagulation accompanied by minimal vaporization and excellent hemostasis [5,15] (Fig. 1a). Post-VLAP, edema and slow sloughing of the coagulated necrotic prostatic tissue cause prolonged urinary obstruction and crippling dysuria [3]. Similarly, ILC with diode laser applied commonly at a wavelength of 830 nm, and with nearly the same hemoglobin and water absorption patterns as the Nd:YAG laser but shallower depth of penetration (5 mm), leads to identically good hemostasis but equally undesirable outcomes [3,5] (Fig. 1b).

The Ho:YAG laser at a wavelength of 2140 nm is strongly absorbed by water and practically not at all by hemoglobin; therefore, its invisible pulsed beam penetrates tissue to a shallow depth of only 0.4 mm, where it induces little coagulation [3]. The absorption pattern of the holmium laser and its pulsed nature play significant roles in its two completely different methods of application in LP and

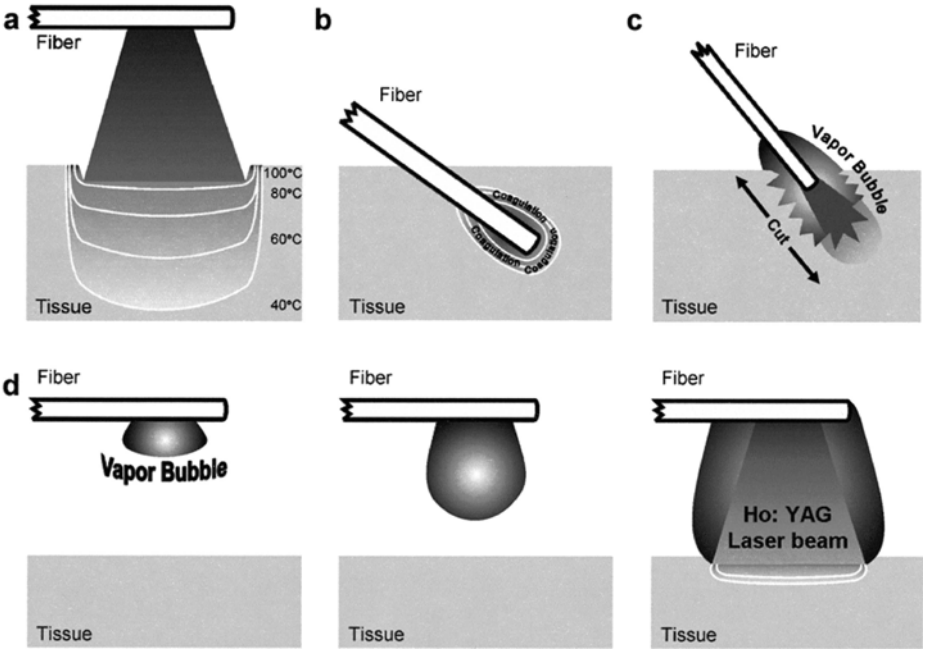


FIG. 1. Laser–tissue interactions in varieties of laser prostatectomy. **a** Visual laser ablation of the prostate (VLAP) by noncontact neodymium:YAG laser coagulation. **b** Interstitial laser coagulation (ILC) of the prostate by diode laser. **c** Contact holmium:YAG (*Ho:YAG*) laser enucleation of the prostate (HoLEP) mediated by mechanical jackhammer-type impact of repetitively (pulsed) formed tiny vapor bubbles on tissue. **d** Noncontact Ho:YAG laser ablation of the prostate (HoLAP) mediated by holmium laser beam transmission through the requisite larger vapor bubble formation (Moses effect). Brief holmium laser–tissue interaction occurs only near the end of each pulsed creation of the Moses effect when the bubble contacts tissue. (Distributed as course material at the American Urological Association Education and Research Inc. 2005 Annual Meeting. Used with permission of Mayo Foundation)

their sequelae. Once the holmium laser beam leaves the tip of the laser fiber, it is absorbed immediately by water in the endoscopic irrigant. Most of the holmium laser energy is thus instantly turned into heat, leading to formation of a vapor bubble [3,5]. What little is left of the holmium laser energy can now traverse the gaseous space created by the vapor bubble (Moses effect) to reach and to vaporize and coagulate the targeted tissue. Having wasted most of its time and energy to create the requisite Moses effect, holmium laser's direct interaction with tissue is quite limited within its short pulse duration. Consequently, during each pulse action, very little tissue has been vaporized and coagulated accompanied by rather limited hemostasis [3,5]. The holmium laser is utilized in two very different varieties of LP:

1. In contact mode for tissue cutting, the mechanical impact of each tiny vapor bubble formed by each laser pulse between the end of the bare fiber tip and the contacted tissue in rapid succession tears the surface of the prostatic lobe (Fig. 1c). This rapidly repetitive tearing and cutting jackhammer type of action is effectively utilized to painstakingly excise (resect) whole prostatic lobes; hence, the procedure is named holmium laser enucleation of the prostate (HoLEP) [3,5]. The excised lobes are pushed back into the bladder and then morcellated and aspirated. Despite outcomes as good as those of TURP, this time-consuming sequence of events in combination with significant technical challenges to master the retrograde enucleative technique and complications of the procedure per se and of tissue morcellation have helped to detract from HoLEP's popularity among urologists [10–14].
2. In noncontact mode for holmium laser prostatic ablation (vaporization), or HoLAP, a larger bubble has to bridge the 0.5- to 1-mm distance between the side-firing laser fiber and the targeted tissue to create the requisite laser-transmitting Moses effect (Fig. 1d). No tearing or cutting action takes place. Instead, HoLAP relies entirely on limited short-lived tissue vaporization and superficial coagulation that occur during a flash of opportunity when the vapor bubble of the Moses effect near its termination briefly contacts tissue (Fig. 1d). Because the time-consuming, energy-wasting Moses effect has to be created repeatedly as a result of the pulsed nature of the holmium laser and because of the inevitable ever-occurring changes in the distance between the fiber and the prostate, which disconnect the laser-transmitting vapor bubble from tissue, vaporization prostatectomy with the holmium laser is, comparatively, slow and inefficient [3,5]. Therefore, HoLAP, which achieves only "adequate hemostasis," is applicable only to small prostates with long-term sub-TURP outcomes [17,18].

The KTP laser at a wavelength of 532 nm is in the visible range of the electromagnetic spectrum, green in color, and produced by frequency-doubling of the 1064-nm Nd:YAG laser. The 532-nm wavelength is highly selectively absorbed by the heme pigment of tissue hemoglobin but almost not at all by the irrigant's water, which, therefore, does not impede the KTP laser beam upon leaving the side-firing fiber from traversing the 0.5- to 1-mm distance (near contact) and reaching the hemoglobin-rich prostatic tissue at practically the speed of light, where it is promptly absorbed by hemoglobin in the superficial layer of the targeted prostatic tissue (optical penetration depth, 0.8 mm). Consequent release in tissue of thus superficially and focally trapped thermal energy results in boiling of tissue water, producing vapor bubbles (Fig. 2a) that rapidly expand and, collectively, disrupt the affected superficial prostatic tissue layers, which erupt as small particles together with vapor bubbles from the exposed surface of the targeted tissue [3,5] (Fig. 2b). Continued application of the KTP laser energy in PVP results in sequential exposure and continued efficient and uninterrupted rapid vaporization of the newly exposed deeper tissue layers. However, the depth of tissue coagulation, irrespective of the power level utilized,

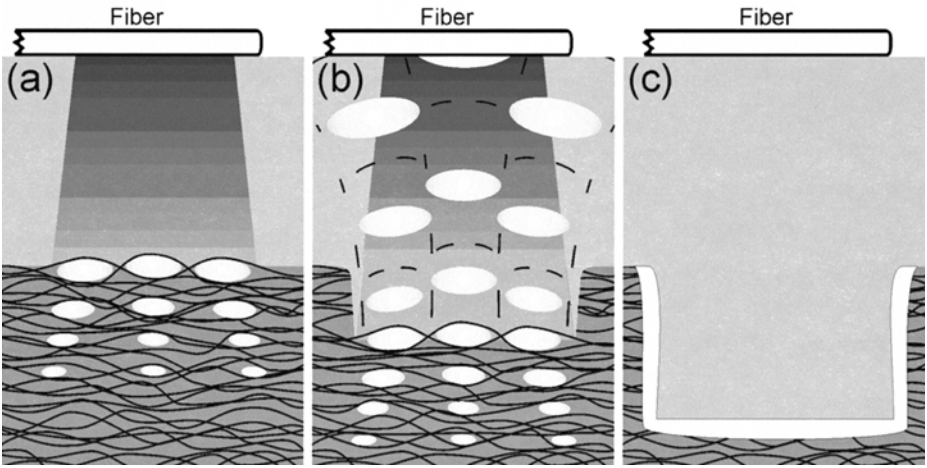


FIG. 2. Potassium-titanyl-phosphate (KTP) laser–tissue interaction in photoselective vaporization of the prostate (PVP). **a** Thermal energy released on hemoglobin absorption of KTP laser beam boils tissue water and generates increasing number of vapor bubbles (*white ovals*) inside tissue. Accumulation of bubbles puts collagen matrix (*black curvilinear areas*) under pressure. **b** Removal of tissue occurs when vapor bubbles burst matrix. Bubbles and tissue fragments erupt from breached surface of tissue. **c** Coagulation zone of 1- to 2-mm (*white area*) lines remaining tissue along crater after laser is discontinued. (Modified from Malek and Nahen [5]. Used with permission)

does not exceed 1–2 mm because most of the thermal energy is both consumed and carried away by the highly efficient vaporization effect [3,5,15,19] (Fig. 2c). The not too shallow and not too deep depth of coagulation accounts, on the one hand, for the usually excellent hemostasis and lymphostasis, preventing dilutional hyponatremia and making PVP safe in patients with deficiencies of hemostasis, and, on the other hand, for the low incidence of tissue necrosis-related post-PVP dysuria [5].

Experimental Foundation of PVP

Original laboratory studies utilizing the KTP laser at 38 W and later at 60 W to vaporize the prostate in living and cadaveric canines and human cadavers were performed by Kuntzman and associates at Mayo Clinic [15,19]. They found that PVP at 60 W for 26 min created a widely patent prostatic cavity, 3 cm in diameter, immediately and with excellent hemostasis [19]. This achievement contrasted with Nd:YAG laser vaporization performed at 80 W with an identical technique in 30 min. Hemostasis was equally impressive with the Nd:YAG laser procedure, but it resulted in inferior outcomes characterized by a smaller 2-cm prostatic

cavity that took 10 days to open up postoperatively. HoLAP in canines had produced even more inferior outcomes [18]. Reportedly, creation of only a 1.9-cm prostatic cavity took a laborious 0.5 h with holmium laser vaporization, which was accompanied by only "adequate" hemostasis [18]. Expectedly, PVP at 60 W was substantially faster than at 38 W; however, the 1- to 2-mm depth of coagulation remained unchanged despite the increase in power [15,19]. Indeed, Kuntzman et al. found that the precise, highly efficient vaporization technique of PVP together with consistently shallow depth of coagulation gave the operator superior control over which tissue is removed and which is left undamaged; in their words, "with the KTP laser, what one sees is very nearly what one gets" [15]. Histopathologic changes of PVP were remarkably mild and especially so when they were compared with those of Nd:YAG coagulation (VLAP) or vaporization [15,19]. In contrast with relatively small, edematously obstructed prostatic cavities surrounded by deep thermal damage, accompanied by extensive mucosal, mural, and extramural collagenous fibrosis and necrosis of neurovascular bundles induced by both types of Nd:YAG laser LP, PVP, irrespective of KTP laser power utilized, acutely created a large, open prostatic cavity characterized by a minimal degree of luminal necrosis, which reepithelialized in 7 weeks, and no mural or extramural necrosis and practically no collagenous scar formation. Impressively, the PVP-treated animals voided within 24 h postoperatively and were continent and able to have erections [15,19].

Clinical Development of PVP

At the time of diminishing popularity of VLAP in the mid-1990s, a hybrid technique was developed at Mayo Clinic [20]. It added the limited vaporization capability of the then-available low-power (38 W) KTP laser to the coagulation effect of the Nd:YAG laser at the termination of VLAP. This approach resulted in significant reduction (66%) in rate and duration (from a mean of 5.4 days to a mean to 3 days) of postoperative retention and a far more patient-friendly rate of dysuria (12.5%) than had been experienced with VLAP alone [20]. Encouraged by these salutary contributions of 38-W KTP laser application to the outcomes of VLAP and the proven technical success and benign histopathological sequelae of 60-W KTP laser vaporization of the prostate in the laboratory [19], Malek developed and pioneered the technique for clinical application of KTP vaporization LP, currently known as PVP, utilizing a prototype 60-W KTP laser generator in 1997 at Mayo Clinic. Malek and associates' original report in 1998 of their pilot study of 24-h outcomes of PVP in 10 patients with obstructive prostate volumes as large as 60 ml [21] was soon followed by their 2-year observations on PVP in 55 patients with obstructive prostate volumes as large as 90 mL in 2000 [22]. Their pilot study clearly showed the technical ease of PVP and the benign nature of its immediate outcomes in that all 10 men were outpatients, became catheter free in less than 24 h, were able to void comfortably with significant ($P<0.003$) improvement in mean maximum flow rate (Q_{max}) of 142%

(unprecedently soon after prostatic surgery), and returned to nonstrenuous physical actively in 2–3 days [21]. Their observations on 55 patients showed not only PVP's safety and efficacy accompanied by the same immediate postoperative benefits but also its 2-year durability manifested by sustained significant ($P < 0.0001$) improvements in mean values of symptomatic and voiding outcomes: mean American Urological Association (AUA) symptom score index 82%, Q_{max} 278%, and post-void residual urine volume (PVR) 75% [22]. Other adverse events were also relatively mild and scarce; they included short-term (2–3 weeks), self-limiting dysuria (7%), delayed hematuria due to strenuous activity (4%), soft bladder neck contracture treated by a single dilation (2%), and retrograde ejaculation in up to only 29%. None of the patients had incontinence or sexual impotence, and none required reoperation [22].

Surgical Principles of PVP

The sole objective of PVP is to relieve prostatic obstruction, irrespective of its cause. Therefore, preoperative evaluation, on par with that undertaken before TURP, is mandatory to establish proof of unequivocal prostatic obstruction as the principal culprit. However, despite identical surgical indications, transurethral approach, anatomical landmarks, and outcome objectives, technically, PVP and TURP are far apart. Significant differences between PVP and TURP techniques (rotational versus pulling action) dictate that urologists, irrespective of the magnitude of their TURP experience, simply cannot translate their TURP expertise into good PVP technique ib initio; old habits (pulling action on a resectoscope loop) die hard and acquiring new ones (rotational fiber movement) takes time. PVP beginners not only have a learning curve, albeit a relatively short one of 15 cases or so, but also, as with TURP, must start doing the procedure with smaller glands (≤50 ml in volume) until they have developed the necessary skills to safely and speedily bring vaporization of a large volume of obstructive tissue to its prescribed conclusion [5]. A 21 F to 23 F continuous-flow laser cystoscope must contain a visual obturator and be introduced gently and atraumatically to prevent mucosal damage or formation of a false passage that leads to difficult-to-discourage vision-blurring bleeding, unrecognized until-too-late fluid absorption, and inefficient vaporization due to attenuated KTP laser energy absorbed by hemoglobin-contaminated irrigant before it can reach the targeted tissue. Current high-power generators emit highly repetitive KTP laser pulses (quasicontinuous) at a maximal average power of 80 W (GreenLight PV; Laserscope, San Jose, CA, USA). The laser beam travels through a 600-μm side-firing fiber that internally deflects it at an angle of 70° relative to fiber axis and delivers it to the targeted tissue [5]. Visualizing the field with a 30° telescope, the laser-emitting distal end of the fiber is rotated in sweeping motions—relatively fast for the KTP laser-friendly glandular tissue but more slowly for more resistant fibrous tissue—through a 30° to 40° arc up and down over the

targeted tissue at near-contact distance of 0.5 to 1 mm (working distance, WD) from it. Efficient tissue vaporization, characterized by vapor bubble formation, is performed evenly beginning at the bladder neck, carried out in successive arcs toward the apex, and terminated before the external urinary sphincter is reached [5]. Facility of cystoscopic and laser fiber maneuvers within the prostatic urethra and adequate continuous flow of saline irrigant are essential technical requirements. For these requirements to be satisfied, a large median lobe, if present, must be removed first by starting vaporization on either side of the lobe in either of the natural grooves that exist between the median and lateral lobes at the 5- and 7-o'clock positions. The laser beam should be aimed from either of these positions toward the midline to avoid damaging the trigone and ureteral orifices, and median lobe vaporization should proceed sequentially and symmetrically from these positions uphill toward the summit of the lobe, which is flattened out last [5] (Fig. 3a–c). Vaporization of the lateral lobes should start at the 1- to 2-o'clock position at the bladder neck and progress to the 5-o'clock position. It is then advanced in sequential arcs, systematically moving distally along the length of the lobe toward the apex (Fig. 3d,e). Lateral lobe tissue should be removed by symmetric excavation of the prostatic cavity laterally toward the surgical

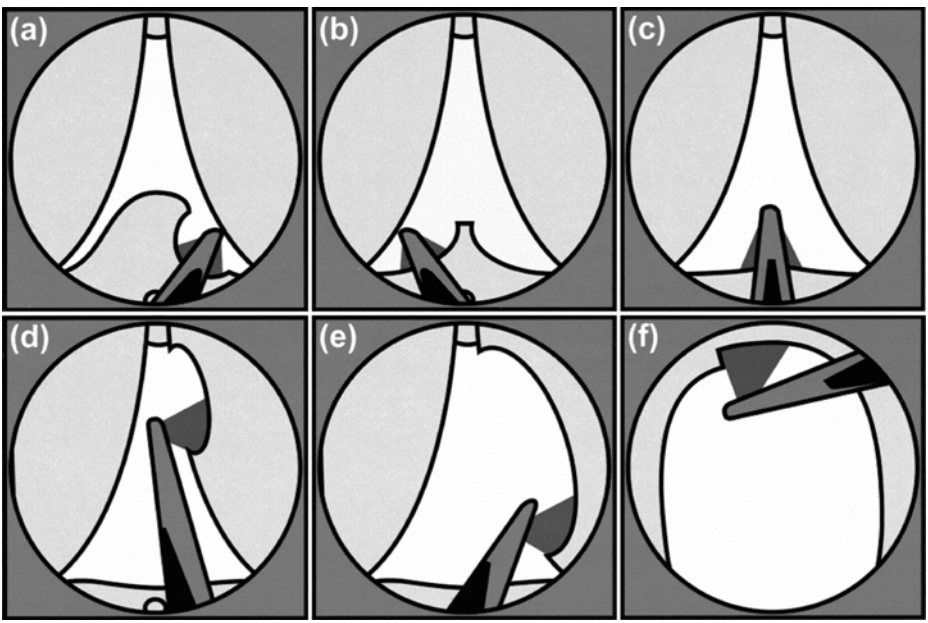


Fig. 3. Cystoscopic view of operative steps of PVP. **a–c** Steps in vaporization of median lobe. **d**, **e** Steps in vaporization of left lateral lobe. **f** Vaporization of anterior (dorsal) tissue. Cytoscope and laser fiber have been rotated 180° to face roof of prostatic fossa. (Modified from Malek and Nahen [5]. Used with permission)

capsule, manifested by the appearance of its white, highly reflective transverse fibers [5]. Lastly, the anterior lobe tissue, if present, is vaporized by turning the cystoscope 180° while tilting its distal end upward with its hollow inner aspect facing the roof of the prostatic fossa [5] (Fig. 3f). The endpoint of PVP is a widely patent TURP-like cavity surrounded by capsular fibers and lined by minuscule coagulated coral-like strands of tissue. Viewing from the level of veru montanum, one should see no tissue projecting into the visual field and a widely open bladder neck and prostatic cavity when the bladder is full. Hemostasis is achieved by coagulating the occasional bleeders with a defocused (WD increased to 3–4 mm) 80-W KTP laser beam directed slightly peripheral to the site of the bleeding vessel to avoid heat-induced expansion and further erosion of the large bleeding vessel accompanied by more bleeding. Alternatively, the laser-power setting may be reduced to 30 W without changing the WD from its original near-contact 0.5–1 mm [5]. Furthermore, for small prostates (<30 ml), PVP at lower power settings of 50–60 W are recommended to minimize thermal damage and formation of bladder neck contracture [5]. Healthy, hemostatically normal patients with average-sized prostates, well functioning bladders, and good immediate surgical outcomes and recovery from anesthesia may be left catheterless. Others, including those who had operation late in the day, are usually well managed by catheterization overnight or a little longer, as their urologic status and comorbidities dictate [23,24].

Typically, PVP is performed with the patient under general or spinal anesthesia. However, it also may be performed with a combination of local prostatic (pudendal) block and managed anesthetic care (MAC) [5]. The relatively light surgical and anesthetic burdens associated with PVP make it ideally suited for ambulatory surgery centers or hospital outpatient (day surgery) facilities. A select few patients, namely, hemostatically normal younger men with no comorbidities and smaller prostates, may undergo PVP at a well-equipped office with full anesthesia coverage. Patients may return to their normal activities and employment within 2 or 3 days after PVP, depending on the nature of their work. However, they should be advised to avoid sexual or strenuous physical activities for at least 2 weeks lest these lead to delayed hematuria [5].

Major New Studies of Outcomes and Durability of PVP

Outcomes of the first U.S. multicenter prospective trial of PVP with the more powerful 80-W KTP laser [23] were as excellent as, and accompanied by low rates of complications similar to, those of PVP performed with the prototype 60-W KTP laser reported earlier by Malek et al. [21,22]. In the multicenter 1-year study of 139 patients, mean prostate volume was 55 ml (range, 21–174) and mean laser time was 39 min (range, 9–140) [23]. Blood loss was clinically insignificant, transfusion was not required, and dilutional hyponatremia was not encountered. PVP was performed on an outpatient basis in most (86%) patients; the remaining few (14%), because of comorbidities and logistical reasons, had a short LOS

of 24–72 h. Outstandingly, despite lack of prior PVP experience of the operators, 32% of the patients required no catheterization at all; mean length of catheterization (LOC) in the remaining 68% was 14 h [23]. Symptomatic and urodynamic outcomes showed significant improvement as early as 1 month, and at 1 year the percentage improvement in mean values of these parameters compared with their respective baseline values were equally significantly ($P<0.05$) improved, as follows: AUA symptom score, 82%; quality-of-life score (QOL), 77%; Q_{max}, 190%; and PVR, 78%. Mean prostate volume diminished significantly ($P=0.0027$) by 37%, consistent with a 31% reduction in mean serum prostate-specific antigen (PSA) value and in line with a similar reduction in PSA value described originally by Malek et al. [22,23]. Complications were similarly scarce and mild as those reported by Malek et al. [22]. They included dysuria (9.4%), transient hematuria (8.6%), transient urgency incontinence (6.5%), recatheterization for retention (5%), bladder neck contracture treated by a single dilation (1.4%), and urethral stricture (0.7%). All sexually active patients remained potent postoperatively, and only 36% experienced retrograde ejaculation [23]. Patients were able to return to work 2–3 days postoperatively.

Durability of remarkable long-term outcomes in 94 men who had undergone PVP with 60-W to 80-W KTP laser by Malek since he pioneered the procedure in 1997 were reported recently [24]. For prostate volumes that ranged from 13 to 136 ml (mean, 45 ml), laser time ranged from 10 to 99 min (mean, 45 min). All men were outpatients (LOS < 24 h), and all but 1 became catheter free in less than 24 h and returned to work in 2–3 days. Intraoperative and perioperative blood loss were minimal or nonexistent. No patient required bladder irrigation or blood transfusion despite antiplatelet therapy in many and untreated factor VII deficiency in 1, and none showed any clinical or laboratory evidence of hyponatremia [24]. Complications were as consistently scarce and mild as those reported earlier [22]. They included transient self-limiting dysuria (6%), delayed hematuria (3%), soft bladder neck contracture treated by a single dilation (2%), and 2-day retention (1%). After PVP, no patient became incontinent, all sexually active patients remained potent, and, in stark contrast to a high rate of retrograde ejaculation noted after TURP, only up to 26% of the patients experienced this adversity [24]. The low rate of retrograde ejaculation vis-à-vis a substantial 100% improvement in Q_{max} in a majority (74%–91%) of the patients suggests that this welcome advantage results from development, after PVP, of a pliable unobstructed prostatic channel in combination with a functional bladder neck—thanks to a relative absence of collagenous scar tissue formation substantiated by canine experiments [15,19]—rather than from limited tissue removal and creation of a small TURP-like defect [24]. Two patients died of unrelated infirmities of advanced age between 4 and 5 years postoperatively, and none of the patients, including those who declined long-term follow up, required reoperation. Over the 5-year period of observation, sustained significant ($P<0.0001$) percentage improvements in symptomatic and urodynamic outcomes compared with their respective baseline values were remarkable: AUA symptom score index, 83%–88%; QOL score, 86%–90%; Q_{max}, 170%–252%; and PVR,

76%–89% [24]. In contrast, the only long-term (7 years) study [17], of 34 patients available from an original group of 79 who underwent holmium laser ablation (vaporization) of the prostate [25], found substantially lower percentage improvement in symptomatic and urodynamic outcomes after HoLAP than those noted after PVP or TURP [23,24,26]. Compared with their baseline values, at 3 months and 7 years after HoLAP, AUA symptom score improved by only 56% and 47% and Q_{max} by only 57% and 83%, respectively [17]. LOC was 6 h–28 days in the HoLAP series and 0–72 h in the PVP series discussed earlier [22–24], and retention developed in 9% of the patients who had HoLAP [25] and in 1%–5% of those who had PVP [23,24]. The rates and types of other complications were similar, except for a reoperation rate of 15% for HoLAP, which was higher than the usual 10% reported for TURP or 0% in the 5-year study of PVP [17,24,25]. Authors of the HoLAP study concluded that its outcomes were "between watchful waiting and TURP."

PVP Versus TURP

That KTP laser effect is pathophysiologically relatively benign was shown by comparative studies of LP in canines at Mayo Clinic [15,19]. In contrast to small, deeply scarred prostatic cavities accompanied by periprostatic necrosis of neurovascular bundles produced by Nd:YAG coagulation or vaporization LP, KTP laser PVP was characterized by a larger (3.0 ± 0.3 cm), smooth, and practically unscarred (collagen-free) prostatic channel with no deeper than a 1- to 2-mm rim of hemostatic coagulation of its walls and no periprostatic neurovascular damage irrespective of KTP laser power applied [15,19]. All forms of transurethral surgery for obstructive BPH cause thermal injury, albeit in a controlled fashion, to create an unobstructed channel. Clearly, elementary physical principles imply that the urodynamic outcomes of these procedures depend not only on the caliber of the newly created channel but also on the expandability of the walls of this channel; logically, a combination of an unscarred and, therefore, pliable (expandable) open prostatic channel and a functioning bladder neck is likely to conduct urine more freely than a scarred, rigid, albeit open bladder neck and prostatic urethra. These features are considered to be the crux of the rather impressive urodynamic and, by extension, symptomatic outcomes of PVP compared with the best of those of some of the contemporary TURP series reported in the literature [22,24]. Indeed, a meta-analytical evaluation of the significantly ($P = 0.000$) improved outcomes of, to this author's knowledge, the only 3-year post-TURP study [26] of 66 patients with a mean prostate volume of 48 ml (range, 31–86 ml), of whom 70%–44% were available for evaluation in 1–3 years, respectively, compared with equally significantly ($P < 0.0001$) improved outcomes of PVP reported by Malek et al. [24] in 94 patients with a mean prostate volume of 45 ml (range, 13–136), of whom 83%–64% were available for evaluation in 1–3 years, respectively, shows the remarkable equivalency of out-

comes and durability of the two procedures. At 1-, 2-, and 3-year postoperative intervals, mean improvement in AUA symptom score for PVP was 83%, 83%, and 85%, respectively (vs. 85%, 80%, and 85% for TURP), mean improvement in QOL score was 90%, 86%, and 90%, respectively (vs. 75%, 75%, and 75% for TURP), mean increase in Q_{max} was 252%, 242%, and 201%, respectively (vs. 214%, 195%, and 216% for TURP), and mean reduction in PVR was 76%, 89%, and 84%, respectively (vs. 80%, 69%, and 63% for TURP) [24,26]. However, all patients in the PVP cohort were outpatients, all but 1 had catheterization for less than 24 h, few had only mild complications, and none required reoperation (vs. 45 evaluable patients who had TURP, 11% of whom required reoperation within approximately 1 year postoperatively) [24,26]. One-year outcomes of an ongoing prospectively randomized trial comparing PVP with TURP in two groups of patients with similar mean prostate volumes (40 vs. 33 ml) showed that both procedures resulted in equally significant ($P<0.005$) percentage improvements in mean international prostate symptom (IPS) scores (54% vs. 47%) and mean Q_{max} (170% vs. 102%) [27]. However, adverse events were markedly less frequent, and mean LOC and LOS were significantly shorter in the PVP group than in the TURP group (13.5 h vs. 40 h and 1.1 days vs. 3.18 days, respectively), with a cost savings of 23% in the PVP group [27]. Concurrently, a biinstitutional trial comparing 6-month outcomes of PVP in 61 patients with those of TURP in 38 patients with similar prostate volumes (63 vs. 57 ml) showed equally significant percentage improvements in mean IPS scores (65% vs. 67%), mean Q_{max} (217% vs. 186%), and mean PVR [28]. PVP and TURP were equally lengthy (mean operative time 53 vs. 55 min), but LOC was significantly longer for the TURP patients; they had significantly more blood loss and dilutional hyponatremia [28]. Furthermore, TURP was complicated by bleeding in 18%, capsular perforation in 5%, and clot retention in 5%, whereas PVP was accompanied only by transient retention in 3% [28]. Vis-à-vis these favorable comparisons of PVP outcomes and complications with those of TURP stand the rather mediocre outcomes and unfavorable sequelae of holmium laser ablation of the prostate. The only, to this author's knowledge, prospectively randomized trial comparing 1-year outcomes in 23 post-HoLAP patients with 13 post-TURP patients with similar mean prostate volumes (39 vs. 34 ml) showed equally significant (P value undeclared) percentage improvement in mean IPS scores (65% vs. 79%) and mean Q_{max} (79% vs. 121%) [29]. However, improvement in mean Q_{max} was considerably inferior to that for PVP or for other TURP series noted earlier in this section [23,24,26–28]. Amazingly, despite the authors' stated fact that the surgeons "never tried to perform a complete laser resection," mean operation time was nearly twice as long for HoLAP at 60–80 W as it was for TURP (75 vs. 40 min; $P=0.0407$), and mean LOC was equally lengthy for both (2.2 vs. 2.1 days), which was considerably longer than the customary LOC after PVP of 0 to less than 24 h [29]. Equally disappointing were the not inconsiderable array of complications for HoLAP compared with none for TURP; they included dysuria and urgency in 20% of patients treated with analgesics, bleeding sufficient to require conversion to TURP in 4%, incontinence in 4%, and reoperation for recurrent

prostatic obstruction within a year in 4% [29]. Interestingly, retrograde ejaculation was noted equally frequently (50%) in both groups [29].

Clearly, then, PVP and TURP, but apparently not HoLAP, have a great deal in common by providing equally excellent improvement in the quality and long-term durability of postoperative symptomatic and urodynamic outcomes. However, it is in the arena of their respective morbidity and applicability to patients with significant comorbidities, prostatic enlargement above and beyond the usual TUR-able limit, and impairment of coagulation that their not inconsiderable differences, manifested by significant advantages in favor of PVP, truly come to light (see below).

PVP Applications Under Adverse Clinical Circumstances

An ever increasing population of older men, many aging into the twilight of their lives burdened by life-threatening comorbidities, pose major therapeutic challenges by presenting in ever increasing numbers with obstructive BPH with or without urinary retention and, frequently, after having failed medical or one or more minimally invasive surgical therapies or both. By then, in some of these men, prostatic sizes have developed beyond the usual estimated TUR-able limit of "100 g" [10], others are in dire clinical straits and, to make matters worse, have to receive lifesaving anticoagulation, or they have a combination of all these detriments, which, alone or in combination, make TURP or open suprapubic adenectomy more risky or prohibitive.

PVP's well established safety profile, afforded by its excellent hemostatic properties even under conditions of significantly impaired hemostasis, lack of dilutional hyponatremia despite some relatively lengthy operative times for larger glands, and its ability to be performed readily under a combination of local (pudendal) block and MAC, has made it the procedure of choice under such adversities in high-risk older men with obstructive BPH [5,24,30]. The remarkable and unique finding that, in contrast to HoLEP or HoLAP, anticoagulated (antiplatelets, heparin, or warfarin) or hematologically impaired (factor VII deficiency) patients could safely undergo PVP with negligible or no intraoperative or postoperative bleeding was first demonstrated by Malek et al. [22]. A more recent 1-year study of 66 high-risk elderly (mean age, 75 years) patients with a mean American Society of Anesthesiology (ASA) score of 3 or more who underwent PVP without discontinuation of therapy, even in the maximally anticoagulated subgroup, clearly showed its remarkable safety under these otherwise next-to-impossible surgical and anesthetic circumstances [30]. Nearly half (44%) of the patients received anticoagulation [coumarin derivatives in 16 patients, INR 1.7–4.3; thrombocyte aggregation inhibitors in 10 patients] or had significant hematologic disorders (hemophilia, 1 patient; idiopathic thrombocytopenia, 1 patient; myelodysplastic syndrome, 1 patient). None of the patients experienced any significant perioperative complications, none required a blood

transfusion, mean LOC was 1.8 days, and only 23% of the patients required catheter irrigation. Five (6%) of the patients died of cardiopulmonary comorbidities 4–14 months after PVP [30]. In yet another recent multicenter study of 83 high-risk older men, all of whom were anticoagulated, none required transfusion. Mean duration of bladder irrigation was 3 h, mean LOC was 2 days, and 3 patients required hematuria-related postoperative intervention: 2 for clot evacuation and 1 to regain hemostasis [31].

Many reports on PVP include uneventfully and successfully treated patients with significantly large prostate volumes [23,24,30]. The largest prostate volumes and their operative times, respectively, reported are as follows: 174 ml and 140 min [23], 136 ml and 99 min [24], and 150 ml and 90 min [30]. Favorable experiences with PVP of specifically large prostates ranging in volumes from 60 to 247 ml (mean, 101.3) in 64 patients were reported recently [32]. PVP was staged in 2 patients because of very lengthy prostatic urethras. Mean laser time was 122 min, and nearly half (44%) of the group was treated under a combination of local prostatic block and MAC, and the remaining patients received general or spinal anesthesia. Estimated blood loss and changes in serum sodium were not significant, and blood transfusion was unnecessary [32]. Remarkably, despite considerable prostatic enlargement in most of the patients and preoperative urinary retention in 28%, after PVP 19% were catheter-less, and another 77% became catheter-free in less than 24 h. Complications were few; they included mild transient hematuria, urinary retention in 3 patients (5%), and recurrent obstruction in 2 patients (1 had bladder neck contracture, and 1 had recurrent prostatic obstruction). Impressively, significant ($P<0.001$) percentage improvements in mean IPS score, Q_{max}, and PVR of 46%, 107%, and 58%, respectively, were noted at only 1 month after PVP. One-year follow-up data available in 21% of the patients showed the same or more improvement in outcome variables [32]. These findings suggest that PVP, under such circumstances, has crossed successfully from the realm of TURP into that of open prostatic enucleation, which many urologists resort to when prostatic size approaches 100 g.

Except for one report of a pure group of patients in urinary retention, other reports describe experiences of their respective authors with PVP in mixed groups of patients with and without urinary retention [30,33,34]. In the pure group of 20 patients with retention, mean prostate volume was 80 ml, mean laser time was 73 min, and complications were the usual mild self-limiting transient hematuria and occasional dysuria. A majority of patients (85%) voided spontaneously within a week after PVP (mean LOC, 33.5 h). Remarkably, at 1 month mean AUA symptom score, Q_{max}, and PVR for the entire group were improved by 30%, 137%, and 62%, respectively [33]. The outcomes of studies of the mixed groups of patients have been equally impressive [30,34]. In the high-risk group of 66 patients referred to earlier, 41% were in retention [30]. Mean prostate volume was 49 ml (range, 15–150 ml), mean laser time was 49 min (range, 15–90 min), mean LOC for the entire group was 1.8 days (range, 0–7),

and recatheterization was required in 11% of patients [30]. Complications were mild, transient, and similar to those described in earlier studies, but 3% of patients treated early in the series with inadequate vaporization of the apical tissue required reoperation within 4 weeks after PVP. Percentage improvement in outcomes for the entire group, including the 41% who had had urinary retention, was highly significant ($P<0.001$): IPS score by 42%, Q_{max} by 176%, and PVR by 75%; improvements were even more remarkable at 1 year [30]. Likewise, in yet another recently reported group of 94 patients, 42 (43%) were in urinary retention before PVP [34]. Comparing both groups of patients with and without retention in this series, complications were equally mild and outcomes were similarly highly impressive during the 2-year follow-up period [34]. Collectively, the remarkably good safety profile, outstanding improvement in symptomatic and urodynamic outcomes, and low morbidity of PVP have made it the treatment of choice not only for relatively healthy patients with obstructive BPH but also for high-risk elderly men who, otherwise, would be relegated to the lifelong miseries of indwelling urinary catheters. However, application of PVP under adverse clinical conditions demands experience, surgical dexterity, and speed, and as such, it is purely in the province of the proficient. Applied by prescribed PVP technique, KTP laser tissue effects, as demonstrated experimentally and clinically, are, indeed, benign. However, misapplication of any type of laser energy, including that of KTP in LP, as with misconducted TURP, may result, at worst, in life-threatening complications and, at best, in poor outcomes.

PVP and Carcinoma of the Prostate

No tissue is recovered during PVP for histopathologic examination. Therefore, not only every effort must be made by performing digital rectal examination of the prostate (DRE), measurement of serum PSA, and transrectal ultrasonography (TRUS) supplemented by biopsy, if indicated, to uncover the existence of undiagnosed prostate cancer before PVP but also it is mandatory to continue postoperative surveillance of patients by periodic DRE and PSA reevaluations at 6 months and annually thereafter to diagnose newly developed malignancies at an early stage [5,22,24]. These guidelines were established originally by Malek et al. [22]. Their systematic pre-PVP evaluations followed by 2-year and later 5-year surveillance of patients after PVP showed a persistent reduction of approximately 30% in serum PSA levels postoperatively [22,24], a finding that was corroborated by the 1-year multicenter study of PVP [23]. Malek et al. found that failure of PSA to decrease after PVP, or its sustained increase after initial decrease, whether or not accompanied by abnormal DRE was suspect [22,24]. TRUS-guided biopsies performed under these circumstances showed a 5% post-PVP incidence of early and readily treated localized prostate cancer among their patients during a 5-year period of observation [24], an incidence not dissimilar to the 6%–7% incidence of prostatic carcinoma discovered by examination of

TURP tissue specimens reported in the contemporary literature of preoperative PSA-TRUS era [26,35].

Patients with prostate cancer who have locally progressive disease and outlet obstruction not uncommonly are plagued by urinary incontinence or obstructive contracture of the bladder neck or both after TURP. PVP with its narrowly divergent (15°) KTP laser beam is an ideal precision tool that facilitates application of thermal energy to exact locations within the prostatic urethra, where vaporization may do the most good by aggressive debulking of the proximal and midportions and the least harm by conservative energy delivery near the apical region in order to maintain continence. After brachytherapy, direct exposure of implanted seeds to the laser beam should be avoided because it may lead to their meltdown and degradation of the side-firing fiber by metal vapor deposition. More importantly, to safeguard against harmful radiation exposure of operating room personnel, a waiting period (e.g., approximately 12 months or >4 half-lives of I-125 implants) is mandatory before PVP may be considered.

Cost of PVP

Considering the substantial beneficial impacts of PVP's low morbidity, relative paucity of complications, and consequent minimal loss of productivity, it is not unexpected that, despite the additional cost of a single-use laser fiber and of a laser generator, PVP actually should cost less than TURP. This was shown readily by a sophisticated cost-analysis study based on available collective data; on a long-term basis, a cumulative probability of reoperation of 52% in the PVP group was required before its expected total cost (including the laser fiber and the generator) approximated that of TURP [36]. Indeed, PVP even on a relatively short-term basis of a 1-year randomized trial has been shown to cost 23% less than TURP [27]. Unsurprisingly, then, PVP appears to satisfy the requirements of patients, physicians, and health care administrators in safely delivering good results, ease of application, and low cost for a very appealing procedure that offers an excellent long-lasting solution to the problems of prostatic obstruction.

References

1. Malek RS (1998) Contemporary management of the benign obstructive prostate: an overview. Mayo Clin Proc 73:589
2. Simopoulos DN, Malek RS (1998) Benign prostatic hyperplasia: the PSA dilemma and new approaches to therapy. Contemp Intern Med 10:42–51
3. Malek RS, Nahen K (2004) Laser treatment of obstructive BPH problems and progress. Contemp Urol 16:37–43
4. Hoffman RM, MacDonald R, Slaton JW, Wilt TJ (2003) Laser prostatectomy versus transurethral resection for treating benign prostatic obstruction: a systematic review. J Urol 169:210–215

5. Malek RS, Nahen K (2004) Photoselective vaporization of the prostate: KTP laser therapy of obstructive benign prostatic hyperplasia. AUA Update Ser 23:153–160
6. Anson KM, Watson GM, Shah TK, Barnes DG (1993) Laser prostatectomy: our initial experience of a technique in evolution. J Endourol 7:333–336
7. McAllister WJ, Absalom MJ, Mir K, Shivde S, Anson K, Kirby RS, Lawrence WT, Paterson PJ, Watson GM, Fowler CG (2000) Does endoscopic laser ablation of the prostate stand the test of time? Five-year results from a multicentre randomized controlled trial of endoscopic laser ablation against transurethral resection of the prostate. BJU Int 85:437–439
8. Martenson AC, De La Rosette JJ (1999) Interstitial laser coagulation in the treatment of benign prostatic hyperplasia using a diode laser system: results of an evolving technology. Prostate Cancer Prostatic Dis 2:148–154
9. Floratos DL, Sonke GS, Francisca EA, Kiemeney LA, Debruyne FM, de la Rosette JJ (2000) Long-term follow-up of laser treatment for lower urinary tract symptoms suggestive of bladder outlet obstruction. Urology 56:604–609
10. Tan AH, Gilling PJ, Kennett KM, Frampton C, Westenberg AM, Fraundorfer MR (2003) A randomized trial comparing holmium laser enucleation of the prostate with transurethral resection of the prostate for the treatment of bladder outlet obstruction secondary to benign prostatic hyperplasia in large glands (40 to 200 grams). J Urol 170(4 pt 1):1270–1274
11. Seki N, Mochida O, Kinukawa N, Sagiyama K, Naito S (2003) Holmium laser enucleation for prostatic adenoma: analysis of learning curve over the course of 70 consecutive cases. J Urol 170:1847–1850
12. Gilling PJ, Mackey M, Cresswell M, Kennett K, Kabalin JN, Fraundorfer MR (1999) Holmium laser versus transurethral resection of the prostate: a randomized prospective trial with 1-year followup. J Urol 162:1640–1644
13. Kuo RL, Kim SC, Lingeman JE, Paterson RF, Watkins SL, Simmons GR, Steele RE (2003) Holmium laser enucleation of prostate (HoLEP): the Methodist Hospital experience with greater than 75 gram enucleations. J Urol 170:149–152
14. Hurle R, Vavassori I, Piccinelli A, Manzetti A, Valenti S, Vismara A (2002) Holmium laser enucleation of the prostate combined with mechanical morcellation in 155 patients with benign prostatic hyperplasia. Urology 60:449–453
15. Kuntzman RS, Malek RS, Barrett DM, Bostwick DG (1996) Potassium-titanyl-phosphate laser vaporization of the prostate: a comparative functional and pathologic study in canines. Urology 48:575–583
16. Narayan P, Fournier G, Indudhara R, Leidich R, Shinohara K, Ingerman A (1994) Transurethral evaporation of prostate (TUEP) with Nd:YAG laser using a contact free beam technique: results in 61 patients with benign prostatic hyperplasia. Urology 43:813–820
17. Tan AH, Gilling PJ, Kennett KM, Fletcher H, Fraundorfer MR (2003) Long-term results of high-power holmium laser vaporization (ablation) of the prostate. BJU Int 92:707–709
18. Kabalin JN (1996) Holmium: YAG laser prostatectomy canine feasibility study. Lasers Surg Med 18:221–224
19. Kuntzman RS, Malek RS, Barrett DM, Bostwick DG (1997) High-power (60-watt) potassium-titanyl-phosphate laser vaporization prostatectomy in living canines and in human and canine cadavers. Urology 49:703–708

20. Kollmorgen TA, Malek RS, Barrett DM (1996) Laser prostatectomy: two and a half years' experience with aggressive multifocal therapy. Urology 48:217–222
21. Malek RS, Barrett DM, Kuntzman RS (1998) High-power potassium-titanyl-phosphate (KTP/532) laser vaporization prostatectomy: 24 hours later. Urology 51:254–256
22. Malek RS, Kuntzman RS, Barrett DM (2000) High power potassium-titanyl-phosphate laser vaporization prostatectomy. J Urol 163:1730–1733
23. Te AE, Malloy TR, Stein BS, Ulchaker JC, Nseyo UO, Hai MA, Malek RS (2004) Photoselective vaporization of the prostate for the treatment of benign prostatic hyperplasia: 12-month results from the first United States multicenter prospective trial. J Urol 172(4 pt 1):1404–1408
24. Malek RS, Kuntzman RS, Barrett DM (2005) Photoselective potassium-titanyl-phosphate laser vaporization of the benign obstructive prostate: observations on long-term outcomes. J Urol 174(4 pt 1):1344–1348
25. Gilling PJ, Cass CB, Cresswell MD, Malcolm AR, Fraundorfer MR (1996) The use of the holmium laser in the treatment of benign prostatic hyperplasia. J Endourol 10:459–461
26. Floratos DL, Kiemeney LA, Rossi C, Kortmann BB, Debruyne FM, de La Rosette JJ (2001) Long-term followup of randomized transurethral microwave thermotherapy versus transurethral prostatic resection study. J Urol 165:1533–1538
27. Bouchier-Hayes DM, Anderson P, Van Appledorn S, Bugeja P, Costello AS (2005) A randomised trial comparing photo-vaporisation and trans-urethral resection of the prostate in patients (abstract). J Urol 173(suppl):421
28. Sulser T, Schürch L, Ruszat R, Reich O, Lehmann K, Bachman A (2005) Prospective comparison of photoselective laser vaporization (PVP) and transurethral resection of the prostate (TURP) (abstract). J Urol 173(suppl):422
29. Mottet N, Anidjar M, Bourdon O, Louis JF, Teillac P, Costa P, Le Duc A (1999) Randomized comparison of transurethral electroresection and holmium: YAG laser vaporization for symptomatic benign prostatic hyperplasia. J Endourol 13: 127–130
30. Reich O, Bachmann A, Siebels M, Hofstetter A, Stief CG, Sulser T (2005) High power (80 W) potassium-titanyl-phosphate laser vaporization of the prostate in 66 high risk patients. J Urol 173:158–160
31. Malloy TR, Sandhu JS, Smith AL, Reddy B, Harryhill JF, Kaplan SA, Te AE (2005) Photoselective vaporization of the prostate (PVP) in anticoagulated patients: a multicenter retrospective evaluation of feasibility (abstract). J Urol 173(suppl):423
32. Sandhu JS, Ng C, Vanderbrink BA, Egan C, Kaplan SA, Te AE (2004) High-power potassium-titanyl-phosphate photoselective laser vaporization of prostate for treatment of benign prostatic hyperplasia in men with large prostates. Urology 64:1155–1159
33. Ulchaker JC, Te AE, Egan C, Sandhu JS, Nseyo UO (2003) Photoselective vaporization or the prostate (PVP) for treatment of urinary retention secondary to benign prostatic hyperplasia (BPH) (abstract). J Endourol 17(suppl):A187–A188
34. Bachmann A, Ruszat R, Seifert H-H, Casella R, Wyler S, Sulser T (2005) Photoselective vaporization of the prostate (PVP) in men with preoperative catheterization due to chronic urinary retention (abstract). J Urol 173(suppl):424
35. Tombal B, De Visccher L, Cosyns JP, Lorge F, Opsomer R, Wese FX, Van Cangh PJ (1999) Assessing the risk of unsuspected prostate cancer in patients with benign

prostatic hypertrophy: a 13-year retrospective study of the incidence and natural history of T1a-T1b prostate cancers. BJU Int 84:1015–1020
36. Stovsky MD, Laskin CR, Griffiths RI (2004) A clinical outcomes and cost analysis comparing photoselective vaporization of the prostate to alternative minimally invasive therapies and TURP for the treatment of benign prostatic hyperplasia (abstract). J Urol 171(suppl):103–104

Holmium Laser Prostatectomy Versus Transurethral Resection of the Prostate

John W. Leyland[1] and Peter J. Gilling[2]

Summary. This chapter compares holmium laser prostatectomy to transurethral resection of the prostate, using current published evidence. The evolution of holmium laser prostatectomy to the technique of enucleation is discussed. The enucleation technique is termed holmium laser enucleation of the prostate (HoLEP).

Keywords. Prostatic hyperplasia, Prostatectomy, Holmium, Laser, Transurethral resection of prostate

Introduction

Benign prostatic hyperplasia (BPH) is a common cause of lower urinary tract symptoms and bladder outflow obstruction in men older than 40 years. A large proportion of these men will require operative intervention during their lifetime, calculated to be approximately 30% of the male population in Europe and the United States [1].

Transurethral resection of prostate (TURP) has been the gold standard for the endosurgical treatment of BPH for the last 30 years. TURP uses an electrocautery energy source through a resecting loop to endoscopically resect the prostate into small chips from the level of the bladder neck to the verumontanum [2]. Haemostasis is obtained with the loop, and a roller ball can be used after resection is complete to coagulate the prostatic fossa. Simultaneous irrigation with an isosmotic nonconducting fluid such as glycine is used to maintain visibility [3].

TURP is widely used and considered safe and efficacious, but problems remain such as bleeding requiring transfusion and irrigation fluid absorption leading to the TUR syndrome, especially for glands larger than 100 g. Other complications include fluid balance disturbances, incontinence, urethral strictures, and erectile

[1]Department of Urology, Tauranga Hospital, Tauranga, New Zealand
[2]Promed Urology Ltd, PO Box 56, Tauranga, New Zealand

dysfunction. Overall, 15%–20% of patients will develop a significant complication. Transfusion rates remain between 5% and 11% [4]. Mortality rates of 0.2%–2.5% have been reported [5]. In addition, 10%–15% of patients require a second intervention within 10 years [6].

Modern medicine continues to advance with technology, and new techniques are continually being sought to improve efficacy, safety, and cost effectiveness. Thus, several minimally invasive alternatives to TURP have been developed, using different energy sources.

The holmium:YAG (Ho) laser (Lumenis, Tel Aviv, Israel) has emerged as an ideal tool for prostatectomy because of its shallow penetration depth, excellent haemostatic properties, and ability to be used with normal saline irrigation. The high-powered (60–100 W) Ho laser has a wavelength of 2140 nm that allows it to be strongly absorbed by tissue water, which comprises more than 70% of prostate tissue. It causes rapid vaporisation of exposed tissue at a depth of approximately 0.4 mm and produces tissue coagulation 3–4 mm below the vaporisation surface tissue. It allows precise incisional surgery in a bloodless field, thus minimising systemic fluid absorption.

The use of the holmium laser for BPH surgery has evolved from tissue ablation to tissue resection and, more recently, enucleation of prostatic lobes combined with morcellation of fragments within the bladder. These techniques are discussed in detail. We then compare the efficacy and morbidity outcomes from several published randomised trials and systematic reviews comparing laser prostatectomy to conventional electrocautery TURP. Other aspects including cost effectiveness, day-case surgery, the learning curve, size limitations, and histological findings are discussed.

History and Evolving Technique of Holmium Laser Prostatectomy

Combined Endoscopic Laser Prostatectomy (CELAP)

The holmium laser was initially utilized for surgical treatment of BPH in conjunction with the Nd:YAG laser in 1994 using a side-firing fibre and a 60-W machine [7,8]. The properties of the holmium laser allowed prostate vaporization to create a channel, while the Nd:YAG laser was used for coagulation. However, it became apparent that the holmium laser alone had a wavelength that resulted in excellent haemostasis if the beam was defocused [7,8].

Holmium Laser Ablation of Prostate (HoLAP)

Prostate ablation can be performed using end-firing and side-firing fibres in a near-contact mode. The initial series using the holmium laser alone was published in 1996 and comprised 79 patients undergoing HoLAP [9]. Long term follow-up (mean, >7 years) from this initial series revealed that HoLAP pro-

duces durable results in terms of symptom relief and improvement in maximum flow rate. There was a high proportion (57%) lost to follow-up, but in those available, Q_{max} improved by 83% and symptom score reduced by 47% on average. The reoperation rate was 15% over the period of follow-up [10].

Mottet et al. performed a randomised comparison of TURP versus HoLAP, published in 1999, that demonstrated significantly less bleeding, catheter time, and hospitalization in the HoLAP group [11].

There has recently been a company-led resurgence in the popularity of laser ablation procedures for smaller prostates with both the KTP and holmium lasers, particularly because of the financial attraction of single-use fibres, its suitability as a day-case procedure, and the higher power setting available (100 W), making it slightly faster than with lower-powered lasers. However, overall it is a time-consuming procedure that generally takes longer than a TURP and is best suited to small glands (<40 g). Smaller amounts of tissue are removed, and these ablation procedures essentially create a highly variable channel, making durability a concern. The lack of tissue for histological analysis is another limitation.

Holmium Laser Resection of the Prostate (HoLRP)

During the initial experience with HoLAP in 1994, it was found that incising into the prostate with an end-fire fibre and resecting the tissue piecemeal drastically improved the efficiency of the procedure; this was termed HoLRP. This was the first time laser energy had been used for excisional prostate surgery [12]. This procedure is performed with a modified 26 Fr. continuous flow resectoscope (Storz, Tutlingen Germany), that has been fashioned with a circular fibre guide in the tip of the scope. The end-firing laser fibre is used as a precise cutting instrument rather than an ablative tool.

The median and lateral lobes are resected down to the capsular plane, and small fragments (<2 g) are released into the bladder. The fragments are then removed with manual irrigation, and larger fragments can be removed with a modified resection loop [12]. One of the other benefits of HoLRP is that prostatic tissue is available for histological analysis. However, the quality of the tissue for histology is inferior to that retrieved by TURP because of thermal artifacts, and only about one third of the removed weight of tissue is retrieved, with the remainder being vaporized [13]. Several randomised trials comparing HoLRP to TURP have been performed with up to 4-year follow-up [13–17] (Table 1). The outcomes of these trials are discussed in the next section.

Holmium Laser Enucleation of the Prostate (HoLEP)

As the surgical planes of the prostate became increasingly understood and identified endoscopically over many patients, the technique of enucleation was developed. The holmium laser fibre in this technique acts much like the index finger of the surgeon during an open prostatectomy to shell out the adenoma. The equipment used and procedure are discussed in further detail next.

Table 1. Published randomised controlled trials

References	Year published	Follow-up (months)	Study design	Interventions (no.)	Prostate size (ml)
Gilling et al. [13][a]	1999	12	RCT	HoLRP (61) TURP (59)	<100
Gilling et al. [16][a]	2000	24	RCT	As above	<100
Westenberg et al. [15][a]	2004	48	RCT	As above	<100
Hammad et al. [14]	2002	6	RCT	HoLRP (30) TURP (40)	NA
Gilling et al. [20]; Tan et al. [21]	2001, 2003	12	RCT	HoLEP (31) TURP (30)	40–200
Kuntz et al. [22][b]	2004	12	RCT	HoLEP (100) TURP (100)	<100
Montorsi et al. [23]	2004	12	RCT	HoLEP (52) TURP (48)	<100

RCT, randomised controlled trial; HoLRP, holmium laser resection of prostate; TURP, transurethral resection of prostate; HoLEP, holmium laser enucleation of prostate; NA, not available

[a]Same group of patients

[b]Share common pool of patients

Holmium Bladder Neck Incision (HoBNI)

Although not strictly a technique for prostatectomy, HoBNI is an excellent substitute for prostatectomy in prostates less than 30 g as a day case [18]. An end-fire fibre and bilateral incisions with or without excision of the median lobe/strip are preferred.

Equipment for HoLEP

The laser unit used currently is the high-powered VersaPulse holmium laser (Lumenis, Tel Aviv, Israel), using a power setting of 2.0 J at 50 Hz (100 W). A 550 μm end-firing quartz fibre is used inside a protective 6 Fr ureteral catheter (Cook, Spencer, IN, USA); this is secured with a Luer-Lok injection port through which the fibre passes (Baxter, Deerfield, IN, USA). A 26 F (Storz) or 27 F continuous flow resectoscope is used (Olympus, Hamburg, Germany). The inner sheath in both is modified to incorporate a laser fibre channel and bridge (Olympus), through which a 30° telescope is passed. Normal saline (0.9%) is used for irrigation. A long Storz nephroscope and adapter are employed through the 26 Fr outer sheath, and the Versacut morcellator (Lumenis) is inserted, which comprises a handpiece with reciprocating blades attached to a high-suction roller pump via silicone tubing and controlled by a variable-speed foot-pedal.

Procedure

Bladder Neck Incisions

Initially, bladder neck incisions are made at both 5- and 7-o'clock positions, down to the surgical capsule.

Enucleation of the Median Lobe

The bladder neck incisions are joined just proximal to the verumontanum with a transverse incision. The median lobe is then dissected off the capsule, incising between the bladder neck incisions, in a retrograde direction toward the bladder neck. Care must be taken not to undermine the bladder neck. The median lobe is detached at the bladder neck and allowed to float into the bladder.

Enucleation of the Lateral Lobes

The lateral lobes are each enucleated from the capsule in a retrograde fashion. The bladder neck incision on one side is first extended laterally and circumferentially at the apex in the surgical plane. Once in this plane, the prostatic tissue comes away from the capsule relatively easily, and one is often able to simply use the pressure of the irrigating fluid and the resectoscope to push and peel away the tissue, using the laser mainly for coagulation. A bladder neck incision is then made at the 12-o'clock position down to the capsule, splitting the anterior commissure. The superior aspect of the lateral lobe can then be peeled down off the capsule laterally and distally to eventually join up with the lower incision and then to complete the enucleation. The same procedure is performed with the other lateral lobe.

Haemostasis

Most of the haemostasis is performed during the enucleation process. The holmium laser is used to coagulate the small vessels at the same time and cut loosely adherent fibres between the prostate lobes and capsule in a virtually bloodless field. Coagulation is performed by slightly increasing the distance between the laser fiber and the tissue ("defocusing" the beam) to utilise its coagulation properties at this distance without incising or vaporising the tissue. Once all three lobes have been enucleated, the entire prostatic fossa is examined to ensure haemostasis is adequate so that the next step of morcellation can take place with clear visibility.

Morcellation

The inner sheath is removed, and the morcellator and nephroscope are then inserted through the urethra. The bladder is distended to avoid mucosal injury. The handpiece with reciprocating blades and suction tubing attached is then

inserted into the bladder. Suction is then used to trap the prostate tissue, and the mechanical blades slice off the fragments with a high-speed guillotine action. The fragments are aspirated at the same time through the tubing and caught in a sieve. Morcellation can remove tissue at up to 10 g/min (average, 4–5 g/min). Evacuation with a Toomey syringe or retrieval forceps can be used for smaller fragments.

Clinical Outcome Comparison Between Holmium Laser Prostatectomy and TURP

There have been a number of randomised controlled trials comparing holmium laser prostatectomy (HoLRP or HoLEP) to transurethral resection of prostate with electrocautery (TURP). Table 1 summarises the characteristics of these trials. Systematic review and meta-analysis has also been performed for holmium laser prostatectomy, giving level I evidence for its efficacy and safety [19,20].

Efficacy Outcomes

HoLRP and HoLEP been shown in randomised trials to be at least as effective as TURP in improving all efficacy outcomes [13–16,21,23]; these include AUA (IPPS) score, single-question quality-of-life (QOL) index, peak flow rate (Q_{max}), and relief of obstruction by urodynamics (Tables 2–5b). The amount of tissue removed is significantly higher with HoLEP compared to TURP and HoLRP (Table 6).

Table 2. American Urological Association AUA Score (IPSS)

Reference (see Table 1)	Months of follow-up	No. of patients	Operation performed	Mean preoperative IPSS	Mean postoperative IPSS	*P* value (postoperative)
13	12	102	HoLRP	21.9	4.2	0.92
			TURP	23.0	4.3	
16	24	86	HoLRP	21.9	3.4	0.84
			TURP	23.0	3.7	
15	48	73	HoLRP	21.9	5.2	0.32
			TURP	23.0	6.6	
14	6	70	HoLRP	NA	5	NS
			TURP	NA	8	
20, 21	12	55	HoLEP	26.0	4.3	NS
			TURP	23.7	5.0	
22	12	175	HoLEP	22.1	1.7	0.0001
			TURP	21.4	3.9	
23	12	100	HoLEP	21.6	4.1	0.58
			TURP	21.9	3.9	

NS, not statistically significant

Table 3. Quality-of-life (QOL) score

Reference	Follow-up (months)	No. patients at follow-up	Operation performed	Mean preoperative QOL	Mean postoperative QOL	*P* value (postoperative)
13	12	102	HoLRP	4.5	0.88	<0.05
			TURP	4.7	1.6	
16	24	86	HoLRP	4.5	0.98	0.88
			TURP	4.7	1.0	
15	48	73	HoLRP	4.5	1.1	0.37
			TURP	4.7	1.4	
14	6	70	HoLRP	NA	1.3	NS
			TURP		1.6	
20, 21	12	52	HoLEP	4.8	1.5	NS
			TURP	4.7	1.4	
23	12	100	HoLEP	4.6	1.4	0.31
			TURP	4.7	0.8	

Table 4. Peak flow (Q_{max})

Reference	Follow-up (months)	No. of cases	Operation performed	Preoperative Q_{max} (ml/s)	Postoperative Q_{max} (ml/s)	*P* value (postoperative)
13	12	102	HoLRP	8.9	25.2	<0.05
			TURP	9.1	20.4	
16	24	86	HoLRP	8.9	25.0	0.14
			TURP	9.1	20.9	
15	48	73	HoLRP	8.9	22.3	0.23
			TURP	9.1	18.5	
14	6	70	HoLRP	NA	24	NS
			TURP		21	
20, 21	12	52	HoLEP	8.4	21.8	NS
			TURP	8.3	18.4	
22	12	175	HoLEP	4.9	27.9	0.76
			TURP	5.9	27.7	
23	12	100	HoLEP	8.2	25.1	0.25
			TURP	7.8	24.7	

Table 5a. Urodynamics: detrusor pressure at maximum flow (P_{det}/Q_{max})

Reference	Follow-up (months)	No. of cases	Operation performed	Preoperative P_{det}/Q_{max} (cmH_2O)	Postoperative P_{det}/Q_{max} (cmH_2O)	*P* value (postoperative)
13	6	106	HoLRP	75.9	35.2	NS
			TURP	83.4	39.2	
14	6	70	HoLRP	NA	37	NS
			TURP		36	
20, 21	6	55	HoLEP	76.2	20.8	<0.001
			TURP	70.0	40.7	
23	12	100	HoLEP	77.3	36.2	0.85
			TURP	81.8	38.5	

Table 5b. Urodynamics: Schäfer grade

Reference	Follow-up (months)	No. of cases	Operation performed	Preoperative Schäfer grade	Postoperative Schäfer grade	*P* value (postoperative)
13	6	106	HoLRP	3.5	0.7	NS
			TURP	3.6	1.2	
20, 21	6	55	HoLEP	3.5	0.2	<0.001
			TURP	3.7	1.2	
23	12	100	HoLEP	3.4	0.9	0.55
			TURP	3.5	1.2	

Table 6. Prostate tissue resection weight

Reference	No. of cases	Operation performed	Preoperative TRUS volume (ml)	Tissue retrieved (g)	*P* value (postoperative)
13	120	HoLRP	44.3	7.9[a] (21.7)	
		TURP	44.6	14.5	
20, 21	61	HoLEP	77.8	40.4	<0.05
		TURP	70.0	20.7	
22	200	HoLEP	53.5	32.6[b]	0.17
		TURP	49.9	37.2	
23	100	HoLEP	70.3	36.1	<0.05
		TURP	56.2[c]	25.4	

[a]Estimated resection weight 21.7 g because estimated 2/3 of tissue lost to vaporisation in HoLRP
[b]Morcellator not available in this study
[c]Note $P<0.05$ for differences in preoperative TRUS volume for the two groups

Table 7. Operating time

Reference	No. of cases	Operation performed	Operating time (min)	*P* value	Tissue removal rate (g/min)	*P* value
13	120	HoLRP	41.5	<0.001	0.52	NS
		TURP	25.3		0.57	
14	70	HoLRP	56	<0.001	N/A	
		TURP	29			
20, 21	61	HoLEP	62.1	<0.001	0.61	NS
		TURP	33.1		0.80	
22	200	HoLEP	94.6[a]	<0.0001	0.34[a]	
		TURP	73.8		0.50	
23	100	HoLEP	74	<0.05	0.48	NS
		TURP	57		0.44	

[a]Morcellator not available in this study

Safety/Adverse Effects

HoLEP generally takes as long or longer than TURP, but tissue removal/retrieval rate (grams/minute) is similar or greater because of more tissue being retrieved with HoLEP (Table 7). All randomised trials have shown that both HoLRP and HoLEP require significantly lower catheter duration and hospital stay when compared to conventional TURP (Table 8). There appears to be no significant

Table 8. Catheter duration and hospitalisation

Reference	No. of cases	Operation performed	Catheter duration (h)	*P* value	Hospital duration (h)	*P* value
13	120	HoLRP	20.0	<0.001	26.2	<0.001
		TURP	37.2		47.5	
14	70	HoLRP	31.2	<0.001	55.2	<0.001
		TURP	55.2		79.2	
20, 21	61	HoLEP	17.7	<0.01	27.6	<0.001
		TURP	44.9		49.9	
22	200	HoLEP	27.6	<0.0001	53.3	<0.0001
		TURP	43.4		85.8	
23	100	HoLEP	31.0	<0.001	59.0	<0.001
		TURP	57.8		85.8	

Table 9. Irrigation volume

Reference	No. of cases	Operation performed	Intraoperative irrigation volume (l)	Postoperative irrigation volume (l)	Total irrigation volume (l)
13	120	HoLRP	15.8	0.7[a]	16.5
		TURP	10.0	28.2	38.2
20, 21	61	HoLEP	23.4	0.7[b]	24.1
		TURP	14.0	10.7	24.7

[a]Only 1 patient in HoLRP group vs. all patients in TURP group
[b]Only 2 patients in HoLEP group vs. 21 (70%) in TURP group

Table 10a. Complications: perioperative

Reference	No. of cases	Follow-up (months)	Operation type	Blood transfusions	Recatheter	Reoperation[a]	UTI
13	102	12	HoLRP	0	5	1	3
			TURP	4	8	4	5
20, 21	52	12	HoLEP	0	5	0	0
			TURP	1	4	2	2
22	175	12	HoLEP	0	0	2	N/A
			TURP	2	5	5	
23	100	12	HoLEP	0	3	1	
			TURP	1	1	1	
Totals	429	12	HoLRP/EP	0 (0%)	13 (1.5%)	4 (0.5%)	3 (0.3%)
			TURP	8 (0.9%)	18 (2.1%)	12 (1.4%)	7 (0.8%)

UTI, urinary tract infection
[a]For bleeding or residual prostatic tissue causing obstruction

difference in perioperative or postoperative complications (apart from bleeding related) with HoLRP/HoLEP compared to TURP (Tables 9, 10b).

Other Adverse Effects

Other adverse effects reported in the foregoing trials occurred less frequently or were not reported at all in some trials; these included TUR syndrome occurring

Table 10b. Complications: strictures/incontinence/potency

Reference	No. of cases	Follow-up (months)	Operation performed	Total urethral stricture	Bladder neck contracture	De novo stress incontinence	Decreased potency compared to preoperative
13	102	12	HoLRP	6	1	2	4
			TURP	6	2	1	5
15	73	48	HoLRP	6	3	2	3
			TURP	6	3	1[a]	6
20, 21	52	12	HoLEP	1	0	1	1
			TURP	3	0	0	1
22	175	12	HoLEP	3	3	1	10
			TURP	1	1	1	9
23	100	12	HoLEP	1		1	0[b]
			TURP	4		1	0
Totals (12-month follow-up)	429	12	HoLRP/EP	11 (1.3%)	4 (0.5%)	5 (0.6%)	15 (1.7%)
			TURP	14 (1.6%)	3 (0.3%)	3 (0.3%)	15 (1.7%)

[a]Required artificial sphincter

[b]Overall, no change in mean score from baseline in either group as measured by the erectile function domain of the IIEF-15 questionnaire. Individual variations not reported

in one patient overall after TURP [23]. DVT was reported in just one patient after TURP [13]. Retrograde ejaculation was reported in similar numbers by Kuntz et al. (74% in HoLEP group, 70% after TURP) [22]. Montorsi et al. reported ten minor (mucosal) bladder injuries (19%) secondary to morcellation which did not require further intervention and were treated with bladder irrigation if necessary [23].

Mortality rates were reported in all studies. There were no perioperative deaths. Westenberg et al. reported 48-month follow-up after HoLRP and TURP. Overall, there were two deaths during follow-up after HoLRP and seven deaths after TURP. All were attributed to cardiovascular causes or malignant disease, with none being considered related to the surgery [15].

Other Outcomes of Holmium Laser Prostatectomy Versus TURP

Cost Effectiveness

One of the perceived disadvantages of laser prostatectomy is the cost, especially the initial capital outlay. However, Fraundorfer et al. performed a cost-effectiveness analysis comparing TURP and HoLRP [24]. Economic and clinical outcome data were prospectively recorded for 1 year on 120 patients randomized to either TURP or HoLRP. HoLRP cost 24.5% less than TURP

during the first year with similar efficacy measurements [13,24]. On the basis of these savings, HoLRP is more cost effective than TURP if a minimum of 93 cases per year are performed to recover capital and service costs of the holmium laser. These costs are expected to be replicated for HoLEP. The morcellator adds to equipment and service costs, but makes the procedure quicker to perform than HoLRP [21]. Cost analysis by Kuntz et al. calculated that amortization of the laser was achieved after 1 year [22]. This calculation was based on about 300 HoLEP and 150 other holmium laser procedures yearly.

Day-Case Surgery

A significant advantage of HoLEP is the reduced bleeding and catheter time. The same applies for larger prostates. In a trial comparing HoLEP to TURP in larger glands of 40–200 g (mean, 77.8 g), Gilling et al. and Tan et al. reported no blood transfusions, a mean catheter time of 17.7 h (range, 11–26 h), and only 2 patients requiring irrigation postoperatively [20,21]. The nursing care required postoperatively is significantly reduced. Larner et al. examined the safety of day-case HoLRP in prostate volumes <60 ml in 38 men [25]. The mean stay after surgery was 302 min. A community nursing service removed the catheters 48 h after the operation. There were 4 readmissions to hospital: 1 for blocked catheter, 2 for failed trial of void at 2 days, and 1 for paraphimosis after removing the catheter. The safety and efficacy of day-case HoLEP (<40 g prostates) has been established in a randomized controlled trial (RCT) compared to HoBNI [18].

Histology

One of the advantages of HoLRP over HoLAP was that tissue could be retrieved for histological examination. For HoLRP, less tissue is retrieved than TURP because an estimated 50%–75% of the resected tissue is vaporised during the operation [12]. In addition, an increased amount of thermal artefact is present after HoLRP, making diagnosis of prostate cancer more difficult [26]. However, HoLEP with morcellation allows adequate histological examination, and the sensitivity in detecting incidental prostate cancer and high-grade PIN is comparable to TURP [23,27]. HoLEP with morcellation also retrieves more tissue than TURP in randomised trials [20,21,23], and intuitively this extra tissue may lead to higher rates of incidental cancer detection. In a large series of 950 consecutive patients who underwent HoLEP, Kuntz et al. reported a 5.1% rate of incidentally detected prostatic carcinoma [28], which is similar to rates reported in contemporary TURP series [29].

Learning Curve

The training requirements for HoLEP have been considered a drawback for some. Most authors describe the learning curve as similar to TURP and that

20–30 cases on glands <60 g should be achieved before proficiency can be expected and larger prostatic enucleations are attempted [20,29–31]. El Hakim and Elhilali confirmed these findings in a study which showed that after 20 procedures under supervision, a urology resident could expect to consistently achieve outcomes similar to those of a more experienced surgeon [32]. Anecdotally, trainees who are new to both TURP and HoLEP tend to find HoLEP easier to learn because of decreased bleeding, improved visibility, and the intuitive nature of dissecting along a surgical plane [22,33]. In contrast to TURP, teaching HoLEP does not have a finite operating time because the risk of TUR syndrome is absent.

Large Prostate Size and Comparison to Open Prostatectomy

One major advantage of HoLEP over TURP is that there is no prostate size or configuration that cannot be treated with HoLEP. Mebust et al. reviewed the outcome of 3885 TURP procedures and found that the incidence of intraoperative bleeding and the TUR syndrome significantly increased when resection time was greater than 90 minutes [6]. Prostate adenomas >80–100 g requiring a longer resection time have traditionally been treated with open prostatectomy rather than TURP. Kuntz et al. conducted a prospective randomized study comparing HoLEP and open prostatectomy for prostate glands >100 g [31]; the operation time was significantly longer for HoLEP (138 vs. 90 min). However the hospital stay and catheter times were significantly less in the HoLEP group (48 vs. 240 h and 24 vs. 144 h, respectively). The clinical outcomes in both groups were equivalent such that HoLEP was as effective as open prostatectomy but with significantly less perioperative morbidity.

Conclusions

Use of the holmium laser for the treatment of benign prostatic hyperplasia has evolved into a technique of enucleation where the laser fibre is used to shell out the adenoma (HoLEP). This technique is a true paradigm shift in transurethral prostatic surgery from older techniques, which created a variable channel in the adenoma by vaporisation or piecemeal resection, to near-complete true enucleation of the entire tumour. Morcellation can then be used to retrieve the fragments from the bladder. Randomised studies have shown at least similar efficacy to electrocautery resection of the prostate (TURP). The weight of tissue removed is generally higher with HoLEP, and extrapolating from this, it is possible that this may result in lower reoperation rates in the future. HoLEP generally takes longer than TURP in smaller glands, but tissue removal rates (in grams/minute) are similar whereas catheter duration and hospital stay are much lower after HoLEP when compared to TURP. Blood

transfusion rates are also lower, whereas other complication rates seem to be comparable.

References

1. Keoghane SR, Lawrence KC, Gray AM, Doll HA, Hancock AM, Turner K, Sullivan ME, Dyar O, Cranston D (2000) A double-blind randomized controlled trial and economic evaluation of transurethral resection vs contact laser vaporization for benign prostatic enlargement: a 3-year follow-up. BJU Int 85:74–78
2. Bosch JLH (1997) Urodynamic effects of various treatment modalities for benign prostatic hyperplasia. J Urol 158:2034
3. Jepsen JV, Bruskewitz RC (1998) Recent developments in the surgical management of benign prostatic hyperplasia. Urology 51:23–31
4. AUA Practice Guidelines Committee (2003) AUA guidelines on management of benign prostatic hyperplasia. Chapter 1: diagnosis and treatment recommendations. J Urol 170:530–547
5. Roos NP, Wennberg JE, Malenka DJ, Fisher ES, McPherson K, Anderson TF, Cohen MM, Ramsey E (1989) Mortality and re-operation after open and transurethral resection of the prostate for benign prostatic hyperplasia. N Engl J Med 320: 1120–1124
6. Mebust WK, Holtgrewe HL, Cockett ATK, Peters PC, Writing Committee (1989) Transurethral prostatectomy: immediate and postoperative complications. A cooperative study of 13 participating institutions evaluating 3,885 patients. J Urol 141: 243–247
7. Gilling PJ, Cass CB, Malcolm AR, Fraundorfer MR (1995) Combination holmium and Nd:YAG laser ablation of the prostate: initial clinical experience. J Endourol 9: 151–153
8. Chun SS, Razvi HA, Denstedt JD (1995) Laser prostatectomy with the holmium:YAG laser. Tech Urol 1:217–221
9. Gilling PJ, Cass CB, Creswell MD (1996) The use of the holmium laser in the treatment of benign prostatic hyperplasia. J Endourol 10:459–461
10. Tan AHH, Gilling PJ (2005) Lasers in the treatment of benign prostatic hyperplasia: an update. Curr Opin Urol 15:55–58
11. Mottet N, Anidjar M, Bourdon O (1999) Randomized comparison of transurethral electroresection and holmium:YAG laser vaporization for symptomatic benign prostatic hyperplasia. J Endourol 13:127–130
12. Gilling PJ, Cass CB, Creswell MD, Fraundorfer MR (1996) Holmium laser resection of the prostate: preliminary results of a new method for the treatment of benign prostatic hyperplasia. Urology 47:48–51
13. Gilling PJ, Mackey M, Creswell M, Kennett KM, Kabalin JN, Fraundorfer MR (1999) Holmium laser versus transurethral resection of the prostate: a randomized prospective trial with 1-year follow up. J Urol 162:1640–1644
14. Hammad FT, Mark SD, Davidson PJ, Gowland SP, Gordon B, English SF (2002) Holmium:YAG laser resection of the prostate: a randomized prospective trial with 1-year follow-up. A N Z J Surg 72:A138
15. Westenberg AM, Gilling PJ, Kennett KM, Frampton C, Fraundorfer MR (2004) Holmium laser resection of the prostate versus transurethral resection of the prostate: results of a randomized trial with 4-year minimum long-term follow-up. J Urol 172: 616–619

16. Gilling PJ, Kennett KM, Fraundorfer MR (2000) Holmium laser resection vs transurethral resection of the prostate: results of a randomized trial with 2 years of follow-up. J Endourol 14:757–760
17. Kitagawa M, Furuse H, Fukuta K, Aso Y (1997) A randomized study comparing holmium laser resection of the prostate to transurethral resection of the prostate. BJU Int Suppl 80:209
18. Aho TF, Gilling PJ, Kennett KM, Westenberg AM, Fraundorfer MR, Frampton CM (2005) Holmium laser bladder neck incision versus holmium laser enucleation of the prostate for prostates less than 40 grams: a randomized trial. J Urol 174:210–214
19. Tooher R, Sutherland P, Costello A, Gilling PJ, Rees G, Maddern G (2004) A systematic review of holmium laser prostatectomy for benign prostatic hyperplasia. J Urol 171:1773–1781
20. Gilling PJ, Kennett KM, Fraundorfer MR (2001) Holmium laser enucleation of the prostate (HoLEP) is superior to TURP for the relief of bladder outflow obstruction (BOO). J Endourol Suppl 15:A41 (abstract A5-P6)
21. Tan AHH, Gilling PJ, Kennett KM, Frampton C, Westenberg AM, Fraundorfer MR (2003) A randomized trial comparing holmium laser enucleation of the prostate with transurethral resection of the prostate for the treatment of bladder outflow obstruction secondary to benign prostatic hyperplasia in large glands (40 to 200 grams). J Urol 170:1270–1274
22. Kuntz RM, Ahyai S, Lehrich K, Fayad A (2004) Transurethral holmium laser enucleation of the prostate versus transurethral electrocautery resection of the prostate: a randomized prospective trial in 200 patients. J Urol 172:1012–1016
23. Montorsi F, Naspro R, Salonia A, Suardi N, Briganti A, Zanoni M, Valenti S, Vavassori I, Rigatti P (2004) Holmium laser enucleation versus transurethral resection of the prostate: results from a 2-center prospective randomized trial in patients with obstructive benign prostatic hyperplasia. J Urol 172:1926–1929
24. Fraundorfer MR, Gilling PJ, Kennett KM, Dunton NG (2000) Holmium laser resection of the prostate is more cost effective than transurethral resection of the prostate: results of a randomized prospective study. Urology 57:454–458
25. Larner TRG, Agarwasi D, Costello AJ (2003) Day-case holmium laser enucleation of the prostate for gland volumes of <60 ml: early experience. BJU Int 91:61–64
26. Das A, Kennett K, Sutton T (2000) Histological effects of holmium:YAG laser resection vs transurethral resection of the prostate. J Endourol 14:459–462
27. Naspro R, Freschi M, Salonia A, Guazzoni G, di Girolamo V, Colombo R, Scattoni V, Rigatti P, Montorsi F (2004) Holmium laser enucleation versus transurethral resection of the prostate. Are histological findings comparable? J Urol 171:1203–1206
28. Kuntz RM, Lehrich K, Ahyai S, Gerlach A Fayad A (2004) Perioperative morbidity of holmium laser enucleation of the prostate (HoLEP): results in 950 consecutive patients. Presented at annual meeting of American Urological Association, San Francisco, CA, May 8–13
29. Borboroglu PG, Krane CJ, Ward JF, Roberts JL, Sands JP (1999) Immediate and postoperative complications of transurethral prostatectomy in the 1990's. J Urol 162:1307
30. Tan AHH, Gilling PJ (2002) Holmium laser prostatectomy: current techniques. Urology 60:152–156

31. Kuntz RM, Lehrich K (2002) Transurethral holmium laser enucleation versus transvesical open enucleation for prostate adenoma greater than 100 gm: a first randomized prospective trial of 120 patients. J Urol 168:1465–1469
32. El-Hakim A, Elhilali MM (2002) Laser enucleation of the prostate can be taught: the first learning experience. BJU Int 90:863–869
33. Tan AHH, Gilling PJ (2003) Holmium laser prostatectomy. BJU Int 92:527–530

Transurethral Microwave Thermotherapy for Benign Prostatic Obstruction

Stavros Gravas

Summary. Scientific and technological advances have challenged established therapy patterns regarding benign prostatic obstruction (BPO), such as transurethral resection of the prostate (TURP) and open prostatectomy. Living in the era of evidence-based medicine, clinicians need high-quality data to make the right treament decisions. Recent developments in transurethral microwave thermotherapy (TUMT) have provided significant data on clinical outcome. Randomised studies of TUMT versus other established therapies of BPO, including medical treatment and TURP, have also contributed to the evaluation of morbidity and the costs of treatment. Long-term results are available that allow the evaluation of treatment durability. This chapter highlights recent advances in the field of TUMT and discusses their potential impact on daily clinical practice.

Keywords. Transurethral microwave thermotherapy, Benign prostatic obstruction, Transurethral resection of prostate, Randomised studies

Introduction

Living in the aging-male era, an increasing number of patients suffering from lower urinary tract symptoms (LUTS) due to benign prostatic obstruction (BPO) will seek adequate management. The last two decades have witnessed a significant change in the management of BPO. Scientific and technological innovations and the rather unchanged morbidity of transurethral resection of prostate (TURP) in terms of early (bleeding, TUR syndrome) and late complications (mainly relating to sexual dysfunction), as well as the need for anaesthesia and hospitalisation, have led to a rising demand for minimally invasive therapies for BPO alternatives to TURP. Many different energy sources have been used to produce heat, but application of microwave technology, solely

Department of Urology, University Hospital of Larissa, Feidiou 6-8, 421 21 Larissa, Greece

through the transurethral route, has gained a firm position among current ablative methods due to the excellent clinical results from the treatment of symptomatic BPO. Transurethral microwave therapy (TUMT) has been much evaluated in the past decade and has been widely used. The recent advances in TUMT have provided significant data on clinical outcome. In addition, urologists should keep up to date with these advances and weigh evidence before making treatment choices. The aim of the present chapter is to provide the best current evidence for the evaluation of TUMT and further elucidation of the role of this minimally invasive therapy in the management of BPO.

Mechanism of Action

TUMT uses a special transurethral catheter with a microwave antenna that emits microwave radiation to deliver heat within the prostate. Microwaves are electromagnetic waves that produce heat when they are absorbed by the tissue. Heat arises mainly by electrical dipoles (water molecules) oscillating in the microwave field and electric-charge carriers (ions) moving back and forth in the field. The eventual goal is to destroy tissue by achieving temperatures that exceed the cytotoxic threshold. It has been demonstrated that heating in excess of 45°C results in coagulation necrosis [1]. The extent of thermal necrosis is dependent on two physical variables: intraprostatic temperature and duration of heat exposure [2].

In addition, Brehmer and Svensson investigated the feasibility of using heat to induce apoptosis in human prostatic stromal cells [3]. Several combinations of temperature and exposure time were evaluated. The most extensive apoptosis (in 76% of the cells) was recorded when cell cultures were exposed to 47°C for 1 h [3]. It has also been suggested that TUMT causes denervation of alpha-receptors, thereby decreasing the smooth muscle tone of the prostatic urethra of the smooth muscle cells [4].

TUMT Devices

Several devices operating at either 915 or 1296 MHz, using different microwave antenna designs, have been introduced. The design of the antenna seems to affect the heating pattern more than the wave frequency does [5]. Other differences between available devices include the cooling systems, treatment time, and monitoring of TUMT effect. Identification of the limitations of first-generation devices, mainly the low-energy software protocols and the often-interrupted energy delivery, contributed to their further evolution regarding heat distribution, treatment time, energy, and monitoring of thermotherapy effect. High-energy thermotherapy (HE-TUMT) was developed following the hypothesis that more energy would create higher temperatures and eventually achieve better clinical outcome. Another modification in the treatment protocols was to reduce treatment time by introducing the heat-shock strategy. Heat-shock

strategy is characterized by a rapid buildup in power and temperatures that causes immediate vascular thromboses, theoretically resulting in similar or better clinical outcome with a shorter-duration treatment [6].

Presently, the main players in the field of microwave thermotherapy are the Prostatron device (Urologix, Minneapolis, MN, USA), the Targis (Urologix), the CoreTherm (ProstaLund, Lund, Sweden), and the TMx-2000 (TherMatrx, Northbrook, IL, USA). In the beginning, Prostatron used the first-generation, low-energy Prostasoft 2.0 software, and subsequently the Prostasoft 2.5 high-energy software was developed. Recently, a 30-min high-energy method has also become available, namely the Prostasoft 3.5 protocol.

The Coretherm system provides intraprostatic temperature monitoring. The measured temperature is used for a real-time calculation of the amount of necrotized tissue by using a combination of the bioheat equation and cell survival data of thermal exposure [7,8]. Consequently, the system allows tailoring of treatment to the needs of each patient.

Targis is a high-energy cooled thermotherapy system. In addition, a third-generation Urologix system, the Cooled ThermoCath (CTC), which uses a 28.5-min treatment at higher temperatures, has been developed. The TherMatrx TMX-2000 differs from other available microwave device systems in that it lacks a cooling system and uses a lower wattage.

Efficacy of TUMT

During the last decade, numerous studies have been published presenting the clinical results from the application of TUMT for the treatment of LUTS associated with BPO. These studies have used different devices with different technical specifications and treatment protocols, have had different follow-up periods and response criteria, and have differed in patient selection. Generally, studies on BPO treatments use the improvement in maximum urinary flow rate (Q_{max}) and changes in International Prostate Symptom Score (IPSS) as the objective and subjective outcome measures, respectively. The objective and subjective improvements of the initial lower-energy TUMT (LE-TUMT) protocols have been proven in prospective randomised sham controlled studies [9–11]. To further improve clinical outcome, higher-energy TUMT protocols have been evaluated and are at the present time predominantly utilized. Short-term subjective and objective improvement with various HE microwave devices has been proven by all these studies. The indication to use microwave treatment has gradually changed from application to patients with solely irritative symptoms to now include patients with evident obstructive elements and patients in urinary retention.

In an interesting review, de la Rosette et al. reported that the maximum improvement in urinary flow rate is achieved 3 months after TUMT [12]. Q_{max} baseline values were on average 9–10 ml/s, whereas 3 months following TUMT Q_{max} improved approximately 5–6 ml/s. It remained stable at 6 and 12 months

follow-up, thus representing an average 50%–60% increase, but some deterioration was noted with time. The average IPSS improvement after high-energy thermotherapy is approximately 60%. The maximum reduction is obtained 3 months after treatment, with a slight but insignificant further improvement at the 6- and 12-month visit.

Because urodynamic investigation in BPO remains an optional test in daily practice, there are only a few studies on the effect of different energy TUMT generators on bladder outlet obstruction. LE-TUMT has minimal impact on bladder outlet obstruction (BOO) overall [13]. Higher-energy devices seem to result in a significant decrease of BOO. In a randomised study, complete urodynamic evaluation was available at 6 months in 102 patients [14]. It was shown that, after TUMT with the Prostasoft 3.5, the urodynamic variables improved significantly. Clinically there was a shift from the obstructed to the nonobstructed region of the plot (50% vs. 82% in the TUMT and TURP groups, respectively). Thalmann et al. investigated urodynamically 162 and 59 patients 6 months and 2 years after TUMT with the Targis device, respectively [15]. Urodynamic parameters were significantly decreased and remained stable at 24 months in more than 75% of patients treated. Osman et al. found that only 50% (20/40) of the patients changed to unobstructed on the pressure-flow nomogram after TUMT using the Targis device, with the younger ones more likely to have urodynamic improvement [16]. These data indicate that symptomatic improvement after TUMT is more pronounced and more frequent than urodynamic amelioration.

TUMT Versus TURP

It is the destiny of all therapeutic modalities for BPO that challenge TURP to be compared to this established treatment. Therefore, we should mainly rely on randomised studies comparing TUMT to TURP for objective, unquestionable evaluation of the TUMT efficacy. Six prospective randomised studies have been conducted presenting the outcome of TUMT compared to TURP [14,17–21]. Five studies found significant decreases in urinary symptoms and significant increases in Q_{max} between baseline and follow-up for both TURP and TUMT, whereas Ahmed et al. [17] found that TUMT did not improve Q_{max}. In addition, all studies showed that TUMT significantly improved IPSS. Although statistical values and absolute numbers are superior for TURP, the difference in clinical terms is less pronounced. Figures 1 and 2 display the outcome of the available randomised studies in terms of Q_{max} and IPSS.

Hoffman et al. [22] brought together separately conducted randomised studies and synthesised their results. This excellent systematic review evaluates the efficacy and safety of microwave thermotherapy in treating men with LUTS and BPO to quantify the therapeutic efficacy. Overall, 540 patients were randomised in the six eligible randomised studies, including 322 to TUMT and 218 to TURP. Treatment was offered by different TUMT devices and software, including Prostatron (Prostatsoft 2.0 and 2.5) and ProstaLund Feedback. TUMT was

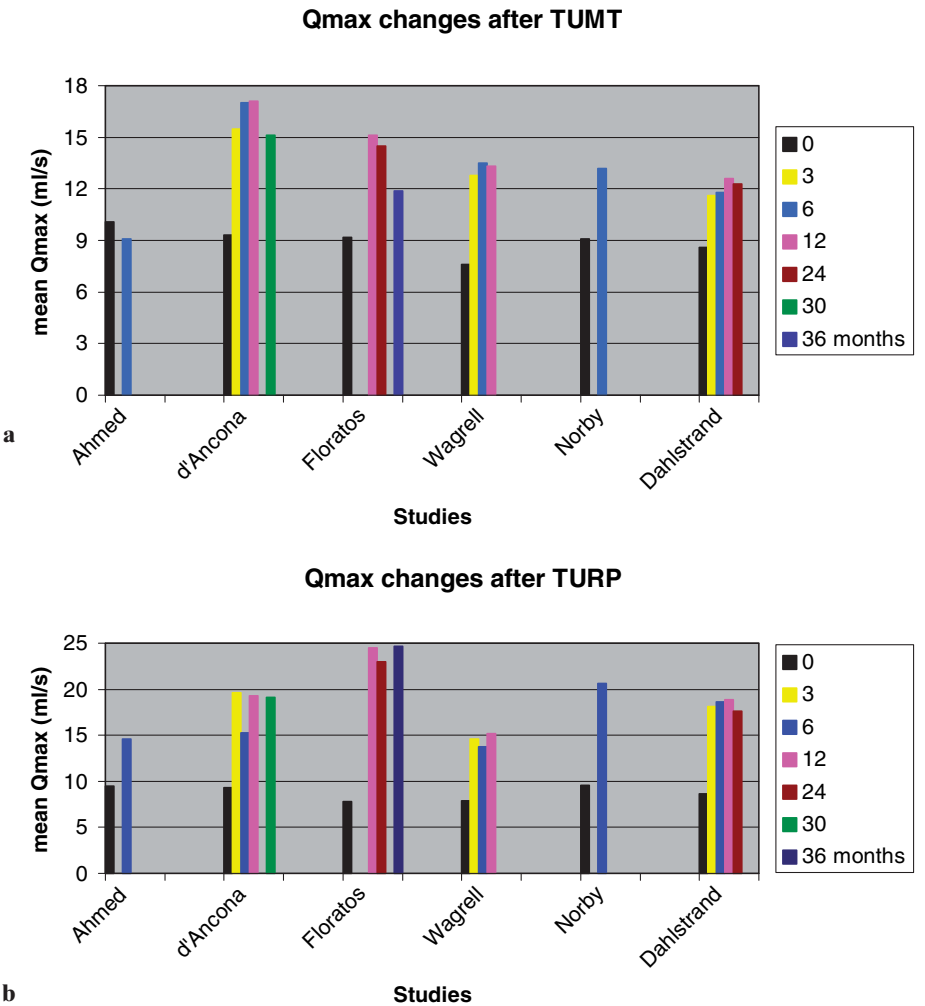


FIG. 1. Changes in maximum urinary flow rate (Q_{max}) after treatment for benign prostatic obstruction (BPO). **a** Transurethral microwave thermotherapy (TUMT). **b** Transurethral resection of the prostate (TURP)

somewhat less effective than TURP in reducing LUTS. Weighted mean differences (WMD) were calculated with 95% confidence interval (CI) for the between-treatment differences in pooled means. WMD for the symptom score at the follow-up for all six studies was –1.83 (–3.09 to –0.58), favouring TURP. It was also found that the mean urinary symptom scores for TUMT patients almost always decreased from the moderate-to-severe symptom range to the mildly symptomatic range.

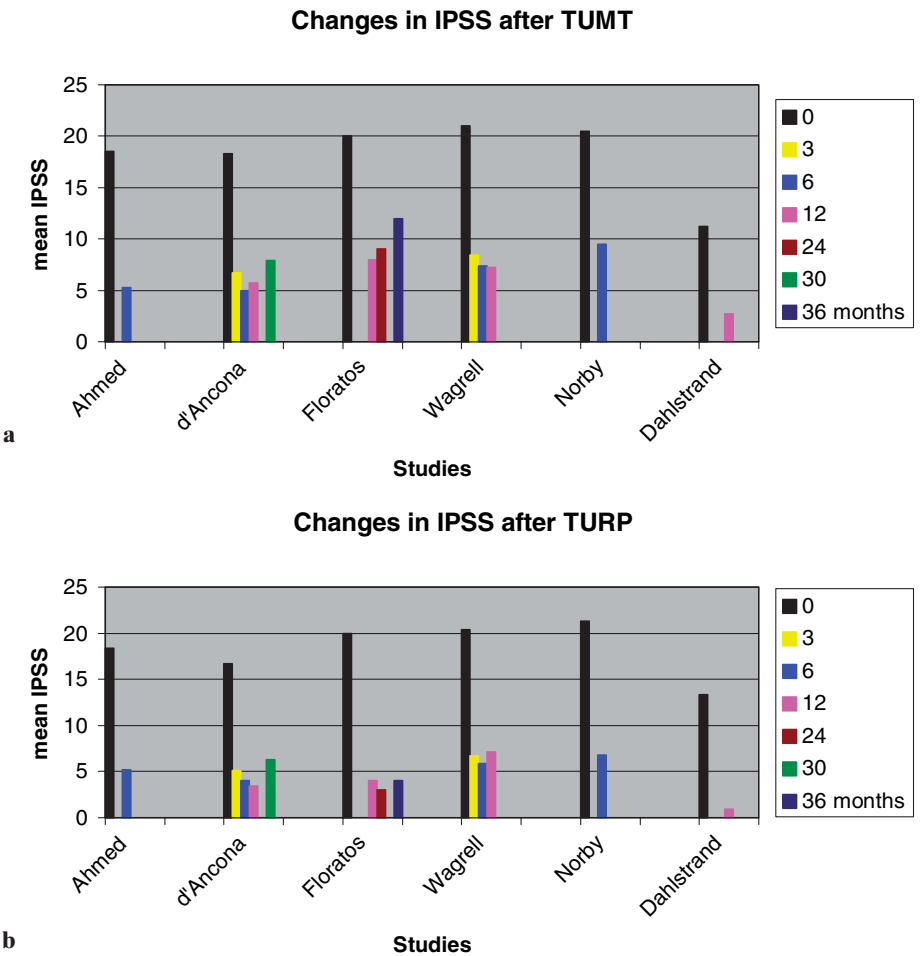


FIG. 2. Changes in International Prostate Symptom Score (IPSS) after treatment for benign prostatic obstruction (BPO). **a** Transurethral microwave thermotherapy (TUMT). **b** Transurethral resection of the prostate (TURP)

The magnitude of improvement in Q_{max} was greater for patients treated with TURP than TUMT, with a WMD for Q_{max} at the follow-up of 5.37 (4.22–6.51) ml/s. The mean Q_{max} after TUMT was usually <15 ml/s, because only two studies reported a mean post TUMT Q_{max} greater than 15 ml/s. In contrast, five studies reported that TURP achieved a mean Q_{max} >15 ml/s. Clinical results of this review are listed in Table 1.

Gravas et al. performed a pooled analysis of three studies of ProstaLund Feedback TUMT with 12-month follow-up [23]. Two randomised studies comparing PLFT (Prosta Lund Feedback Treatment) to TURP and an open label study with no comparative group were combined. Inclusion and exclusion crite-

Table 1. Clinical outcome of TUMT systematic review and pooled data of PLFT

Reference	Treatment	Patients (*n*)	Symptom score			Maximum flow rate (ml/s)		
			Preop.	Postop.	Change	Preop.	Postop.	Change
Hoffman [22]	TUMT	322	19.4	6.7	65%	7.9	13.5	70%
	TURP	218	19.6	4.5	77%	8.6	18.7	119%
Gravas [23]	TUMT	183	20.9	6.4	69%	7.7	16.1	109%
	TURP	65	20.7	7.1	66%	7.5	18.6	148%

TUMT, transurethral microwave thermotherapy; PLFT, ProstaLund Feedback Treatment; TURP, transurethral resection of the prostate

ria of the three studies were identical, and this fact reduced any selection bias. The responder rate was 85.3% and 85.9% in the PLFT (183 patients) and TURP (65 patients) groups, respectively. One-sided 95% CI analysis showed noninferiority of PLFT as compared to TURP. A responder was defined as a patient who following treatment had an IPSS of 7 or less, and/or 50% or greater improvement in IPSS from baseline, and/or Q_{max} of 15 ml/s or more, and/or 50% or greater improvement in Q_{max} from baseline. Detailed data of IPSS and Q_{max} improvement are presented in Table 1. It is suggested that PLFT seems to have an efficacy that in terms of IPSS and responder rate is not inferior to that of TURP.

TUMT Versus Medical Therapy

The position of TUMT compared to medical therapy for the management of LUTS with BPO has also been evaluated. Djavan et al. conducted a prospective study with 103 patients with BPO who were randomised to receive either targeted TUMT or medication with terazocin [24]. It was demonstrated that the clinical outcomes of TUMT were significantly greater than those achieved by terazosin. Mean IPSS improved significantly from baseline by 6 months in both groups, with a greater improvement in patients after TUMT, where the IPSS was 38% lower than that in the terazosin group. Q_{max} also increased significantly from baseline in both groups by 6 months and remained stable thereafter; it was 19.8% higher after microwave treatment than with terazosin. The percentage of TUMT patients having a ≥50% improvement in Q_{max} and IPSS at 6 months (64.7% and 78.4%, respectively) markedly exceeded that in the terazosin group (9.6% and 32.7%, respectively).

TUMT in Patients in Urinary Retention

Men with retention represent a specific group of BPO patients who in general are at increased risk of perioperative morbidity and mortality and present a lesser response to any treatment that resolves obstruction [25]. In the past,

TUMT was thought to be contraindicated because of a high failure rate, but nowadays urologists feel more confident to offer this minimally invasive option to patients in retention due to the advanced devices and treatment protocols. Success rate is defined as the percentage of patients who regain their ability to void spontaneously. Schelin reported that 80% of their cohort became catheter free after TUMT, and those who failed all had large median lobes or protruding lateral lobes into the bladder [26].

Naqvi et al. treated and followed up 167 men using Prostasoft 2.5, of whom 93% were able to void spontaneously with acceptable Q_{max} after therapy [27]. In another study by Kellner et al., 32 of 39 patients (82%) were able to void after HE-TUMT, but only 6 (15%) of the patients who were voiding were able to stop their medication for BPO [28].

However, most of the studies had a very short follow-up (≤12 months), which raises difficulties for the estimation of durability of TUMT outcome on patients with retention. Floratos et al. found that the 1-year retreatment rate was estimated to be 25% [29]. Gravas et al. assessed durability of TUMT using the Prostasoft 3.5 with follow-up up to 5 years. The cumulative re-treatment risk at 5 years was 58.8% for patients in retention, whereas the corresponding risk for patients without retention was 42.3% ($P = 0.03$) [30].

Durability

A critical question for any minimally invasive treatment is whether it passes the test of time. Therefore, durability of long-term improvement is a prerequisite for acceptance of TUMT and should be investigated. In most available studies the attrition rate was significant; thus, fewer than half the initial group of patients treated have been analysed at 4–5 years.

Historically, LE-TUMT has been abandoned because of the disappointing durability of its effects. At 5 years after TUMT with the Prostasoft 2.0, 41% of the patients had received instrumental additional treatment, and 17% were being retreated with medication [31]. More recent studies confirm the limited durability of clinical outcome obtained by lower-energy programs, with a retreatment rate up to 84.4% after 5-year follow-up [32–34].

There are only three randomised studies comparing TUMT to TURP with a follow-up up to 3 years. In a randomised study by Floratos et al. [14], the results of 36 months of follow-up were presented. Improvement in Q_{max} of the TUMT group from 9.2 ml/s retreatment to 15.1 ml/s, 14.5 ml/s, and 11.9 ml/s at 1, 2, and 3 years, respectively, was reported, whereas the IPSS symptom score improved from 20 to 8, 9, and 12, respectively. These data indicate that the level of improvement is durable up to 3 years. Similarly, d' Ancona et al. randomised 52 patients to receive either TUMT with the Prostatron software version 2.5 (31 patients) or undergo transurethral resection (21 patients) [18]. Treatment outcomes for the TUMT group were significant, with an increase in Q_{max} from 9.3 to 15.1 ml/s at 30 months (62%), whereas the IPSS decreased from 18.3 to 7.9 (54%). The

corresponding improvement for the TURP group was 105% (from 9.3 to 19.1 ml/s) and 62% (from 16.7 to 6.3), respectively. The level of improvement was durable up to 2.5 years. It was concluded that TUMT and TURP achieved durable results in patients with LUTS suggestive of BOO, although the magnitude of improvement was higher with resection.

Recently, Wagrell et al. presented the 3-year results of a prospective randomised multicenter study comparing TUMT with PLFT (Core-Therm device) to TURP [35]. At 36-month follow-up, the average value for the PLFT group was 8.2, 1.2, and 11.9 ml/s for IPSS, quality of life (QoL), and Q_{max}, respectively. The corresponding values for the TURP group were IPSS 5.0, QoL 1.0, and Q_{max} 13.5 ml. The degree of improvement was in the same range as that observed after 12 and 24 months for both groups. These data suggest that at 3 years, clinical results obtained with PLFT TUMT were comparable to those seen after TURP.

Trock et al. performed a pooled analysis of 6 multicenter studies of cooled thermotherapy [36]. In total, 541 patients were pooled, and the data showed an improvement of 55% and 51%, respectively, in American Urological Association (AUA) symptom score and Q_{max} 3 months after TUMT. A slight decrease was observed at 48 months but subjective and objective improvement remained durable (43% and 35%, respectively). AUA symptom score decreased from 20.9 to 9.5 and 11.5 at 1 and 4 years, respectively, while Q_{max} increased from 7.9 ml/s to 11.5 and 10.94 ml/s at the same follow-up visits [36].

Retreatment rate, defined as the percentage of any additional therapy given for primary treatment failure, represents an important parameter for the evaluation of treatment durability. Retreatment of TUMT is related to primary treatment failure, whereas retreatment of TURP is related to complications of resection, including urethral strictures, bladder neck sclerosis, meatal stenosis, and, rarely, treatment failure [12]. Reported retreatment rates after TUMT range from 19.8% to 29.3% but with different mean follow-up duration (from 30 to 60 months) [14,15,18,37]. In the randomised study by Floratos et al. [14], the cumulative risk of retreatment for TUMT Prostasoft 2.5 and TURP was 19.8% and 12.9%, respectively. Similarly, d'Ancona et al. found a retreatment rate of 26% and 4.7% for TUMT and TURP in their randomised study with a mean follow-up of 30 months [18]. The relatively longer-term outcomes still favoured TURP in both these studies.

In a recent multicenter trial, Miller et al. evaluated the durability of the Targis 60-min treatment on 150 patients during a 5-year period [37]. They reported that 29.3% of the patients (44/150) underwent additional BPO treatment at some point before 5 years, while they estimated that the cumulative Kaplan–Meier retreatment risk was 33.9% at 5 years [37]. In a study using the TUMT 3.5 protocol, 213 patients with or without retention were treated and followed for up to 5 years; 28.6% of patients without urinary retention required additional treatment, while treatment failure was 37.8% in the retention group, but the cumulative risk at 5 years was 42.3% and 58.8%, respectively [30].

Interesting results come from the comparison of TUMT to medical therapy. In an update of the study on TUMT versus medical management by Djavan et

al., patients have been followed up for 18 months [38]. The subjective and objective improvements observed at 6 months was maintained at 18 months and was significantly greater in the TUMT group compared to the terazosin group by 35% and 22%, respectively. By 18 months, 21 patients had failed terazosin therapy, 13 because it was ineffective and 8 because of side effects. Three patients failed TUMT by 18 months and proceeded to surgery. The actuarial rate of treatment failure at 18 months in the terazosin group (41%) significantly exceeded that of the TUMT group (5.9%) [38].

Outcome Predictors

Several studies attempted to answer the question why some patients respond favourably for many years and some patients do not and eventually require additional treatment. However, different devices were used, and a wide disparity in the applied criteria among the studies was observed. The predictive baseline parameters for the Prostatron device, including a lower Q_{max}, higher URA (Urethral Resistance factor), and higher total amount of energy, could not be associated with favourable clinical results when they were applied in the ProstaLund and Urowave series [39]. This finding suggests that a predictive factor for a particular device cannot necessarily be applied to the other devices.

Independent baseline parameters predicting unfavorable outcome were advanced age of the patient, small prostate volume, mild to moderate bladder outlet obstruction, and low amount of energy delivered during treatment [40]. Controversial results have also been published regarding the effectiveness of baseline prostate-specific antigen (PSA) as a predictor of the clinical outcome after TUMT. Djavan et al. demonstrated that baseline PSA could identify patients with favourable clinical results after TUMT with the Targis device [41]. Laguna et al. could not confirm this finding in a study using the Prostatron device [42].

Safety and Morbidity

Safety of treatment and morbidity represent two of the main considerations for both clinicians and patients. TUMT sessions are usually well tolerated by patients. They experience discomfort that usually appears as a mild feeling of perineal warmth and a mild urge to urinate, although sporadically there are complaints of significant discomfort. The need for sedoanalgesics in every patient has been questioned, and topical urethral anesthesia alone has been shown to be effective [43]. Pooled data from three studies on PLFT TUMT demonstrated that serious adverse events (SAE) probably or possibly related to the treatment occurred in 6.0% of the patients (11/183) in the PLFT group, including postoperative hemorrhage, urethral disorder, fever, urinary incontinence, hemorrhoids

thrombosed, urethral stricture, urinary retention (2 cases), vertigo, sepsis, and epididymitis [23]. In the TURP group, 15.4% of the patients (10/65) presented SAEs probably or possibly related to the treatment, including gout, delirium, sepsis, postoperative hemorrhage (2 cases), hematuria (3 cases), urinary tract infection, orchitis, and urethral stricture. The difference between groups was significant ($P = 0.035$) [23].

High-quality data regarding morbidity coming from the systematic analysis of published randomised studies comparing TUMT to TURP confirm this standpoint [14,15,17,19,21,44,45]. For patients treated with TURP, the length of hospital stay and catheterisation time was 4.0 days (range, 3.9–4.1 days) and 3.6 days (range, 3–4.1 days), respectively, whereas in the TUMT group the corresponding mean values were 0 and 13.7 days (range, 12.7–14 days), respectively. Table 2 presents pooled data of randomised controlled studies on morbidity following TUMT and TURP [22,46]. Incidence of dysuria/urgency and urinary retention were in favour of TURP. The incidence of hematuria, clot retention, transfusions, and TUR syndrome is reported to be significantly less for TUMT than for TURP. The impact of TUMT on sexual function in terms of erectile dysfunction and retrograde ejaculation has also been studied in comparison to TURP, with pooled data in favour of TUMT (Table 2) [22,46]. Therefore, the reported low morbidity and the absence of any anaesthesia (spinal or general) needed, make TUMT a true outpatient procedure, representing an excellent option for patients in high operative risk (American Society of Anaesthiologists classification 3 and 4) who are unsuitable for an invasive treatment [47].

Table 2. Morbidity following TUMT and TURP (pooled data)

	Walmsley [46]		Hoffman [22]	
Variables	TUMT	TURP	TUMT	TURP
Urinary tract infections (%)	9.0 (3–19)	6.0 (5–9)	17.7 (43/244)	13.9 (21/151)
Dysuria (%)	51.0 (12–99)	15.0 (9–23)	31.2 (53/170)	13.1 (14/107)
Retention (%)	15.0 (1–33)	5.0 (4–8)	23.9 (51/213)	6.9 (9/130)
Clot retention (%)	NA	NA	0.5 (1/183)	4.0 (4/100)
Transfusions (%)	1.5 (0–9)	8.0 (5–11)	0 (0/144)	5.7 (6/105)
TUR syndrome (%)	NA	NA	0 (0/176)	6.1 (6/98)
Erectile dysfunction (%)	8.7 (0–8)	10.0 (7–13)	5.7 (8/140)	13.9 (10/72)
Retrograde ejaculation (%)	20.0 (2–49)	65.0 (56–72)	22.2 (10/45)	57.6 (19/33)

TUMT, transurethral microwave thermotherapy; TURP, transurethral resection of the prostate; NA, not available

Hoffman et al. estimated the rate of retreatment resulting from treatment failure or strictures and meatal/bladder neck stenosis during the follow-up [22]. These data were reported as the number of events per person per year of follow-up. TUMT and TURP failure was 7.5/100 and 1.0/100 person-years, respectively. On the other hand, TURP patients (5.85/100 person-years) were more likely than TUMT (0.63/100 person-years) to require surgical retreatment for strictures (meatal, urethral, or bladder neck). Pooled data from randomised studies showed similar results [46]. Variables were presented as the percentage of adverse events (ratio of events to pooled subjects). TUMT patients were more likely (18%; range, 10.8%–25.8%) than TURP patients (2.6%; range, 0%–4.8%) to require retreatment for BPO symptoms. The reported rate of reintervention due to strictures or stenosis was 2.0% (0%–9%) and 7.0% (5%–8%) for the TUMT and TURP group, respectively [46].

Cost

Different economic models evaluating the cost effectiveness of minimal invasive therapies for BPO have been introduced [48–50]. The results coming from the application of that model suggest that TUMT is a reasonable cost-effective alternative to both TURP and medical therapy for treatment of moderate to severe BPO [48,49]. Manyak et al. presented an economic model for comparison of medical, minimally invasive, and surgical therapy for BPO [50]. This model showed that thermotherapy was more effective at a higher but reasonable cost than the medical therapy. In addition, TUMT had a higher utility and lower cost than TURP.

de la Rosette et al. recently performed a cost-consequence analysis based on a randomised TURP against TUMT study with a 3-year follow-up [51]. The initial fixed cost of the procedure was higher for TUMT than TURP, although the retreatment risk in both groups was not significantly different. The outpatient use of TUMT was the critical factor that reduced the direct cost and rendered this method economically advantageous compared to TURP, which required a mean hospital stay of 5.3 days [51].

Another recent study estimated the cost of PLFT and TURP and costs associated with reinterventions for up to 3 years [52]. The authors found that PLFT is markedly less expensive than TURP over the first year, and preliminary data from the 3-year follow-up suggest that PLFT cost remains lower than TURP despite the larger number of reinterventions [52].

In addition, savings depend on the number of men who seek treatment for BPO [53]. Although TUMT has been associated with high investment costs, its large treatment capacity causes these costs per patient to be relatively low. In addition, the aging of the population results in long waiting lists and a growing demand for effective and cost-worthy alternatives. Within this framework, TUMT appears to be a very attractive option.

Current Position of TUMT in the Urological Community

The steadily increasing number of publications for TUMT suggests acceptance of the method and the efforts taken to optimize treatment outcome. A survey of 854 certified urologists showed that 18.5% of respondents have already had access to TUMT, putting microwave thermotherapy in third place between available alternative minimal invasive techniques for BPO management after electrovaporisation and laser therapy and before the other minimal treatments [54]. However, when asked what kind of equipment they would like to have access to among alternative minimally invasive techniques, 40% preferred holmium laser, 11% electrovaporisation, 5% TUNA, 5% TUMT, 4% Gyrus, and 3% interstitial laser coagulation, while 61.5% of the respondents did not choose any of the proposed equipment. It was considered that these results reflected urologists' satisfaction with the devices to which they have access, or different fields of interest, or lack of belief in the clinical potential of alternative treatments [54].

Seki et al. performed a questionnaire survey on the prevalence and preference with regard to various types of surgical treatment for BPO [55]. It was found that TURP remains the gold-standard surgical option in terms of both cost effectiveness and overall usefulness amongst Japanese urologists. Transurethral vaporisation of the prostate by thick loop (TUVP), followed by interstitial laser coagulation of the prostate (ILC) and TUMT, were also recognized as the most preferable treatments for dealing with the prevalence from now on at general hospitals. Ercole et al. surveyed certified urologists practicing in Minnesota on the utilization of minimally invasive treatments for BPO [56]. Both minimally invasive and traditional alternatives would be offered by 59% of the respondents, 10% would recommend only minimally invasive therapy (MIT), and 29% would suggest only traditional therapy. The most common MITs offered were transurethral microwave thermotherapy and (55%) and transurethral needle ablation (33%) [56]. These results seem to confirm the speculation that the level of acceptance of TUMT is increasing in the urological community all over the world.

Conclusions

High-level clinical evidence suggests that TUMT is an effective treatment for BPO that can be delivered to outpatients and has fewer adverse events compared to TURP. However, TURP offers greater improvements in symptom scores and Q_{max}, resulting in a smaller number of patients requiring retreatment for BPO. European Association of Urology Guidelines state that TUMT is considered the most attractive interventional modality alternative to TURP and should be reserved for patients who want to avoid surgery or who do not respond favourably to medication [57]. According to the AUA Guidelines, TUMT is effective in partially relieving symptoms in BPO patients, whereas there is no

evidence of superiority of one device over another [58]. The recent 6th International Consultation on New Developments in Prostate Cancer and Prostate Diseases concluded that TUMT has good clinical outcomes that seem durable and have low morbidity, thus representing an option when instrumental treatment is indicated (except when absolute indication for surgery exists) [59].

References

1. Brehmer M, Baba S (2000) Transurethral microwave thermotherapy: how does it work? J Endourol 14:611–615
2. Wagrell L, Schelin S, Bolmsjo MB, Mattiasson A (2000) Aspects on transurethral microwave thermotherapy of benign prostatic hyperplasia. Tech Urol 6:251–255
3. Brehmer M, Svensson I (2000) Heat-induced apoptosis in human prostatic stromal cells. BJU Int 85:535–541
4. Brehmer M, Hilliges M, Kinn AC (2000) Denervation of periurethral prostatic tissue by transurethral microwave thermotherapy. Scand J Urol Nephrol 34:42–45
5. Bolmsjo M, Wagrell L, Hallin A, Eliasson T, Erlandsson BE, Mattiasson A (1996) The heat is on—but how? A comparison of TUMT devices. Br J Urol 78:564–572
6. Eliasson T, Damber JE (1998) Temperature controlled high energy transurethral microwave thermotherapy for benign prostatic hyperplasia using a heat shock strategy. J Urol 160:777–781
7. Bolmsjö M, Sturesson C, Wagrell L, Anderson-Engels S, Mattiasson A (1998) Optimizing transurethral microwave thermotherapy a model for studying power, blood flow, temperature variations and tissue destruction, Br J Urol 81:811–816
8. Bolmsjö M, Schelin S, Wagrell L, Larson T, de la Rosette JJMCH, Mattiasson A (2000) Cell-kill modeling of microwave thermotherapy for treatment of benign prostatic hyperplasia. J Endourol 14:627–635
9. de la Rosette JJMCH, de Wildt MJAM, Alivizatos G, Froeling FM, Debruyne FMJ (1994) Transurethral microwave thermotherapy (TUMT) in benign prostatic hyperplasia: placebo versus TUMT. Urology 44:58–63
10. Larson TR, Blute ML, Bruskewitz RC, Mayer RD, Ugarte RR, Utz WJ (1998) A high-efficiency microwave thermoablation system for the treatment of benign prostatic hyperplasia: results of a randomised, sham-controlled, prospective, double-blind, multicenter clinical trial. Urology 51:731–742
11. Ogden CW, Reddy P, Johnson H, Ramsay JW, Carter SS (1993) Sham versus transurethral microwave thermotherapy in patients with symptoms of benign prostatic bladder outflow obstruction. Lancet 341:14–17
12. de la Rosette JJMCH, Laguna P, Gravas S, de Wildt MJAM (2003) TransUrethral Microwave Thermotherapy: the ‘gold standard’ for minimal invasive therapies for patients with benign prostatic hyperplasia? J Endourol 17:245–251
13. Hofner K, Gonnermann O, Grunewald V, Kuczyk M, Jona U (1998) Urodynamics and transurethral microwave thermotherapy. World J Urol 16:131–137
14. Floratos DL, Kiemeney LA, Rossi C, Kortmann BB, Debruyne FM, de la Rosette JJ (2001) Long-term followup of randomised transurethral microwave thermotherapy versus transurethral prostatic resection study. J Urol 165:1533–1538
15. Thalmann GN, Mattei A, Treuthardt C, Burkhard FC, Studer UE (2002) Transurethral microwave thermotherapy in 200 patients with a minimum followup of 2 years: urodynamic and clinical results. J Urol 167:2496–2501

16. Osman Y, Wadie B, El-Diasty T, Larson T (2003) High-energy transurethral microwave thermptherapy: symptomatic vs urodynamic success. BJU Int 91:365–370
17. Ahmed M, Bell T, Lawrence WT, Ward JP, Watson GM (1997) Transurethral microwave thermotherapy (Prostatron version 2.5) compared with transurethral resection of the prostate for the treatment of benign prostatic hyperplasia: a randomised, controlled, parallel study. Br J Urol 79:181–185
18. d'Ancona FC, Francisca EA, Witjes WP, Welling L, Debruyne FM, de la Rosette JJ (1998) Transurethral resection of the prostate vs high-energy thermotherapy of the prostate in patients with benign prostatic hyperplasia: long-term results. Br J Urol 81:259–264
19. Dahlstrand C, Walden M, Geirsson G, Pettersson S (1995) Transurethral microwave thermotherapy versus transurethral resection for symptomatic benign prostatic obstruction: a prospective randomised study with a 2-year follow-up. Br J Urol 76: 614–618
20. Norby B, Nielsen HV, Frimodt-Moller PC (2002) Transurethral interstitial laser coagulation of the prostate and transurethral microwave thermotherapy vs transurethral resection or incision of the prostate: results of a randomised, controlled study in patients with symptomatic benign prostatic hyperplasia. BJU Int 90:853–862
21. Wagrell L, Schelin S, Nordling J, Richthoff J, Magnusson B, Schain M, Larson T, Boyle E, Dueland J, Kroyer K, Ageheim H, Mattiasson A (2002) Feedback microwave thermotherapy versus TURP for clinical BPH. A randomised controlled multicenter study. Urology 60:292–299
22. Hoffman RM, McDonald R, Monga M, Wilt TJ (2004) Transurethral microwave thermotherapy vs transurethral resection for treating benign prostatic hyperplasic: a systematic review. BJU Int 94:1031–1036
23. Gravas S, Laguna P, Ehrnebo M, Wagrell L, Mattiasson A, de la Rosette JJMCH (2005) Seeking for evidence that cell kill guided thermotherapy gives results not inferior to transurethral resection of prostate: results of a pooled analysis of 3 studies on feedback transurethral microwave thermotherapy. J Urol 174:1002–1006
24. Djavan B, Roehrborn CG, Shariat S, Ghawidel K, Marberger M (1999) Prospective randomised comparison of high energy transurethral microwave thermotherapy versus alpha-blocker treatment of patients with benign prostatic hyperplasia. J Urol 161:39–43
25. Doll HA, Black NA, McPherson K, Williams GB, Smith JC (1993) Differences in outcome of transurethral resection of the prostate for benign prostatic hypertrophy between three diagnostic categories. Br J Urol 72:322–330
26. Schelin S (2001) Microwave thermotherapy in patients with benign prostatic hyperplasia and chronic urinary retention. Eur Urol 39:400–404
27. Naqvi SA, Rizvi SA, Hasan AS (2000) High-energy microwave thermotherapy in patients in urinary retention. J Endourol 14:677–681
28. Kellner DS, Armenakas NA, Brodherson M, Heyman J, Fracchia JA (2004) Efficacy of high-energy transurethral microwave thermotherapy in alleviating medically refractory urinary retention due to benign prostatic hyperplasia. Urology 64:703–706
29. Floratos DL, Sonke GS, Francisca AE, Kiemeney LALM, Kortmann BM, Debruyne FMJ, de la Rosette JJMCH (2000) High energy transurethral microwave thermotherapy for the treatment of patients in urinary retention. J Urol 163:1457–1460
30. Gravas S, Laguna P, Wijkstra H, Kiemeney LALM, Debruyne FMJ, de la Rosette JJMCH (2005) Durability of treatment following the 30-minute High Energy Trans Urethral Microwave Therapy in 213 patients with BPH. J Endourol 19(S1):A118

31. Keijers CBJM, Francisca EAE, D'Ancona FCH, Kiemeney LA, Debruyne FM, de la Rosette JJ (1998) Long-term results of lower energy TUMT. J Urol 159:1966–1973
32. Tsai YS, Lin JSN, Tong YC, Tzai TS, Yang Wh, Chang CC, Cheng HL, Lin YM, Jou YC (2001) Transurethral microwave thermotherapy for symptomatic benign prostatic hyperplasia: long term durability with Prostcare. Eur Urol 39:688–692
33. Terada N, Aoki Y, Ichioka K, Matsuta Y, Okubo K, Yoshimura K, Arai Y (2001) Microwave thermotherapy for benign prostatic hyperplasia with the Dornier Urowave: response durability and variables potentially predicting response. Urology 57:701–706
34. Ekstrand V, Westermark S, Wiksell H, Bergman B, Cronwall K (2002) Long-term clinical outcome of transurethral microwave thermotherapy (TUMT) 1991–1999 at Karolinska Hospital, Sweden. Scand J Urol Nephrol 36:113–118
35. Wagrell L, Schelin S, Nordling J, Richthoff J, Magnusson B, Sschain M, Larson T, Boyle E, Duelund J, Kroyer K, Ageheim H, Mattiasson A (2004) Three-year follow-up of feedback microwave thermotherapy versus TURP for clinical BPH: a prospective randomised multicenter study. Urology 64:698–702
36. Trock BJ, Brotzman M, Utz WJ, Ugarte RR, Kaplan S, Larson TR, Blute ML, Roehrborn CG, Partin AW (2004) Long-term pooled analysis of multicenter studies of cooled thermotherapy for benign prostatic hyperplasia results at three months through four years. Urology 63:716–721
37. Miller PD, Kastner C, Ramsey EW, Parsons K (2003) Cooled thermotherapy for the treatment of benign prostatic hyperplasia: durability of results obtained with the Targis System. Urology 61:1160–1164
38. Djavan B, Seitz C, Roehrborn CG, Remzi M, Fakhari M, Waldert M, Basharkhah A, Planz B, Harik M, Marberger M (2001) Targeted transurethral microwave thermotherapy versus alpha-blockade in benign prostatic hyperplasia: outcomes at 18 months. Urology 57:66–70
39. Tubaro A, d'Ancona FCH (1998) Case selection for high-energy transurethral microwave thermotherapy. World J Urol 16:124–130
40. d'Ancona FCH, Francisca EAE, Debruyne FMJ, de la Rosette JJMCH (1997) High-energy transurethral microwave thermotherapy in men with lower urinary tract symptoms. J Endourol 11:285–289
41. Djavan B, Bursa B, Basharkhah A, Seitz C, Ramzi M, Ghawidel K, Hruby S, Marberger M (2000) Pretreatment prostate-specific antigen as an outcome predictor of targeted transurethral microwave thermotherapy. Urology 55:51–57
42. Laguna MP, Kiemeney LA, Debruyne FJ, de la Rosette JJMCH (2002) Baseline prostatic-specific antigen does not predict the outcome of high energy transurethral microwave thermotherapy. J Urol 167:1727–1730
43. Djavan B, Shariat S, Schafer B, Marberger M (1998) Tolerability of high energy transurethral microwave thermotherapy with topical urethral anesthesia: results of a prospective, randomised, single-blinded clinical trial. J Urol 160:772–776
44. d'Ancona FCH, Francisca EAE, Witjes WPJ, Welling L, Debruyne FM, de la Rosette JJ (1997) High energy thermotherapy versus transurethral resection in the treatment of benign prostatic hyperplasia: results of a prospective randomised study with a 1-year follow-up. J Urol 158:120–125
45. Francisca EAE, d'Ancona FCH, Meuleman EJH, Debruyne FM, de la Rosette JJ (1999) Sexual function following high energy microwave thermotherapy: results of a randomised controlled study comparing transurethral microwave thermotherapy to transurethral prostatic resection. J Urol 161:486–490

46. Walmsley K, Kaplan S (2004) Transurethral microwave thermotherapy for benign prostatic hyperplasia: separating truth from marketing hype. J Urol 172:1249–1255
47. d' Ancona FCH, van der Bij AK, Francisca EAE, Kho H, Debruyne FM, Kiemeney LA, de la Rosette JJ (1999) The results of high energy transurethral microwave thermotherapy in patients categorized according to the American Society of Anaesthiologists operative risk classification. Urology 54:18–22
48. Ackermann SJ, Rein AL, Blute ML, Beusterien K, Sullivan EM, Tanio CP, Manyak MJ, Strauss MJ (2000) Cost-effectiveness of microwave thermotherapy in patients with benign prostatic hyperplasia. Part I—Methods. Urology 56:972–980
49. Blute ML, Ackermann SJ, Rein AL, Beusterien K, Sullivan EM, Tanio CP, Manyak MJ, Strauss MJ (2000) Cost-effectiveness of microwave thermotherapy in patients with benign prostatic hyperplasia. Part II—Results. Urology 56:981–987
50. Manyak MJ, Ackerman SJ, Blute ML, Rein AL, Beusterien K, Sullivan EM, Tanio CP, Strauss MJ (2002) Cost effectiveness of treatment for benign prostatic hyperplasia: an economic model for comparison of medical, minimally invasive, and surgical therapy. J Endourol 16:51–56
51. de la Rosette JJMCH, Floratos DL, Severens JL, Kiemeney LA, Debruyne FMJ, Laguna MP (2003) Transurethral resection versus microwave thermotherapy of the prostate. A cost-consequences analysis. BJU Int 92:713–718
52. Kobelt G, Spangberg A, Mattiasson A (2004) The cost of feedback microwave thermotherapy compared with transurethral resection of the prostate for treating benign prostatic hyperplasia. BJU Int 93:543–548
53. Baltussen RMPM, Wielink G, Stoevelaar HJ, van der Wilt GJ, Severens Jl, Ament AJ (1998) The economic impact of introducing transurethral microwave thermotherapy in the treatment of benign prostatic hyperplasia: a scenario analysis. World J Urol 16:142–147
54. de la Rosette JJMCH, Gravas S, Muschter R, Rassweiler J, Joyce A, on behalf of the members of the board of the ESUT (2003) Present practice and development of minimally invasive techniques, imaging and training in European urology: results of a survey of the European Societyof Uro-Technology (ESUT). Eur Urol 44:346–351
55. Seki N, Naito S, Oshima S, Hirao Y, Higashihara E (2003) Prevalence and preference with regard to various surgical treatments for benign prostatic hypertrophy: a survey for the Japanese endourology and ESWL society member. Nippon Hinyokika Gakkai Zasshi 94:495–502
56. Ercole B, Lee C, Best C, Fallon E, Skenazy J, Monga M (2005) Minimally invasive therapy for benign prostatic hyperplasia: practice patterns in Minnesota. J Endourol 19:159–162.
57. de la Rosette JJMCH, Alivizatos G, Madersbacher S, Perachino M, Thomas D, Desgrandchamps F, de Wildt M (2000) EAU guidelines on benign prostatic hyperplasia (BPH). Eur Urol 40:256–263
58. AUA Practice Guideline Committee (2003) AUA guidelines on management of benign prostatic hyperplasia. Chapter 1: Diagnosis and treatment recommendations. J Urol 170:530–547
59. Baba S, Badlani G, Elhilali M, Gravas S, Muschter R, Naito S, Netto NR, de la Rosette JJMCH (2007) New minimally invasive and surgical developments in the management of BPO. In: McConnell J, Abrams P, Akaza H, Roerborn C (eds) 6th international consultation on prostate cancer and prostate diseases, Paris, France (in press)

Transurethral Bipolar Electrosurgery in the Lower Urinary Tract

Anup Patel

Summary. Several factors have driven the development of bipolar vaporization and resection technology in the lower urinary tract in the past decade; these include prostate size and vascularity, which have impacted on the morbidity of monopolar TURP (transurethral resection of the prostate), particularly with regard to complications such as TUR (transurethral resection) syndrome. The avoidance of this at a time when experience with TURP is diminished among the next generation of urologists due to the significant impact of the medical therapy paradigm, along with the lack of affordability of complex laser technology and the failure of urologists to get the best out of monopolar vaporization, has left a gap that was filled with bipolar saline resection techniques. Of the growing band of bipolar resection systems, the plasmakinetic variety is the oldest in the marketplace, began with vaporization, and diversified to resection loops and incision electrode configurations. Others have followed this lead with variation on a theme, but common to all is the need for dedicated resectoscopes and generators. The main challenge has been how to generate plasma reliably around the active component of the electrode to enable smooth cutting without delay, with adequate surface haemostasis, but without deep coagulation that could result in prolonged irritative symptoms after hospital discharge. Clinical studies are still relatively sparse, particularly with regard to multicentre prospectively randomized studies with durable follow-up, and in fact, published data only relate to two of the four available bipolar systems. Aspects of the basic design elements and pertinent clinical data published to date are described and reviewed in this chapter.

Keywords. Bipolar, Transurethral prostate resection (TURP), Basic concepts, Clinical outcomes

Department of Urology, St. Mary's Hospital at Imperial School of Medicine, Praed Street, London W2 1NY, England

Introduction

The safe application of electrical energy to living organisms has underpinned many important surgical advances in the past two centuries. After Bottini first applied transurethral electricity to the prostate, further developments followed with adoption of endoscopic visual control, use of irrigants to improve visual control in the face of bleeding, and then came the design of powerful high-frequency energy sources that worked reliably in fluid. These energy sources were coupled to insulated active wire loop-and-ball electrodes of varying sizes and thickness as the importance of low and high current density was discovered with its different tissue effects using the same waveform. Other useful developments came with foot-pedal control, improved sprung working elements of different types (Iglesias and Baumrucker), the Hopkins rod-lens optics systems, and, more recently, powerful halogen-xenon lamp light sources and endoscopic camera technology. Meanwhile, improved antibiotic drugs, safer anaesthetic techniques, and the wider availability of blood transfusion have all helped to establish the place of the modern-day monopolar electrosurgical TURP as the gold standard treatment for symptomatic and complicated obstructive benign prostatic hyperplasia

In the past two decades, the urological community has seen the advent of a major paradigm shift in the management of lower urinary tract symptoms associated with benign prostatic obstruction, away from primary surgical intervention and towards medical management. At the same time, with varying success, a plethora of minimally invasive thermal based therapies, such as transurethral microwave thermotherapy (TUMT), interstitial radiofrequency ablative techniques (e.g., TUNA) and laser therapies (ILC), have also sought to gain a foothold in this arena, on a platform of potential for lower morbidity and outpatient delivery with sedoanalgesia. Together, these factors have impacted significantly on the numbers of TURPs performed worldwide. Evidence of this decline is seen in the number of TURPs that are performed annually on Medicare patients, which has progressively fallen since the peak of 258 000 was reached in 1987 (Table 1). In the face of such stiff competition, interest in improving TURP technology has remained undiminished. Although monopolar electrosurgery got a second lease of life through transurethral electrovaporization with various roller electrode configurations and vapor-resection with modified

Table 1. Changing Medicare TURP demographics

Year	Medicare code 52601 Single-stage TURP	Medicare code 52612 First of two-stage TURP	Medicare code 52620 TURP of residual obstructive tissue after 90 days
1995	130 724	518	1 239
1996	120 232	347	1 156
1997	110 055	467	987
1998	88 626	365	858

loops, these were not perceived by the majority as useful tools to wield against large vascular glands, and consequently have failed to topple the supremacy of TURP. Lasers have come, gone, and come again in the guise of high-power holmium resection (enucleation–morcellation or direct ablation) and latterly KTP, but these are prohibitively costly for the majority and may require steep technical learning curves. Hence, although monopolar loop resection has endured, primarily because urologists are well trained in its use and are familiar with the equipment, giving it a high "comfort factor rating" in the hands of the majority, there is still an imperative to improve it.

Problems that have still not been completely overcome by the enduring gold standard of TURP relate to the issues of morbidity [1–3], particularly from bleeding, absorption of irrigant and its associated effects (hypothermia and TUR syndrome), loss of potency, urinary incontinence, urethral stricture formation, and rare complications such as bladder perforation (iatrogenic or from induced or stray currents causing inadvertent neuromuscular stimulation), and diathermy burns from poorly applied return electrodes used to complete the circuit from active electrode to earth. Finally, there is the issue of possible malfunction of certain types of pacemaker [4]. Prostate size and vascularity are perceived to be the two most important factors that impact on the morbidity of monopolar TURP. In practical terms, to maximise safety, resection time is usually limited to 60 min. However, as most resections remove an average of 40%–50% of total gland volume, which equates to the transition zone volume, and resection rates vary from 0.5 to 1 g/min., the size of a gland that can be safely tackled ranges from 70 to 100 ml at most. Personal observation seems to suggest that the legacy of a decade or more of medical therapy with alpha blockade may have bequeathed large vascular glands, perhaps with worse detrusor function, to the next generation of urological surgeons. Further, as an undesired by-product of prostatic pharmacotherapy, the experience of performing TURP in today's generation is significantly reduced, and consequently surgeons will be ill equipped to tackle the challenges posed by these larger prostates.

The development of bipolar vaporization and resection systems in the last decade have tried to address some of these issues, as they provide a potential to allow the electrosurgical removal of obstructive prostatic adenomatous tissue using an iso-osmotic normal saline irrigant solution (and hence theoretically without the same time limitation as with monopolar loop resection). Further, they may also provide improved surface coagulation during resection without the deep coagulation effects associated with high-voltage monopolar coagulation current.

Bipolar Electrosurgical Prostate Technology

The first bipolar device brought to clinical practice in urology began its clinical life in gynecology and was subsequently modified for use in urological endoscopic vaporization [5]. Since that time, other commercial systems have appeared. In

Table 2. Generator characteristics (available manufacturer's data)

Device	Operating frequencies	Peak coagulation voltage (Vrms)
Gyrus	320–450 KHz	80–120
ACMI	100-KHz square wave	65–115
Olympus	350 KHz	120

chronological order, these are the Gyrus Plasmakinetic (PK) system, which permits vaporization, resection, and incision of tissue with different electrodes, the Vista Coblation system (ACMI), the SurgMaster TURis system (Olympus), and, more recently, a new bipolar resection system from Karl Storz. These last three systems permit loop resection only at present. All use electrical energy output from custom-made, dedicated, specialized electrosurgical generators. Operating frequencies differ between the units, as shown in Table 2, but all are lower than their monopolar counterparts.

The challenges faced by each system are these:

1. To reliably establish a cutting plasma corona, preferentially at the distal active electrode.
2. To achieve a plasma condition with acceptably short delays from the time of footswitch activation by the surgeon (i.e., instantaneous fire-up) and to maintain this under all cutting conditions.
3. To provide adequate haemostasis from both cut and coagulation sources of foot-switch operation.

In monopolar electrosurgery, cutting current arcs from the small active electrode to the tissue bed just before contact is made with the tissue before instantaneously heating and vaporizing the tissue through ohmic resistance (which creates very high temperatures) before returning to the site of the externally applied return electrode. In contrast, bipolar electrosurgery is closer to cold cutting (Fig. 1). At the appropriate power setting, the bipolar generator is designed to produce a high initializing power and/or voltage spike with foot-pedal activation; this establishes a voltage gradient between in the intervening gap between the bipolar electrode active and return components. If the activated bipolar electrode is not in contact with the tissue or the gap is too wide, or if there is insufficient power, current flow is simply dissipated to no effect by the large volume of electrolyte solution in a full bladder. On the other hand, if the power/voltage spike was not high enough to both form and maintain the plasma vapour pocket, stuttered cutting will result, depending on the quality of tissue contact.

As a result of these challenges, the initial plasmakinetic (PK) Gyrus system, which was the first to encounter some of these difficulties, has been modified in recent years, culminating in the availability of the latest Gyrus PK Superpulse

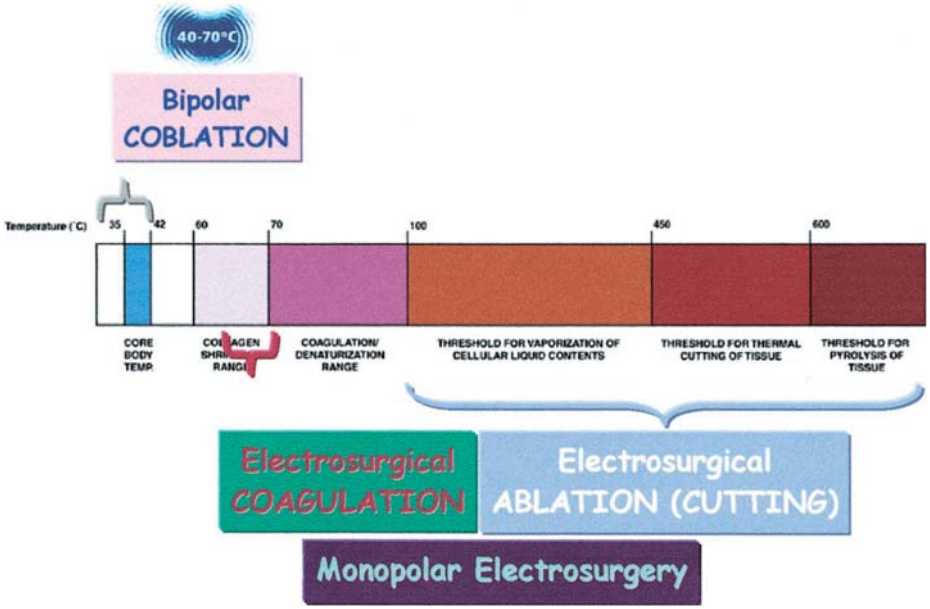


FIG. 1. Electrosurgical thermal range of tissue effects.

(SP) generator. This newer device is preconfigured for maximal allowable current under low impedance conditions. However, the surgeon is able to choose between two sets of cut voltages that are preset and represented by SP1 and SP2 mnemonics. The PK Superpulse generator is designed to recognise the active electrode and offers default settings that are optimal for a range of conditions at the tip, e.g., SP2 160, corresponding to a maximum voltage of 307 Vrms sinusoidal (434 V peak) and 160 W maximum average power. The PK Superpulse generator contains an energy reservoir facility in the form of a bank of internal capacitors. In this way, there is provision of sufficient voltage for both instant fire-up at the start of each cut and for power ride-through under challenging conditions of impedance. In this way, this manufacturer has resolved the problems of stuttered cutting that occurred with their previous generation device. The reservoir bank is quickly precharged before foot-pedal RF voltage initiation by the surgeon. Tests have shown that under high flow and cold saline conditions, more power than normal is required to initiate and maintain plasma conditions at the active electrode tip. The capacitor reservoir can provide up to 4000 W of power for short periods (~10 ms), but only if the tip impedance is low enough.

At baseline, before RF voltage application, the impedance differential between bipolar active and return electrodes is between 23 and 60 ohms depending on the saline temperature and the proximity of the active electrode to the tissue bed. At high power (4000 W) and low impedance (23 ohms), a voltage close

to 300 Vrms can be sustained by the PK Superpulse generator long enough to allow saline immediately surrounding the active loop to be actively heated to reach boiling point in a few milliseconds. This phenomenon is due to current crowding at the reduced surface area of this part of the active electrode and creates a nonequilibrium vapour pocket containing charged sodium ions (Fig. 2a–c). Plasma can then be established inside the enveloping vapour pocket. This plasma of activated sodium ions is visible to the naked eye as an orange glow in saline solution (Fig. 3) as confirmed by optical emission spectroscopic analysis (whereas a blue glow is visible in a potassium chloride solution). There is a time delay of 1–2 μs from the initial negative current spike until light is emitted [6]. Once formed, the impedance of this plasma is higher and ranges from 500 to 3000 ohms, depending on how much of the loop is in the vapour pocket as opposed to being in local contact with saline and depending on the length of the vapour pocket (higher impedances with longer plasma vapour pocket lengths). Power delivery now becomes focused around the active loop rather than being dissipated in the saline and tissue between active and return components of the active electrode. Thereafter, sustaining the plasma requires much less power, the energy reservoir is no longer required and is automatically replenished, while output voltage falls by being repetitively formed during each half-cycle of the high-frequency exciting voltage waveform. Plasma volume is smaller and impedance is lower at the lower preset voltage setting SP1, detected visually by a less intense orange glow around the active electrode. The SP2 setting gives the surgeon the option of larger plasma volume and slightly higher preset voltage if cutting becomes difficult under the conditions encountered. Fire-up should usually take no more than 20 ms after activation by the surgeon as a result of the capabilities of the capacitor reservoir bank. In vivo saline tissue-based models have shown that, in practice, once an activated loop is in contact with tissue, no more than 100 W power is usually required to sustain the user-defined maximum voltages. It is likely that, in future, newer waveform algorithms could also be developed for different clinical scenarios requiring better haemostasis, such as novice system users or in cases where there is a particular interest in minimizing bleeding as in large vascular prostates. Hence, the natural evolution of this technology will be in the direction of greater versatility of application.

Photographic examination of the plasma discharge shows a concentration of the optical emissions at the outer periphery of the active electrode. At the point of tissue contact, it is thought that cutting takes place as there is disintegration of tissue through molecular dissociation as the current flows to the nearby return electrode. Energetic species of the charged ions from the plasma cause breakage of organic carbon–carbon and carbon–nitrogen bonds in addition to electron impact dissociation of water molecules into excited fragments of H and OH ions, and the cumulative effect is to rupture the cell membranes, resulting in visible cutting.

It is thought that the tissue effects of bipolar prostate electrosurgery occur at much lower temperatures (~40°–70°C; see Fig. 1) compared to monopolar

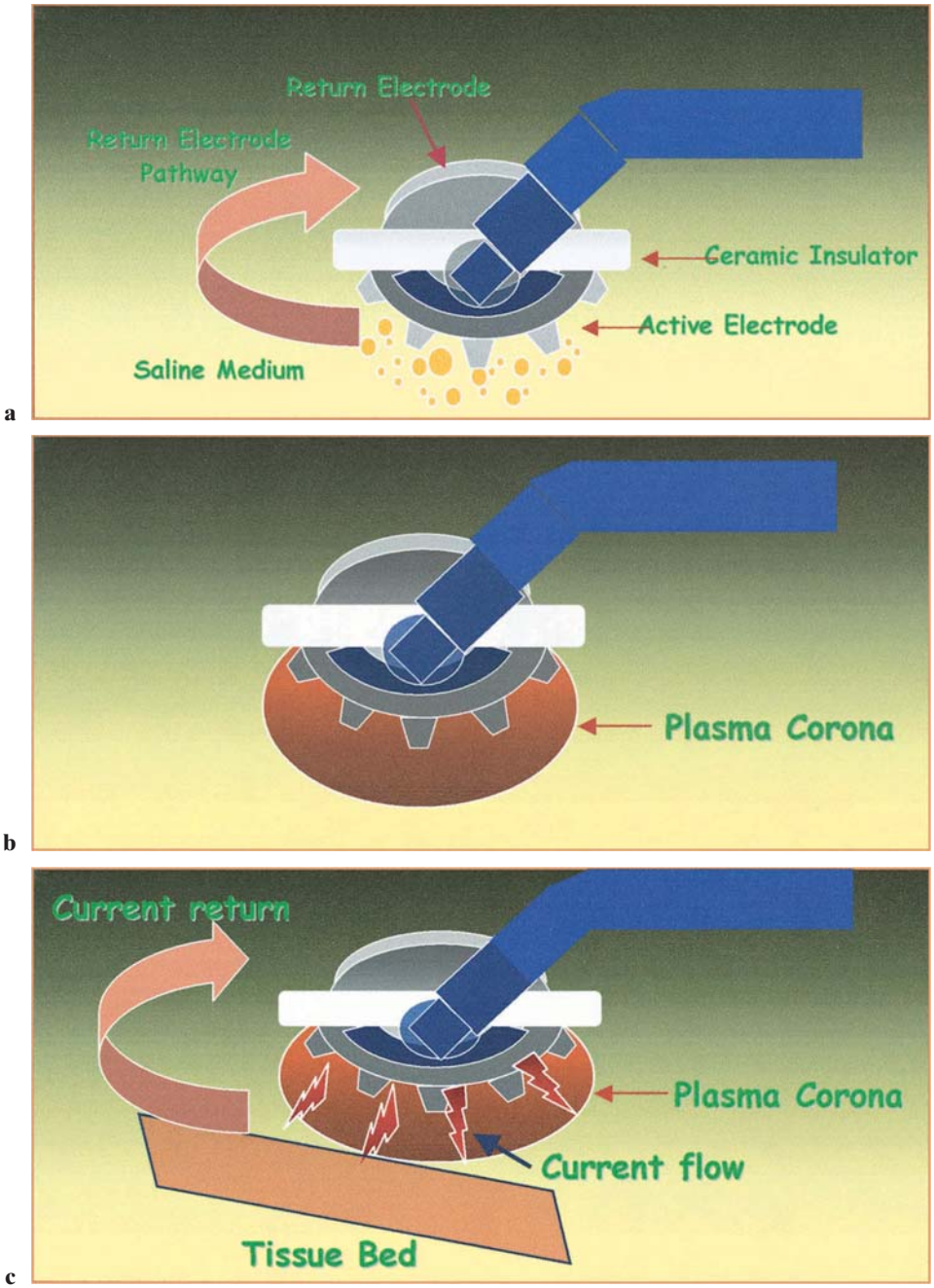


FIG. 2. **a** Plasmakinetic device showing small bubbles forming as saline at tip approaches boiling point. **b** Plasmakinetic device with formation of plasma pocket; high resistance between active and return electrode components. **c** Plasmakinetic device with current flow through low-resistance plasma pocket to tissue bed and back to return

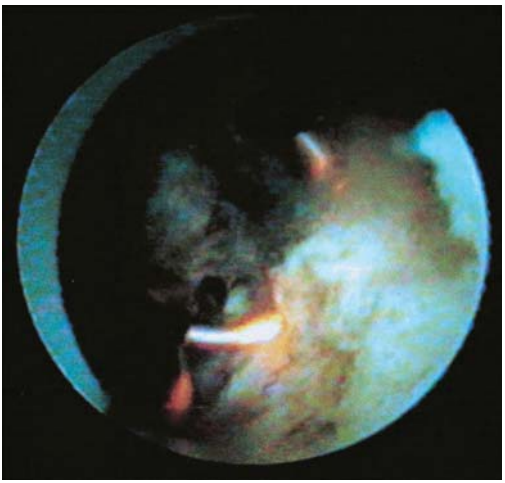
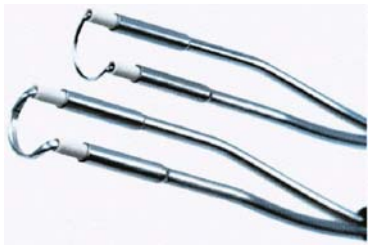


Fig. 3. Orange glow of activated sodium ions in plasma pocket

electrosurgery (300°–400°C). If true, and as the charged ions only have a short penetration of 50–100 µm, this should mean less collateral thermal damage to the surrounding tissue and less tissue char. The end result should be excellent localised cutting, with little in the way of the burnt smell usually associated with monopolar cutting. This lack of char smell and cleaner-looking chips have been confirmed by the author's experiences and by user surveys (personal communication to author) [7]. After a period of cutting, as with bipolar systems in air, tissue residue can stick to the slightly larger return electrode (which has a lower current density), and when this happens, as it impedes current flow through the plasma arc, cutting efficiency may be impaired. If this should occur, the electrode should be carefully cleaned with an appropriate soft brush, which is usually provided by the manufacturer.

Other than differences in generator profiles, commercially available bipolar systems differ in the design, size, and shape and thickness of their active electrodes (Fig. 4a–e), the housing in the working element, and the size of the resectoscope. However, common to all to date is the need for a dedicated system of instruments for bipolar resection. The Gyrus PK electrodes are the most diverse range at this time and are constructed of a platinum iridium alloy, allowing attributes of excellent tensile strength and high corrosion resistance.

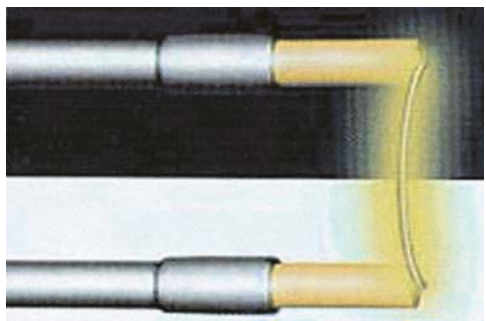
The Vista Coblation system (controlled ablation), which is no longer commercially available due to the recent acquisition of its manufacturer ACMI by Gyrus, had an operating frequency that was five times lower than a monopolar RF system, with the premise that the lower the operating frequency in bipolar mode, the less the risk of stray induced currents, and therefore the less likely were unwanted incidences of neuromuscular stimulation in the unparalysed patient, euphemistically known as the "obturator jerk." This is more important when resecting bladder tumours (although it may still occur during prostate resection when treating the bladder neck or in the presence of an iatrogenic



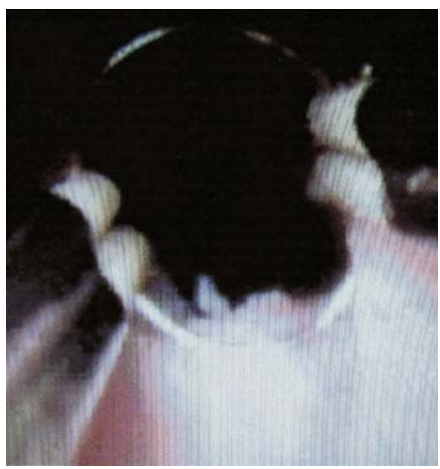
a

b

c



d



e

FIG. 4. **a** Gyrus thick and thin resecting loops. **b** Gyrus incision electrodes. **c** ACMI Vista system double loop. **d** Olympus Surgmaster resecting loop. **e** Storz system bipolar loop

anterolateral capsular perforation), as it is then that inadvertent bladder perforation can occur as a result of an unexpected obturator jerk, spilling cancer cells outside the confines of the bladder. Thus, use of a bipolar resection system generally means that the patient need not be paralysed and intubated during the procedure and should have quicker recovery from anaesthesia as a result. The Vista Coblation system also had a unique loop design. The Vista active electrode was a 4-mm-diameter double-loop design where the current flowed from a thin leading loop 0.35 mm thick for active plasma formation to an equivalent diameter thicker trailing loop (0.5 mm) held in parallel with an insulated gap between the two of 1.52 mm (see Fig. 4c). Further, the surgeon had foot-pedal control of the cut settings on the dedicated generator, and the device was available in a smaller (25 Fr) resectoscope.

The Surgmaster system loops (from Olympus) use similar design principles to those developed by Gyrus for their loops (see Fig. 4d), but they are of a slightly smaller diameter thin-wire design separated by yellow insulating material from a thicker, more bulbous return end. The resectoscope itself is 26 Fr in size and has a working length of 194 mm. As with the other two systems, this design permits current crowding at the thinner active loop to allow the plasma pockets to be formed. The current reaches the active portion of the loop from the generator through the white plastic housing in the bottom of the working element, while the return current flows through the return portion of the electrode in contact with the working element and then back to earth through a lead connected to the working element handle (Fig. 5). Hence, part of the telescope

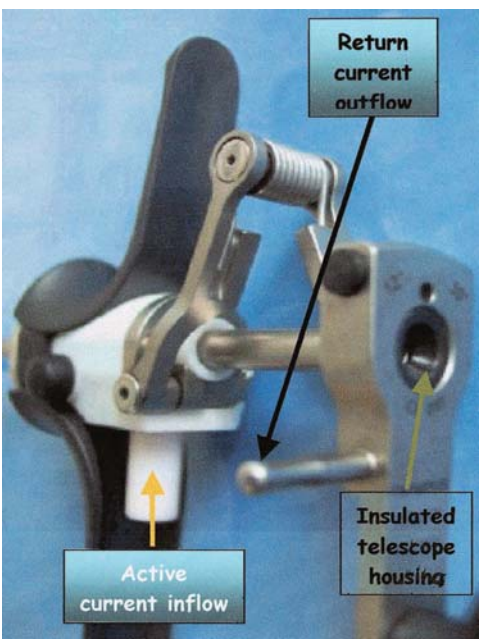


Fig. 5. Olympus Surgmaster working element

housing of the working element is specially insulated to make it fit for this purpose without compromising patient safety by return current leakage into the resectoscope sheath. At the resectoscope tip, the electrode and telescope are separated from the metallic outer sheath by insulating material (Fig. 6). The Surgmaster generator in the TURis mode allows saline resection through two cutting modes (pure and blend with maximum power output of 320 W) and coagulation through two modes designated Coag 1 (maximum 200 W) and Coag 2 (maximum 80 W), although only in combination with the Surgmaster resectoscope. It also has a capability to produce a monopolar output for standard surgical and endosurgical use. In a limited personal clinical experience with this device, cutting seems to be reliable. However, at this time, there are no published clinical studies comparing use of the Surgmaster system to any of the established resection systems, either monopolar or bipolar, in the peer-reviewed published literature.

Also at the time of writing, no specific details are available on the new Storz bipolar resection system, but as shown in Fig. 4e, this system has a different double-loop configuration to that seen with the Vista system. It consists of a double loop with a 5-mm-diameter thin-wire active component and a flat thick bow loop bent in the opposite direction, which is the return component, with both loops mounted on the same axis of a dedicated resectoscope. Again this return loop is wider and thicker to allow current crowding necessary for plasma formation to take place at the thin active loop. Although there are no clinical data, Wendt-Nordahl et al. [8] compared this device against a standard monopolar loop under laboratory conditions similar to the ones they previously reported on for the Vista system using an isolated porcine blood-perfused kidney model. Both the monopolar and the bipolar loop were activated by the same electrosurgical generator, an Autocon 400 II (Storz), using an output power of 240 W and Coag. degree 2 for the ex vivo and an output power of 350 W and Coag. degree 4 for the in vivo experiments, respectively. At low power (80 Watt), monopolar loop cutting was possible but bipolar cutting was impossible. Bipolar cutting became easier as power increased to above 240 W, whereas 300 W was needed for in vivo cutting.

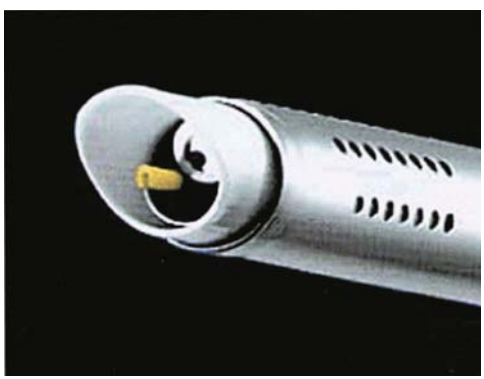


FIG. 6. Insulation at tip of resectoscope between active loop and outer sheath of Surgmaster resectoscope

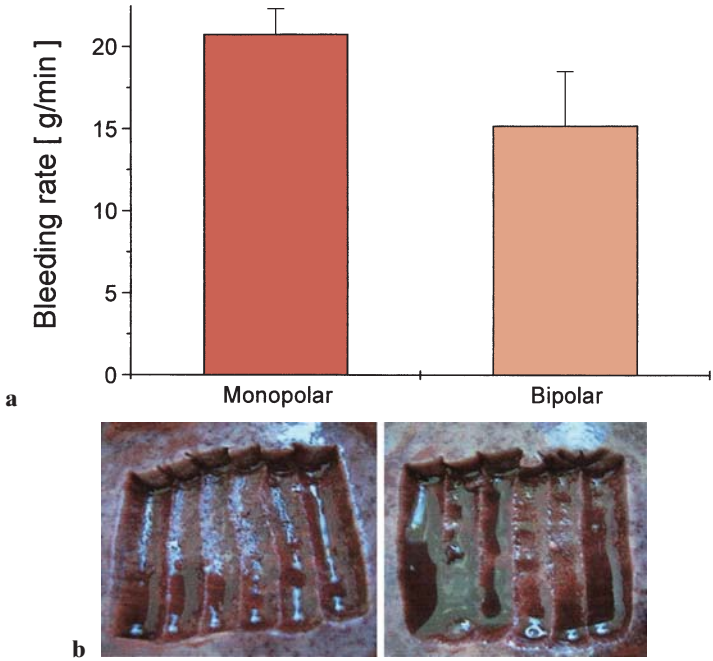


FIG. 7. **a** Bleeding rate using Autocon generator comparing Storz bipolar resction loop to standard monopolar loop ($n=5$) (Storz) ($P<0.05$, significant). (From Gunnar Wendt-Nordahl, with permission). **b** Bleeding kidney surfaces after ablation with the Storz bipolar resection loop (*left*) and the conventional monopolar loop (*right*). (From Gunnar Wendt-Nordahl, with permission)

Furthermore, there was a delay of almost 1 s. until the loop became submerged in the tissue before reliable cutting occurred. When cutting did take place at the higher power, bleeding was significantly reduced from the monopolar device rate of $20.78 \pm 1.52\,g\,min^{-1}$ to $15.16 \pm 3.3\,g\,min^{-1}$ for the bipolar device ($P<0.05$) (Fig. 7a, b), although the exact incident set power for the monopolar and bipolar modes for these measurements is not stated in the paper. The coagulation zone was slightly deeper for the bipolar device, but the difference with monopolar was not significant (Fig. 8). Electrical recordings by these authors suggested that using the standard generator, the 0.8-s delay in onset of bipolar cutting and consistency of cutting quality (as with many of its predecessors) was due to the time taken for the high current output at low impedance to produce the vapor pocket, and this in turn is critically dependent on electrode configuration and on generator design and function. To my mind, the electrical measurements in Fig. 9 taken during a single bipolar cut, showing the delay to actual cutting, followed by voltages of up to 450 V and power of up to 475 W under varying impedance conditions during actual cutting, support the need for dedicated generator design with such bipolar devices, because it is likely that bipolar systems that do have

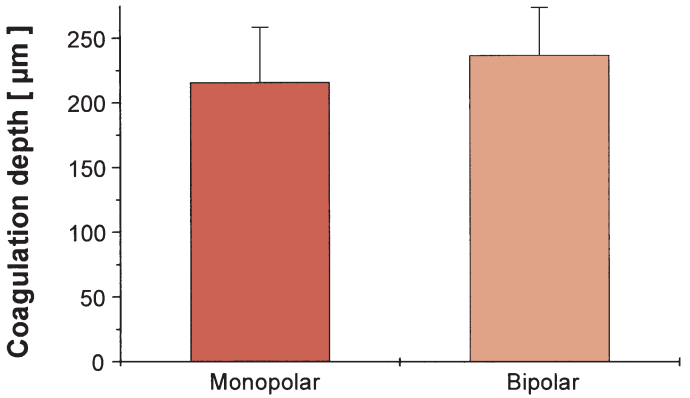


FIG. 8. Coagulation depth comparison for Storz bipolar resction loop to standard monopolar loop ($n=5$) using Autocon generator (Storz) ($P>0.05$, NS). (From Gunnar Wendt-Nordahl, with permission)

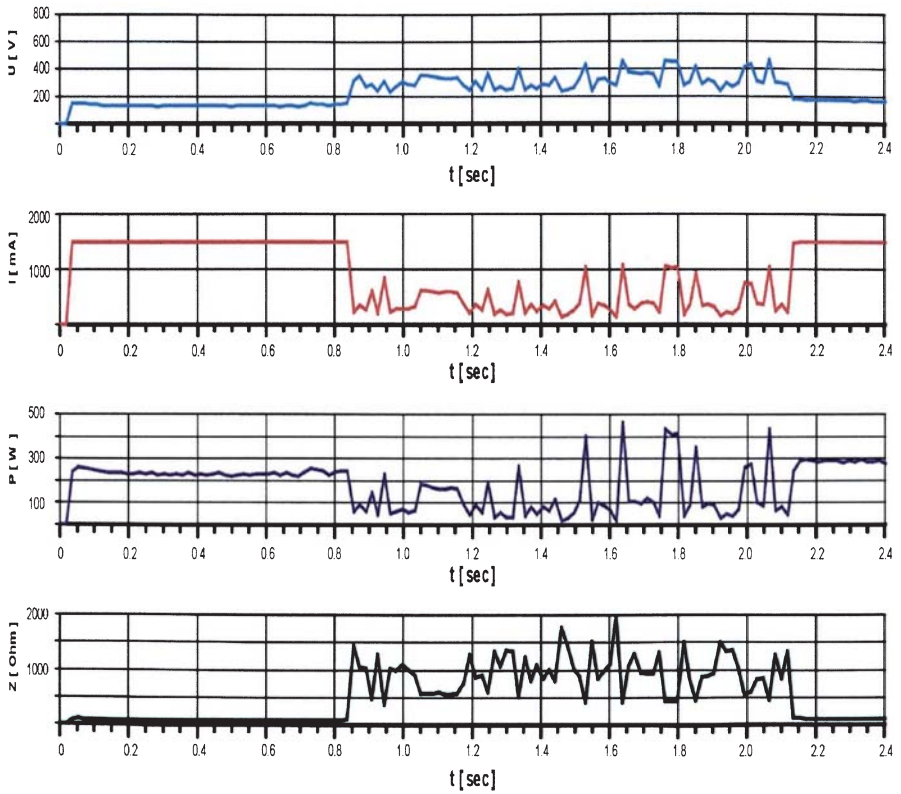


FIG. 9. Real-time electrical measurements during single cut with Storz bipolar resection loop showing delayed onset of cutting action of 0.85 s: voltage, current, power, and impedance, respectively, from *top* to *bottom*. Note that current was high while impedance was low during the delay before cutting started. (From Gunnar Wendt-Nordahl, with permission)

difficulty initiating fire-up will have greater thermal spread in tissue at the point of RF initiation, as the surgeon cannot move the loop until the vapour pocket and plasma have been (slowly) established.

In bipolar systems with dedicated generators, as a rule, coagulation takes place at much lower peak voltages compared to monopolar systems (80–100 V vs 500–800 V). This occurs because at higher peak voltages, the liquid is converted into a gaseous phase, which has higher impedance, which in turn changes the type of resistance from a resistive to a capacitative mode, which reduces energy flow and dissipated heat, thereby limiting the final coagulation effect.

As a general rule, safety is further increased by use of bipolar electrosurgical energy, as there is no need for a large return electrode applied to the skin; thus, the low incidence of inadvertent skin burns at small points of localised contact from a poorly applied return electrode is completely eliminated. There is also a small cost saving as these return electrodes are not necessary and the current returns to earth through components of the active electrode or resectoscope working element (as in the case of the Surgmaster system) and cord, respectively. The combination of low operating frequency and low voltage in bipolar prostate electrosurgery should also eliminate the possibility of interference with all types of cardiac pacemakers.

Bipolar Electrosurgical Clinical Experience

Despite its presence in the marketplace for several years, there is a paucity of peer-reviewed published data with regard to bipolar technology in prostate treatment beyond a learning curve experience and one or two small single-center randomised trials. Published clinical data are only available for the Gyrus and Vista systems, and this review is confined to these systems only.

Bipolar prostate electrovaporization with the first-generation Gyrus Plasmakinetic (PK) system was reported by Botto et al., in 2001 [5]. They reported a significant decrease in mean IPSS and improvement of mean peak flow at 3 months in 42 patients. There was no apparent difference in the duration of surgery, which appeared to be similar to monopolar TURP (although degree of tissue removal was not quantified), and there was no significant intraoperative bleeding. The authors opined that the system they used was more efficient than their experiences of monopolar electrovaporization.

In a UK-based study, Eaton et al. [9] also evaluated the use of the same bipolar electrovaporization system for day-case surgery of the prostate. Forty men underwent PK prostate vaporization by one surgeon using a dedicated continuous-flow 27 Fr sheath resectoscope and saline irrigant, with intent for same-day discharge, which was achieved in 85%. Mean prostate volume and operative time were 34.9 ml and 33 min, respectively. All voided successfully at 48 h, but 2 required treatment for blocked catheters. At 4 months, there was a subjective improvement with IPSS and QOL improved by 64% and 83%, respectively. Sim-

ilarly, objective improvement was seen as flow rate improved by a mean 200% (although no baseline data were reported in any of these categories).

Dunsmuir and colleagues [10] reported a prospective single blind study of 51 patients randomized to bipolar vaporization ($n=30$) or monopolar TURP ($n=21$), of whom 40 (20 in each group) attended for follow-up at 1 year. There was no subjective or objective difference between the groups in clinical outcomes, amount of irrigant used, haematocrit of effluent, or hospital stay. However, recatheterization rate was significantly higher in the bipolar vaporization group (30%) compared to the TURP group (5%). Of course, one does not know whether those that did not attend for 1 year follow-up (10 PK vaporization and 1 TURP) had an unsatisfactory outcome as the reason for nonattendance.

Although these early data tell us that PK bipolar vaporization has sparked the interest of a few urologists and that it is associated with reasonable early clinical outcomes, mature outcomes data in a large cohort of patients treated at many different centers are still lacking for this modality, and there are still no peer-reviewed published data from any prospectively randomized controlled trials comparing completeness and rates of tissue removal as well as clinical outcomes and morbidity after the best of monopolar electrovaporization with that of bipolar plasma kinetic vaporization.

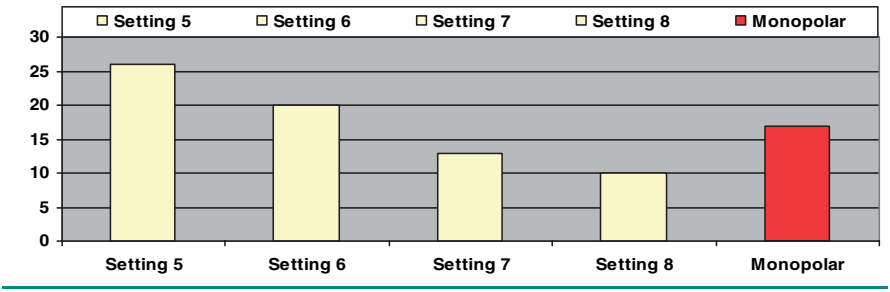
The optimal technique for bipolar Gyrus PK electrovaporization has also not been described in detail yet, specifically whether the active electrode should be moved unidirectionally from bladder neck to apex or whether this movement should be bidirectional to obtain the best combination of vaporization and coagulation.

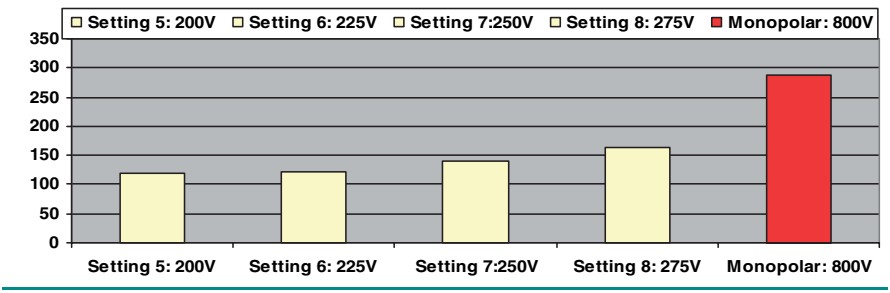
Others [11] have used Gyrus bipolar PK incision electrodes (see Fig. 4b) to try to emulate the holmium laser enucleation technique developed by Gilling and Fraundorfer. In a small study of 22 men, a Plasma-Cise electrode was tested, but the duration of postoperative catheterization was 29.8 h as compared to 17.8 h after holmium laser resection.

Certainly, one theoretical concern would be a possible higher urethral stricture rate with the use of a 27 Fr Bipolar PK Gyrus resectoscope, but only time and longer follow-up in such series in the future can give us useful information in this regard. Further, use of these systems in future may be made more attractive by manufacture of appropriately sized working elements that fit resectoscopes of all common manufacturers.

Recently, Vista Bipolar loop resection was compared to standard monopolar loop resection with regard to cutting qualities, ablation rate, blood loss, and depth of coagulation using an isolated blood perfused porcine kidney model [12]. The Vista system and active electrode used with saline were compared to a 5-mm-diameter monopolar loop (Storz, Tuttlingen, Germany) in standard mannitol/sorbitol solution (Fresenius, Bad Homburg, Germany). The Vista bipolar loop ablation rate (determined by the loop diameter and drag rate through the tissue) was similar to the ablation rate reached with the monopolar loop, indicating that

the loops moved through the tissue at similar speeds. At Vista cut setting 7 (265 V) and 8 (292 V), blood loss was significantly lower ($P<0.05$) than monopolar resection at a power setting of 160 W (Autocon, Karl Storz, Tuttlingen). The bleeding rate was 13.16±5.47 g/min (setting 7) and 10.43±4.76 g/min (setting 8), compared to 17.08±4.57 g/min for the monopolar loop. The bleeding rates (g min^{-1}) in cut modes and coagulation depths (μm) in coagulation modes, respectively, are shown in the following graphs.





These data confirm that coagulation zones are smaller with bipolar resection compared to monopolar equivalents, as expected from the lower voltages in the bipolar system. The limited bipolar surface coagulation at the resected tissue interface, whilst avoiding deep tissue heating, should in theory avoid delayed tissue sloughing and prolonged irritative symptoms. On the flip side of this coin, the theoretical disadvantages could be a higher incidence of delayed haemorrhage in fibrous prostates or when the patient strains heavily in the early postoperative period (either at stool or from vomiting caused by anaesthetic/opiate analgesic agents). Further, there is no firm evidence of efficacy in reducing bleeding complications in the anticoagulated patient as yet. These issues must be studied further and proven in the context of multicenter randomized controlled trials in future.

With regard to bipolar loop resection in humans, Issa et al. [13] reported a subgroup of 5 patients from an institutional cohort of 58 patients treated with PK bipolar TURP between 2001 and 2003. This subgroup had large prostate resec-

tion weights (>35 g) and significant comorbidity as determined by ASA (American Society of Anesthesiology) risk category 3 or more. Of this subgroup, mean resected weight was 49.6 g (32–67 g), achieved during a mean operating time of 2 h and 22 min (98–175 min), giving a tissue removal rate of 0.35 g/min. In these long operations, which would have carried a high risk of developing TUR syndrome with monopolar resection, the mean serum sodium concentration decreased by only 1.6 mg/dl, while mean haematocrit dropped by 5.6%. These findings were consistent with the range expected for procedures of this duration. None of these patients required transfusion, and all voided spontaneously before discharge.

In our own series of 32 patients treated with the Vista 25 Fr continuous flow resection system [7], 12 had prostates larger than 50 cc on TRUS with the largest resection weight of 62 g in a 126-cc^3 prostate measured. Median operation time (defined as the interval between the commencement of resection to the placement of the final Foley catheter) in this cohort of large glands was 73 min (25–120 min) and median dry resection weight was 36 g (20–62 g), giving a median tissue removal rate in these large glands of 0.49 g/min. In our experience, with this bipolar resection system, the gap between the double loop was best seen with a 30° lens, but the extremes of electrode excursion were better seen with a 12° lens. Cutting was immediate, only occurred when the loop made contact with the tissue, and was "felt" by the operators to be smoother than with monopolar loop TURP. There was excellent visualization of the capsule and other endoscopic landmarks such as the bladder neck and apex. The cut setting could be increased by the surgeon from a white button on the foot pedal in a cyclical fashion from the preset starting value of 6 on the generator. Coagulation required accurate placement of the bleeding vessel in the gap between the loops, but slightly closer to the thicker backloop, followed by gentle downward pressure to permit the current to flow tangentially through the mouth of the open vessel. Coagulation was best when there was no movement of the loops across the vessel during activation of the foot pedal. A longer activation time (~5 s) for the coagulation mode (coupled with a slightly lower flow of irrigant if possible without compromising visual control) also appeared to improve the coagulation effect in our experience. As length of resection increased beyond 30 min, tissue debris accumulated on the rear one of the two loops and required cleaning with a gauze swab, later replaced by a soft brush provided by the manufacturer.

Although there should be no problem with TUR syndrome with bipolar resection, we adhered to the principle that there should be no place for complacency as far as surgical technique was concerned. Hypervolaemia and hypothermia from cold saline absorption through the resection fossa can still occur leading to heart failure in elderly patients with cardiac comorbidity, so we recommend that irrigant fluid should still be warmed before use, and that the operator should empty the bladder of accumulated irrigant from time to time (because inflow is usually greater than outflow even with continuous flow resectoscope systems). Furthermore, regular bladder emptying also helped to show up bleeding points better, so that they could be controlled in a timely fashion. We also took

advantage of the gap between the double loop and devised a "wedging" coagulation technique around the bladder neck by trapping the cut edge in the gap between the two loops and activating the coagulating current for better haemostasis at this important site.

In 2005, Tefekli et al. [14] from Turkey published the results of a prospective randomized comparison of monopolar TURP versus a hybrid of bipolar Gyrus PK vaporization and loop resection in a total of 101 men with either symptomatic LUTS from benign prostatic obstruction or urinary retention with indwelling catheters, with complete data on 96 men. As with previous studies, significant advantages of shorter operating time (40.3 vs 57.8 min), lesser irrigant volume requirement, and shorter catheterization times (2.3 vs 3.8 days) in favour of the PK hybrid treatment were noted. Although completeness of tissue removal was not quantified, there was no difference in overall subjective and objective improvement between the two groups and no difference in blood transfusion requirement postoperatively (low at 2%). However, early postoperative problems occurred in 16.3% of the PK hybrid group versus only 8.5% of the monopolar TURP group (P=0.0014), early severe irritative symptoms were more common, at 12.2% versus 4.3%, and long-term complications were also higher at 10.2% versus 6.3%, respectively (not significant), for the PK hybrid group. The urethral stricture rate was also significantly higher at 6.1% versus 2.1% in the PK hybrid group.

These data tell us that the shorter catheter time of the hybrid PK technique in this study was offset by significant disadvantages postoperatively. If, as is suggested by the studies of Wendt-Nordahl et al. [12], bipolar coagulation is less deep than with monopolar coagulation, at least with the Vista system, then it is likely that the higher incidence of postoperative irritative symptoms (which are usually the result of an excessively coagulated tissue bed and delayed sloughing of this tissue, as was seen with Nd:YAG laser therapies in the past) in this particular study was due to the primary use of the larger surface area bipolar vaporization electrode before the bipolar loop was deployed at the end to tidy up the apex. These irritative symptoms could potentially have been avoided by using the bipolar loop throughout rather than an expensive hybrid technique predominantly with a larger surface area vaporization electrode. This mistake was compounded by reuse of the electrodes to save cost (especially as either design of bipolar active electrodes are not labelled for reuse despite the local practice in this particular institution). Evidence to support this contention is provided by the study of Singh et al. [15] from India, who also performed a randomized controlled trial in 60 men comparing the Vista bipolar resection system versus a regular monopolar loop. Here, there was no difference in clinical outcomes parameters and, in particular, irritative symptoms of postoperative dysuria were less common with a thin wire bipolar resection loop. Further, their data indicated a significantly lower fall in serum sodium (1.2 mEq/l for bipolar vs 4.6 mEq/l for monopolar) in exchange for a slightly slower tissue removal rate (0.61 g min^{-1} vs 0.74 g min^{-1}), and no difference in any other clinical or laboratory parameter studied. Additional studies on a larger scale are needed to specifically address

this issue for each of the various bipolar devices comparing them to their monopolar equivalents (i.e., bipolar loop vs monopolar loop and bipolar vaporization electrode vs monopolar vaporization electrode used predominantly in the cut mode with the right generator).

The most recently published randomized controlled study was from de Sio et al. [16] in which 70 men were randomized to Gyrus bipolar resection versus monopolar TURP. Again there was a significant advantage in favour of shorter need for postoperative irrigation, shorter catheterization time for the bipolar group (72 vs 100 hs), and consequently for shorter hospital stay. No other differences were found between the groups either perioperatively or at 1 year follow-up.

Training and Morbidity

Bipolar TURP should allow more time for teaching and training urology residents how to resect prostatic adenomatous tissue without compromising patient safety, for all preliminary studies have shown the risk of hyponatremia to be uniformly low. This is a welcome advantage for the novice trainee, freed of the shackles of time constraint to a large degree both for the resection phase and also for the coagulation phase of the operation. This is particularly important when the use of TURP has been declining, and a large proportion of patients requiring surgery are either in acute or chronic retention or have large vascular glands. With regard to the technique, only minor changes are needed, and for urologists already proficient in performing monopolar TURP, as bipolar systems are almost identical with regard to equipment, the learning curve should be almost negligible. At this time it is not known whether the risk of capsular perforation and subsequent impotence will be reduced [17,18] until this issue is formally studied. Haemostasis seems to be slightly improved at the resected tissue surface, but deep coagulation is limited and care must still be taken to avoid opening large venous sinusoids.

One of the concerns that exist for many transurethral bipolar resection systems, as with monopolar electrosurgery, is the potential for urethral and bladder neck stricture formation postoperatively. Although reports on bladder neck strictures for the bipolar systems are sparse, the incidence of urethral strictures in the study by Tefekli et al. [14] at 6.1% (vs 2.1% for the monopolar TURP arm) is of concern. Aetiologically, there are many possible reasons for the higher stricture rate in these two studies, including larger resectoscope diameter (27 Fr), especially if the urethra is not adequately predilated before passage of the resectoscope, higher incident power (even if in short bursts), and if a larger prostate is tackled or one is tackled by a relative novice resulting in a long operating time. The higher recatheterization rates reported by Dunsmuir et al. [10] and Tefekli et al. [14] in the PK vaporization studies may be a consequence of residual tissue oedema but may also contribute to urethral stricture formation and may be an indication that bipolar loop resection is preferable to the vaporization option.

Of interest is the paper from Morishita et al. [19], which in 1992 indicated that urethral stricture formation post-TURP may be closely related to electrical resistance and current leakage of appliances. They investigated old and new monopolar and bipolar loops, finding that the new unused bipolar loops had low electrical resistance of 0.5–0.6 ohms, increasing with multiple use (for at least 60-min durations) to 1–115 ohms (mean, 26.4 ohms), whereas none showed current leakage. In comparison, all monopolar loops exhibited current leakage after the first use and showed relatively high resistance. These data indicate the superior durability of bipolar loops compared to their monopolar counterparts and, if reproduced in currently available bipolar loops, confirms their superior safety over their monopolar counterparts; however, clearly there is a need to develop bipolar continuous-flow resectoscopes smaller than 27 Fr in the not too distant future.

Transitional Cell Tumour Resection

No doubt there will soon be a growing impetus to use bipolar systems to resect transitional cell tumours in the bladder (and possibly in the renal pelvis). Less char will mean better potential histological analysis, but use of an isotonic solution means that loose cancer cells from higher-grade bladder tumours would not be lysed as they would in a bladder full of hypotonic irrigant such as sterile water, leaving a greater theoretical possibility of seeding viable cancer cells. However, one must stress that these are theoretical concerns and none have been studied in detail at this time. Safety with regard to systemic fluid absorption and its sequelae would certainly be increased with saline irrigant when resecting renal pelvis tumors (although in the overall spectrum of TCC treatment, this represents only a small number of cases).

Cost

This issue has not been studied in detail. A financial analysis study by Ruiz-Deya et al. [20] showed the cost of bipolar saline TURP to be 10.56% less than for conventional monopolar TURP. This translated into cost savings of $1138 per patient in their institution, but they did not take into account the cost of purchasing a new dedicated generator, a new resectoscope or at least a new working element, active electrodes that are more than 8–10 times the cost of a regular loop, not to mention a longer possible operating room time use (which could be offset by lower morbidity). Further, one does not yet have a good sense of loop durability in long resections, and cost will increase if more than one loop has to be used in larger glands. Thinner loops may also be damaged or deformed by repeated contact with prostatic concretions of the variety that are sometimes encountered at the junction between transition and peripheral zones. On the other hand, costs may be lowered in future through multispecialty use of the gen-

erator (in dermatological, ENT, orthopaedic, and gynecological procedures) [21–23], as well as its use in laparoscopic surgery.

Conclusion

Transurethral bipolar electrosurgical vaporization and resection systems undoubtedly have future potential for a variety of reasons outlined in this chapter, particularly at a time when urologists may be tackling more large prostates endoscopically. In the face of stiff competition from higher-powered lasers (both holmium and KTP), whether this potential will be bright or just a passing fad like so many other technologies that have failed to endure will depend on mass acceptance of the technique in the established urological workplace and particularly in training centers that will nurture the urological surgeon of tomorrow. To achieve this, the cost comparisons and outcomes in appropriately designed larger multicenter studies where bipolar loop resection is pitted against the enduring gold standard of monopolar resection must be forthcoming as a high-quality solid evidence base which will ultimately drive registration and reimbursement—without which no new technology can endure.

References

1. Madersbacher S, Marberger M (1999) Is TURP still justified? Br J Urol 83:227–237
2. Harrison RH III, Boren JS, Robinson JR (1956) Dilutional hyponatremic shock: another concept of the transurethral prostatic resection reaction. J Urol 75:95–110
3. Horninger W, Unterlechner H, Strasser H, Bartsch G (1996) Transurethral prostatectomy: mortality and morbidity. Prostate 28:195–200
4. Kellow NH (1993) Pacemaker failure during transurethral resection of the prostate. Anaesthesia 48:136–138
5. Botto H, Lebret T, Barre P, Orsoni JL, Herve JM, Lugagne PM (2001) Electrovaporization of the prostate with the Gyrus device. J Endourol 15:313–316
6. Stadler KR, Woloszko J, Brown IG, Smith CD (2001) Repetitive plasma discharges in saline solutions. Appl Phys Lett 79(27):4503–4505
7. Patel A, Adshead J (2004) First clinical experience of a new transurethral bipolar prostate electrosurgery resection system: controlled tissue ablation (Coblation technology). J Endourol 18:967–972
8. Wendt-Nordahl G, Hacker A, Fastenmeier K, Knoll T, Reich O, Alken P, Michel MS (2005) New bipolar resection device for transurethral resection of the prostate: first *ex-vivo* and *in-vivo* evaluation. J Endourol 19(10):1203–1209
9. Eaton AC, Francis RN (2002) The provision of transurethral prostatectomy on a day-case basis using bipolar plasma kinetic technology. Br J Urol Int 89:534–537
10. Dunsmuir WD, McFarlane JP, Tan A, Dowling C, Downie J, Kourambas J, Donnellan S, Redgrave N, Fletcher R, Frydenberg M, Love C (2003) Gyrus™ bipolar electrovaporization versus transurethral resection of the prostate: a randomized prospective single blind trial with 1 year follow-up. Prostate Cancer Prostat Dis 6:182–186

11. Watson G (2002) A randomized study comparing holmium laser enucleation with bipolar plasma enucleation of the prostate. J Endourol 16 (suppl):A51, P11–P19.
12. Wendt-Nordahl G, Häcker A, Reich O, Djavan B, Alken P, Michel MS (2004) The Vista system: a new bipolar resection device for endourological procedures: comparison with conventional resectoscope. Eur Urol 46:586–590
13. Issa MM, Young MR, Bullock AR, Bouet R, Petros JA (2004) Dilutional hyponatremia of TURP syndrome: a historical event in the 21st century. Urology 64:298–301.
14. Tefekli A, Muslumanoglu AY, Baykal M, Binbay M, Tas A, Altunrende F (2005) A hybrid technique using bipolar energy in transurethral prostate surgery: a prospective randomized comparison. J Urol 174 (4 pt 1):1339–1343
15. Singh H, Desai MR, Shrivastav P, Vani K (2005) Bipolar versus monopolar transurethral resection of prostate: randomized controlled study. J Endourol 19(3): 333–338
16. de Sio M, Autorino R, Quarto G, Damiano R, Perdona S, di Lorenzo G, Mordente S, D'Armiento M (2006) Gyrus bipolar versus standard monopolar transurethral resection of the prostate: a randomized prospective trial. Urology 67(1):69–72
17. Hanbury DC, Sethia KK (1995) Erectile function following transurethral prostatectomy. Br J Urol 75:12–13
18. Bieri S, Iselin CE, Rohner S (1997) Capsular perforation localization and adenoma size as prognostic indicators of erectile dysfunction after transurethral prostatectomy. Scand J Urol Nephrol 31:545–548
19. Morishita H, Nakajima Y, Chen X, Kimura M, Sato S (1992) Electrical resistance and current leakage of appliances for transurethral resection. Hinyokika Kiyo 38(4):413–417
20. Ruiz-Deya G, Hellstrom W, Thomas R (2002) Minimally invasive treatment of BPH using a novel electrocautery system (Gyrus): a retrospective financial analysis versus standard monopolar resection. J Endourol 16 (suppl 1):A25
21. Timms MS, Temple RH (2002) Coblation tonsillectomy: a double blind randomized controlled study. J Laryngol Otol 116(6):450–452
22. Mancini PF (2001) Coblation: a new technology and technique for skin resurfacing and other aesthetic surgical procedures. Aesthet Plast Surg 25(5):372–377
23. Fernandez H, Gervaise A, de Tayrac R (2000) Operative hysteroscopy for infertility using normal saline solution and a coaxial bipolar electrode: a pilot study. Hum Reprod 15(8):1773–1775

Ethanol Injection Therapy of the Prostate for Benign Prostatic Hyperplasia

Nobuyuki Goya[1] and Shiro Baba[2]

Summary. Ethanol injection therapy of the prostate has been developed as a minimally invasive procedure for the treatment of patients with symptomatic benign prostatic hyperplasia (BPH). Dehydrated ethanol (absolute ethanol) is injected directly into the prostate, mainly via the transurethral route (transurethral ethanol ablation of the prostate, TEAP). This chapter reviews TEAP based on the relevant papers published during the past 10 years. TEAP can be performed using standard endoscopic equipment or a specially designed disposable instrument (InjecTx or ProstaJect endoscopic device) under local anesthesia. The most common mild to moderate complications are irritative voiding symptom, urinary retention, and hematuria, most of which resolve without intervention by 1 month after TEAP. Most patients do well with catheter removal 3–7 days after the procedure. Although clinical reports are limited, the IPSS (AUA) score, QOL score, and peak flow rate are improved after TEAP compared with before TEAP, and the improvement persists for 12 months. Maintenance of good results up to 3 years afterward has been reported. This method is safe if performed carefully and major complications are rare, but serious complications such as bladder necrosis have occasionally been reported. TEAP is minimally invasive and cost-effective, and the finding that erectile dysfunction and retrograde ejaculation were rare in many studies seems to be a major advantage of TEAP over TURP (transurethral resection of the prostate).

Keywords. Ethanol injection, Benign prostatic hyperplasia, Minimally invasive treatment, Chemoablation

Ethanol Injection Therapy of the Prostate

Ethanol injection therapy of the prostate is defined as a minimally invasive procedure for the treatment of patients with symptomatic benign prostatic

[1]Department of Urology, Tokyo Women's Medical University, 8-1 Kawada-cho, Shinjuku-ku, Tokyo 162-8666, Japan
[2]Department of Urology, Kitasato University School of Medicine, 1-15-1 Kitasato, Sagamihara, Kanagawa 228-8555, Japan

hyperplasia (BPH) by direct injection of anhydrous ethanol (dehydrated ethanol, absolute ethanol) into the prostate. Ethanol may be injected via either the transurethral [1–16] or transperineal route [17–19], but the former route is mainly used in the clinical setting.

Few report [18,19] on transperineal injection have been published. However, the risk of causing a hematuria is small, and irritation of the lower urinary tract is also slight with this method. This technique is less invasive because the urinary tract is not instrumented, so further exploration of the transperineal method can be expected in the future.

However, we mainly discuss the transurethral method in this report.

Transurethral Ethanol Ablation of the Prostate

Transurethral ethanol ablation of the prostate (TEAP) was introduced as one of the emerging therapies for BPH in the American Urologists Association (AUA) guideline on management of BPH (2003) [20]. At TEAP, anhydrous ethanol is injected to a periurethral prostatic nodule under continuous urethroscopic irrigation. Goya et al. [1] in 1999 reported the first encouraging transurethral ethanol injection therapy for BPH. Microscopically, the ethanol injection creates a uniformly demarcated line of tissue necrosis, which does not extend to the capsule of the prostate or to the sphincter. The prostate capsule integrity acts as a relative barrier to ethanol diffusion, and systemic absorption of ethanol is minimal. Excessive bleeding from a given injection site is not a problem, although it may be prudent to have a Bugbie electrocautery device available. Extensive sloughing of necrotic tissue can sometimes cause obstruction of the prostatic urethra, and this may account for failure to achieve improvement of voiding symptoms. In the United States, the evaluation of the safety and tolerability of transurethral alcohol injection for the treatment of BPH was started for formal U.S. Federal Drug Administration (FDA) approval as a new drug for treatment of BPH (investigational new drug 61337) in March 2002, enrolling 150 patients, and was completed in 2004, awaiting the final decision [2]. Including this study, TEAP procedures have been mostly performed by using the single-piece disposable instrument of InjecTx or the ProstaJect endoscopic device, which is a 20 G passive deflection hollow-core needle with an infusion channel [21,22]. One accepted drawback of chemoablation is that no tissue is available for pathology. Transrectal biopsy is not advocated at the time of this procedure; disruption of the prostatic capsule might allow unwarranted extravasation of the absolute alcohol [21].

Collection of Relevant Publications

To comprehend the results of the safety and efficacy of TEAP, the relevant papers published during the last 10 years in the peer-reviewed literature were collected from Medline and the Cochrane database. Embase and the Biosis database were also checked to search for abstracts of relevant papers from AUA

Table 1. Relevant published articles on transurethral ethanol ablation of the prostate (TEAP)

References	Year	No. of Patients	Study group[a]	Type of study	Device	Level of evidence
Goya et al. [1]	1999	10	1	Case series	Straight Needle	3
Plante et al. [3]	2002	5	2	Case series	OPAL	3
Ditrolio et al. [4]	2002	15	3	Case series	InjecTx	3
Palmer et al. [5]	2002	30	4	Case series	ProstaJect	3
Badlani et al. [6]	2002	60		Quasi-RCT[b]	ProstaJect	2
Badlani et al. [7]	2003	60	5	Quasi-RCT[b]	ProstaJect	2
Badlani et al. [8]	2003	60		Quasi-RCT[b]	ProstaJect	2
Guttierez et al. [9]	2003	15	6	Case series	ProstaJect	3
Martov et al. [10]	2003	20	7	Case series	ProstaJect	3
Buchholz and Andrews [11]	2003	4	8	Case series	ProstaJect	2
Gutierrez-Aceves et al. [12]	2003	200	+10[c]	Case series	ProstaJect	3
Plante et al. [13]	2003	200	+10[c]	Case series	ProstaJect	3
Plante et al. [14]	2003	115	9	Case series	ProstaJect	3
Grise et al. [15]	2004	115	9	Case series	ProstaJect	3
Goya et al. [16]	2004	78	1	Case series	Straight Needle	3
Plante et al. [2]	2004	150	10	RTC	ProstaJect™	2

RCT, randomized controlled trial

[a]The case series were grouped, if the enrollment protocol seems to be identical

[b]Quasi-RCT; method to generate random allocation is not reported

[c]A study group combined with group no. 10

(American Urological Association), EAU (European Association of Urology), WCE (World Congress on Endourology and SWL) and SIU (Societe Internationale d'Urologie). Structured Medline review articles on intraprostatic ethanol injection have been published [22–25]. The relevant articles on TEAP published in the literature [1–16] are listed in Table 1.

Histopathological Changes of the Prostate after TEAP

Several animal and human studies have been performed describing the mechanism of action of ethanol injection into the prostate [1,26–29]. A comparative animal study [26] was performed using a canine model to investigate the ethanol-induced effect between the transurethral and transperineal routes. The total injected dose was equivalent to either 25% or 50% of the prostate, as calculated by TRUS (transrectal ultrasonography). There was coagulative necrosis with associated protein denaturation, which was generally lobular and wedge shaped. This study clearly demonstrated that the former route has fewer overall extraprostatic effects compared to the latter approach, if a safety margin of 1 cm from the prostatic capsule was maintained. Other studies in the canine model [27,28] demonstrated that superficial injections lead to the formation of cavities, which are confluent with the prostatic urethra. Levy et al. [28] confirmed that

ethanol injections are safely performed in a dog model under ultrasound guidance. The highly echogenic appearance of the ethanol makes transrectal ultrasound monitoring of the procedure feasible. In a human study [29], immunohistochemical technique showed complete destruction of nerve cells and nerve endings within the necrotic area of the prostate.

Anesthesia

Guitierrez et al. [9] evaluated the feasibility of performing TEAP under local anesthesia with paraprostatic injection of 20 ml of 1% lidocaine in 15 subjects, and reported that this procedure can be safely performed with good patient tolerance. Plante et al. [30] reported the results of 14 men who underwent TEAP using either oral anesthesia or periprostatic block alone or in combination. Ethanol doses ranged from 6 to 24 ml, injected in one to three sites per lateral lobe. By the Wong–Baker Faces pain scale, 71% of subjects rated pain as mild or moderate. Transrectal block with oral anesthesia achieved the most consistent results. Nevertheless, almost all cases have been performed under regional anesthesia combined with topical mucosal anesthetic.

Safety of the Injection Procedure

The main drawback of transurethral ethanol injection is the difficulty in planning an accurate prostatic map for injection sites to standardize the procedure [25]. In most studies, dehydrated ethanol in a concentration of 95%–99.5% v/v is injected by means of the ProstaJect Ethanol Injection System (American Medical Systems, Minnetonka, MN, USA). This device can be inserted through any currently available rigid cystoscope, allowing direct visual monitoring of the prostate and the injection site while maintaining continuous irrigation. This injection device uses a curved needle that passively deflects in an axial plane, allowing for deeper prostatic injection.

Grise et al. [15] and Plante et al. [3,14] (study groups 2 and 9 in Table 1) described that the first plane of injection was 1 cm distal to the bladder neck, at the 3-o'clock and 9-o'clock positions. For a larger prostate, a second plane of injection was used 0.5 to 1.0 cm distal to the first. The dosage of injected ethanol for each lobe ranged from 3 to 5 ml depending on gland size and urethral length, and was selected from the recommended dosage table [15]. Average ethanol injection was 14 ml (10–16 ml), which resulted in 27% of the prostatic volume. Among the 94 patients, who were followed through 12 months, 2 patients (2.13%) developed bladder necrosis, requiring open surgery [15]. One underwent urinary diversion, and the other required a ureteral reimplantation for distal ureteral stenosis.

Goya et al. [1,16] used a standard cystourethroscopy injection system and a straight needle (Olympus or Richard Wolf) for ethanol injection (study group 1 in Table 1). The first plane of the injection was the midprostatic urethra. For a

smaller prostate, the injection was limited at 3-o'clock and 9-o'clock positions, but the injection site was increased for a larger prostate at 2-o'clock, 4-o'clock, 8-o'clock, and 10-o'clock positions. Injection of ethanol into the prostatic tissue was monitored under transrectal ultrasonography when necessary [1,16]. Based on their experience with ultrasound monitoring, dehydrated ethanol caused a hyperechoic area, which remained well within the prostatic capsule so long as the injection needle remains inside the prostate gland. To prevent retrograde ejaculation, ethanol was not injected into the bladder neck. Mean ethanol volume injected was 6 ml (range, 3 to 14 ml), and the ratio of injected ethanol volume to prostatic volume ranged from 6.5% to 27% (mean, 13.3%). No serious complications such as bladder necrosis were reported.

DiTrolio et al. [4] performed injections at least 1.5 cm proximal to the external sphincter at the 3- and 9-o'clock positions in the lateral lobes and at the 6-o'clock position in the median lobe. In a larger prostate, a second plane of injections was required. A total of no more than 25 ml ethanol were injected at a maximum of five injection sites per prostate (study group 3 in Table 1). The average total alcohol dose was 13.1 ml (8–22 ml), and the ratio of injected ethanol volume to the prostatic volume was 27.3%. No serious adverse events have been documented with this method. A similar injection procedure was reported by Gutierrez-Aceves et al. [12].

Plante et al. [13] reviewed the complications of TEAP among 200 patients from 15 countries. Most patients fare well with catheter removal 3 days after the procedure. Overall, more than 90% of patients were able to void 96 h after TEAP [13]. The most commonly reported adverse events were irritative voiding (21.5%), urinary retention (17.5%), and hematuria (13%), most of which resolved without intervention by 1 month post-TEAP. Urinary incontinence, erectile dysfunction, and retrograde ejaculation occurred in less than 5% of the patients overall. Bladder necrosis was reported in 3 cases, including one requiring urinary diversion. Among 51 subjects from FDA Phase I/II trial (IND 61337) who have completed the 6-month evaluation, Plante [2] reported mild to moderate complications including irritative voiding symptom (42%), hematuria (46%), pain/discomfort (30%), urinary retention (23%), and urinary incontinence (15%). These complications again required no intervention. Using the AUA guidelines, complications reported posttreatment are comparable to other minimally invasive therapies currently available for BPH.

Need for reintervention of any kind at 1 year among 200 subjects was less than 10% overall in each case [13]. Badlani et al. [6,7] reported a randomized comparative study of TURP versus transurethral anhydrous alcohol injection for bladder outlet obstruction. Sixty men with significant LUTS (lower urinary tract symptoms) were enrolled in a randomized, three-arm study to compare the effects of superficial injection (0.5 cm) of ethanol, deep injection (2.0 cm) of ethanol, and TURP. Thirteen to 14 subjects from each group were followed up through 6 months after TEAP or TURP (study group 5 in Table 1). TEAP conversion to TURP was reported in 10% of the deep injection group and 15% of the superficial injection group [7].

Efficacy of TEAP

Clinical results of several studies on TEAP, with a follow-up as long as 4.3 years [1,3–6,10–12,15,16], have been published. After TEAP, IPSS, and QOL score decreased significantly at 1 month, and these improvements were sustained at 12 months (Tables 2,3). Goya et al. [16] followed 17 patients for longer than 3 years (median follow-up, 4.3 years), and reported durable improvements in International Prostate Symptom Score (IPSS), quality of life (QOL) score, peak

Table 2. Changes in International Prostate Symptom Score (IPSS) [American Association of Urologists (AUA)] after TEAP (mean)

References	No. of Patients	Preoperative	3 months	6 months	12 months	
Goya et al. [1]	10	23.1	12.2*			*$P<0.01$
Plante et al. [3]	5	23.4	12.2	11.4	13.8*	*$P<0.05$
Ditrolio et al. [4]	13	22.4	5.6	5.8	5.9	
Palmer and Keen [5]	30	22	11*	11*	9*	*$P<0.01$
Badlani et al. [6] (S)	14	22.7	10.4	11.7*		$P<0.05$
Badlani et al. [6] (D)	13	17.2	6.5	4.7*		$P<0.05$
Martov et al. [10]	20	24.7	8.9			
Buchholz and Andrews [11]	4	18.5	4.5	4.5		
Gutierrez-Aceves et al. [12]	118	21.2	10.3*	9.9*	10.7*	*$P<0.001$
Grise et al. [15]	93	20.6	10.3*	10.6*	10.3*	*$P<0.05$
Goya et al. [16]	29	21.8	10.4*	10.8*	9.6*	*$P<0.001$

S, superficial injection group; D, deep injection group
Number of patients indicates those followed through the final evaluation

Table 3. Changes in quality of life (QOL) score after TEAP (mean)

References	No of Patients	Preoperative	3 months	6 months	12 months	
Goya et al. [1]	10	5.1	3.2*			*$P<0.01$
Plante et al. [3]	5	4.0	1.6	2.2	2.8*	*$P<0.05$
Ditrolio et al. [4]	13					No report
Palmer et al. [5]	30	5	2*	2*	2*	*$P<0.001$
Martov et al. [10]	20	4.75	2.0			
Buchholz and Andrews [11]	4	3.5	2.5	2.5		
Gutierrez-Aceves et al. [12]	116	4.4	2.2*	2.1*	2.1*	*$P<0.001$
Grise et al. [15]	93	4.4	2.2*	2.3*	2.1*	*$P<0.05$
Goya et al. [16]	29	5.0	2.6*	2.7*	2.3*	*$P<0.001$

Number of patients indicates those followed through the final evaluation

flow rate, and postvoid residual volume. With regard to the peak flow rate, an increase of 45% was evident 3 months after TEAP (Table 4), and the effect was mostly sustained through 12 months. As summarized in Table 5, the postvoid residual volume seems to be decreased by TEAP [1,5,16], but the change has not been remarkable in some studies [3].

The reported reintervention rate ranged from 13% by 1 year [15] to 61% by 3 years after TEAP [16]. If the reported case series are continuously observed for another 4 years, the retreatment rate may increase further.

Table 4. Changes in peak flow rate (ml/s) after TEAP (mean)

References	No of Patients	Preoperative	3 months	6 months	12 months	
Goya et al. [1]	9	8.0	13.1*			*$P<0.05$
Plante et al. [3]	5	9.9	13.8*	13.0*	13.1*	*$P<0.05$
Ditrolio et al. [4]	13	5.7	11.7	11.7	11.9	
Palmer et al. [5]	30	11	14*	14*	12	*$P<0.002$
Badlani et al. [6] (S)	14	7.9	13.8*	11.2*		$P<0.05$
Badlani et al. [6] (D)	13	9.0	14.5*	13.3*		$P<0.05$
Martov et al. [10]	20	8.4	13.4			
Buchholz and Andrews [11]	4	6	16	16		
Gutierrez-Aceves et al. [12]	130	9.3	13.1*	13.2*	13.7*	*$P<0.001$
Grise et al. [15]	90	9.9	13.4*	13.4*	13.4*	*$P<0.05$
Goya et al. [16]	29	8.3	12.5*	12.9*	13.6*	*$P<0.001$

S, superficial injection group; D, deep injection group
Number of patients indicates those followed through the final evaluation

Table 5. Changes in residual urine (ml) after TEAP (mean)

References	No of Patients	Preoperative	3 months	6 months	12 months	
Goya et al. [1]	9	129.0	49.3*			*$P<0.05$
Plante et al. [3]	5	118.8	89.8	111.4	111.2	n.s.
Ditrolio et al. [4]	13					No report
Palmer et al. [5]	30	93	107	64*	97	*$P<0.02$
Martov et al. [10]	20	133.7	10.7			
Buchholz and Andrews [11]	4					No report
Gutierrez-Aceves et al. [12]	118					No report
Grise et al. [15]	93					No report
Goya et al. [16]	29	93	34*	30*	35*	*$P<0.001$

Number of patients indicates those followed through the final evaluation

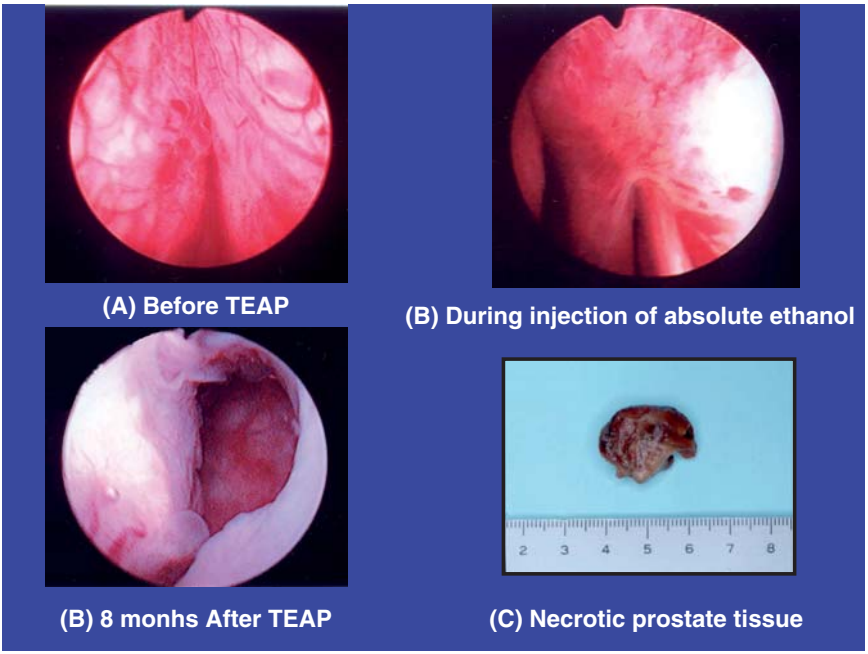


FIG. 1. Case 1. Before TEAP (endoscopic findings). 2. During injection of absolute ethanol. 3. After TEAP: a large part of the prostate is missing and the occluded lumen of the posterior urethra was mostly cleared. 4. Necrotic prostate tissue removed from the urethra at 58 days after TEAP. The patient was a 76-year-old man. His preoperative data included a prostate volume of 84.4 ml, IPPS of 21, QOL index of 5, and maximum urinary flow rate (Q_{max}) of 9.0 ml/sec. A total of 18.0 mL of absolute ethanol was injected transurethrally at 6 sites in total. At 58 days after the procedure, necrotic prostate tissue that sloughed from the posterior urethra was removed when the patient presented with obstruction of the anterior urethra. The patient's urinary symptoms improved markedly after removal of the necrotic tissue. The patient's postoperative data included an IPPS of 9, QOL index of 2, and Q_{max} of 18.3 ml/s after 3 months. His prostate volume was 51.3 mL after 6 months. This case indicates that injection of ethanol may cause extensive prostatic tissue necrosis that results in sloughing of the tissue, although it is rare

Cost-Effectiveness

Compared with TURP, the procedure time required for TEAP is much shorter, and it could be performed within 20 min [4,6]. Ethanol is inexpensive and readily available. The expense of this short procedure performed under regional anesthesia as an outpatient case must be weighed against the cost of TURP, which is performed as an inpatient procedure with 48 h of postoperative hospitalization.

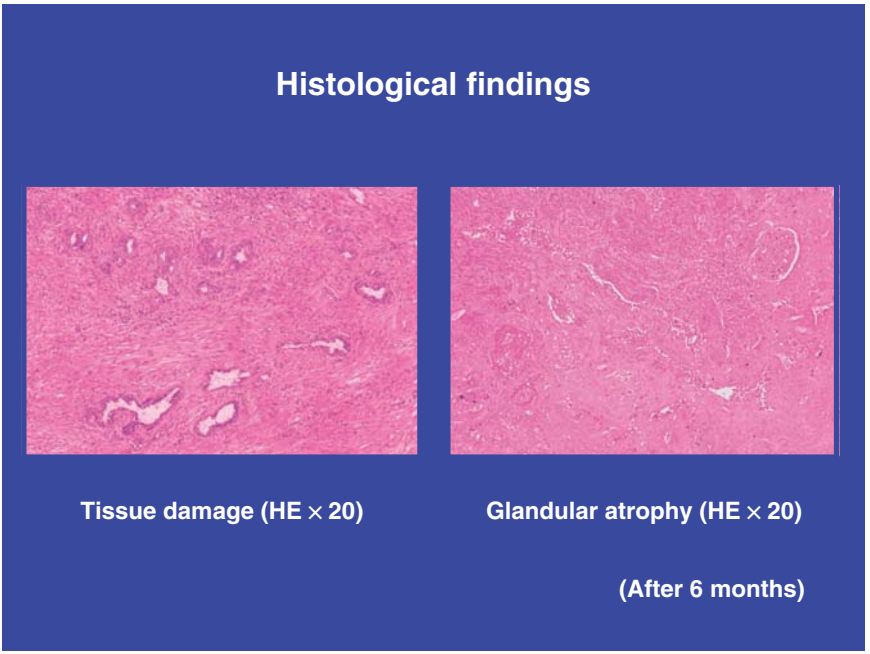


FIG. 2. Histological findings: coagulative necrosis with ductal atrophy and fibrosis was observed histologically 6 months after TEAP

Conclusions

TEAP is effective and may be a suitable option for patients with comorbidities who are unfit to undergo TURP. The fact that erectile dysfunction and retrograde ejaculation rarely occurred in many studies seems to be the major advantage of TEAP over TURP. With regard to durability, 12-month data have only limited value. Further follow-up for another 3–5 years is required before this procedure is considered to be a reasonable alternative treatment for BPH. Local toxicity in the form of spreading necrosis warrants further research in establishing a safe injection site before it could be put to regular clinical use.

References

1. Goya N, Ishikawa N, Ito F, Ryoji O, Tokumoto T, Toma H, Yamaguchi Y (1999) Ethanol injection therapy of the prostate for benign prostatic hyperplasia: preliminary report on application of a new technique. J Urol 162:383–386
2. Plante M (2004) A safety comparison of a randomized multi-center study evaluating transurethral ethanl ablation of the prostate (TEAP) for the treatment of benign prostatic hyperplasia (BPH). Eur Urol (suppl 3)2:143

3. Plante KM, Bunnel ML, Trotter SJ, Jackson TL, Esenler AC, Zvara P (2002) Transurethral prostatic tisuue ablation via a single needle delivery system: initial experience with radio-frequency energy and ethanol. Prostate Cancer Prostat Dis 5:183–188
4. DiTrolio JV, Patel P, Watson RA, Irwin RJ Jr (2002) Chemo-ablation of the prostate with dehydrated alcohol for the treatment of prostatic obstruction. J Urol 167: 2100–2104
5. Palmer J, Keen M (2002) ProstaJect ethanol injection therapy for benign prostatic hyperplasai- 12 month results. Eur Urol (suppl 1)1:131
6. Badlani G, Desai M, Kumar A (2002) A randomized comparative study of TURP vs Transurethral anhydrous alcohol injection for bladder outlet obstruction. J Endourol 16(suppl 1):A48
7. Badlani G, Desai M, Kumar A (2003) A randomized trial comparing transurethral ethanol ablation of the prostate (TEAP) treatment and TURP for bladder outlet obstruction (BOO). J Urol 169(4 suppl):391 (abstract 1460)
8. Badlani G, Desai M, Kumar A (2003) A prospective randomized study of transurethral ethanol injection versus TURP for bladder outlet obstruction (BOO). J Endourol 17(suppl1):A158 (abstract)
9. Guitierrez J, DiGrazia E, Favela R, Franco D (2003) Transurethral ethanol ablation of the prostate (TEAP): can it be performed under local anesthesia? J Endourol 17(suppl 1):A157 (abstract MP20.07)
10. Martov AG, Pavlov DA, Gushchin BL (2003) Initial results of absolute ethanol chemoablation in benign prostatic obstruction treatment. J Endourol 17(suppl 1): A157 (abstract MP20.01)
11. Buchholz NPN, Andrews HO (2003) Transurethral ablation of the prostate (TEAP) as an alternative to TURP in high risk patients. J Endourol 17(suppl 1):A157 (Abstract MP20.02)
12. Gutierrez-Aceves J, Gilling P, Schettini M, Grise P, Sagarra JM, Hernandes C (2003) Transurethral ethanol ablation of the prostate (TEAP), initial long term report of two prospective multi-center studies. J Urol 169(suppl):466 (abstract AUA)
13. Plante MK, Palmer J, Martinez-Sagarra J, Guttierrez J, Gilling P (2003) Complications associated with transurethral ethanol ablation of the prostate for the treatment of benign prostatic hyperplasia: a worldwide experience. J Urol 169(suppl):392 (abstract 1466)
14. Plante M, Baena V, Ballanger P, Castinieras J, Chicharro J, Erdmann J, Escaf-Bermadah S, Gonzales-Martinez M, Grise P, Hernandez C, Jacqmin D, Martinez-Sagarra J, Schettini M, Mirone V, Teillac P, Zerbib M, Rolo F, Palmer J (2003) Evaluation of transurethral anhydrous alcohol injection for symptomatic benign prostatic hyperplasia (BPH): an European multi-center experience. Eur Urol (suppl 2)1:103
15. Grise P, Plante M, Palmer J, Martinez-Sagarra J, Hernandez C, Schettini M, Gonzales-Martin M, Castinieras J, Ballanger P, Teillac P, Rolo F, Baena V, Erdmann J, Mirone V (2004) Evaluation of the transurethral ethanol ablation of the prostate(TEAP) for symptomatic benign prostatic hyperplasia: a European multi-center evaluation. Eur Urol 46:496–502
16. Goya N, Ishikawa N, Ito F, Kobayashi C, Tomizawa Y, Toma H (2004) Transurethral ethanol injection therapy for prostatic hyperplasia: 3-year results. J Urol 172:1017–1020

17. Zvara P, Plante MK (2000) Re: Ethanol injection therapy of the prostate for benign prostatic hyperplasia: preliminary report on application of a new technique. J Urol 163: 552–553
18. Savoca G, De Stefani S, Gattuccio I, Paolinelli D, Stacul F, Belgrano E (2001) Percutaneous ethanol injection of the prostate as minimally invasive treatment for benign prostatic hyperplasia: preliminary report. Eur Urol 40:504
19. Chiang PH, Chuang YC, Huang, CC, Chiang CP (2003) Pilot study of transperineal injection of dehydrated ethanol in the treatment of prostatic obstruction. Urology 61:797
20. AUA Practice Guidelines Committee (2003) AUA guideline on management of benign prostatic hyperplasia. Chapter 1: Diagnosis and treatment recommendations. J Urol 170:530–547
21. Ditrolio J, Patel P, Watson RA, Irwin RI Jr (2003) An endoscopic injection device: a potential advance in the transurethral treatment of benign prostatic obstruction. BJU Int 92:143–145
22. Plante KM, Folsom JB, Zvara, P (2004) Prostatic tissue ablation by injection: a literature review. J Urol 172:20–26
23. Kim ED (2002) Ethanol injection for the treatment of benign prostatic hyperplasia. Curr Urol Rep 3:276–279
24. Buchholz NN, Andrews HO, Plante MK (2004) Transurethral ethanol ablation of prostate. J Endourol 18(6):519–524
25. Naspro R, Salonia A, Colombo R, Cestani A, Guazzoni G, Rigatti P, Montorsi F (2005) Update of the minimally invasive therapies for benign prostatic hyperplasia. Curr Opin Urol 15:49–53
26. Plante MK, Gross AL, Kliment J Jr, Kida M, Zvara P (2003) Intraprostatic etnanol injection chemoablation via transurethral and transperineal injection. BJU Int 91: 94–98
27. Zvara P, Karpman E, Stoppacher R, Esenler AC, Plante MK (1999) Ablation of canine prostate using intraurethral intraprostatic absolute ethanol injection. Urology 54:411–415
28. Levy DA, Cromeens DM, Evans R, Stephens LC, von Eschenbach AC, Pisters LL (1999) Transurethral ultrasound-guided intraprostatic injection of absolute alcohol with and without carmustine: a feasibility study in canine model. Urology 53:1245–1251
29. Guitierrez-Aceves J, Camacho JRF, Carrillo DF, Gomez EV (2004) Histological changes of the prostate gland after transurethral ethanol ablation. J Urol 171:401 (abstract AUA)
30. Plante M, Anderson R, Badlani G, Rukstalis D (2003) Transurethral ethanol ablation of the prostate using local anesthesia. J Endourol 17(suppl 1):A158 (abstract)

Urethral Stents: Review of Technology and Clinical Applications

Mordechai Duvdevani, Ben H. Chew, and John D. Denstedt

Summary. Urethral stents are a minimally invasive therapy used in the treatment of benign prostatic hyperplasia, urethral stricture, or detrusor sphincter dyssynergia. This chapter reviews the different types of urethral stents, indications for their use, and clinical results. Urethral stents may be positioned in the urethra or prostatic urethra and are classified as temporary or permanent. Temporary stents are further subdivided into biodegradable and nonbiodegradable. This form of therapy is particularly useful in patients who are at high anesthetic risk and are unable to undergo surgical procedures considered to be the gold standard, such as transurethral prostatectomy or open urethroplasty for prostatic enlargement and urethral stricture disease. Urethral stents can provide an effective alternative to transurethral and open procedures in many urological disorders that affect the prostate and urethra.

Keywords. Urethra, Stent, Benign prostatic hyperplasia, Detrusor sphincter dyssynergia, Stricture

Introduction

The term "stent" is defined as "a thread, rod, or catheter, lying within the lumen of tubular structures, used to provide support during or after an anastomosis, or to assure patency of an intact but contracted lumen" [1]. Urethral stents are typically made of a metal alloy or polymeric or biodegradable material in a variety of designs that are rigid enough to maintain urethral patency.

Urethral stents are designed to relieve bladder outlet obstruction caused by various etiologies. Indications in appropriate patients for urethral stent placement include urethral stricture disease, benign prostatic hyperplasia (BPH), detrusor-sphincter dyssynergia (DSD), and bladder outlet obstruction second-

Division of Urology, University of Western Ontario, London, Ontario, Canada

Table 1. Characteristics of the ideal urethral stent

1.	Easy to insert
2.	Easy to remove
3.	Biocompatible (i.e., induces no reaction to surrounding tissue and is not altered by the in vivo environment)
4.	Radiopaque (to facilitate stent insertion using fluoroscopy and confirm position during follow-up radiography)
5.	Rigid enough to relieve urethral obstruction
6.	Resistant to encrustation and infection even after prolonged indwelling times
7.	Resistant to migration
8.	Comfortable
9.	Internal lumen large enough to alleviate the obstruction and to facilitate cystoscopy if needed

ary to locally advanced prostate cancer [2,3]. Patients with BPH who have failed medical management or patients with locally advanced prostate cancer causing bladder outlet obstruction who are not medically suitable for anesthesia are potential candidates for urethral stent insertion as opposed to an indwelling Foley catheter or intermittent catheterization [3]. Patients with neurogenic bladder and DSD may also benefit from a urethral stent [4,5]. Urethral stents are placed endoscopically under either radiologic or cystoscopic control and should be easily inserted or removed and be of large enough diameter to relieve urethral obstruction as well as to facilitate cystoscopy if necessary. Characteristics of the "ideal" urethral or prostatic stent are listed in Table 1. To date, however, no stent encompasses all these factors.

Indications and Contraindications for Urethral Stent Placement

There are several accepted indications for placement of a temporary or permanent urethral stent, which include patients with enlargement of the prostate gland and significant obstruction of urinary flow (BPH or patients with locally advanced prostate cancer) who are unsuitable for surgical procedures requiring anesthesia. Other indications for placement of urethral stents include patients with mechanical obstruction of the urethra due to urethral stricture disease or with functional obstruction of the bladder outlet due to DSD.

Likewise, several contraindications for urethral stent insertion exist including acute prostatitis, an active infection of the urethra or bladder, cystolithiasis, penile urethral stricture, stricture involving the external urethral sphincter, or recurrent bladder tumors (these patients require repeated cystoscopy for follow-up, which may be problematic after stent insertion).

Before placement of a urethral stent, patients should be evaluated with investigations appropriate for the underlying disease process. Irregardless of the etiology of the stricture, a thorough anatomical and functional evaluation of the

urethra should be performed to delineate the anatomical location and length of the diseased area via retrograde or antegrade (if a suprapubic catheter is present) urethrography, magnetic resonance imaging (MRI), uroflowmetry, videourodynamic studies and cystoscopy. Urinary tract infection should be ruled out with a urinalysis and culture.

Stents for the Treatment of Obstructing Prostate Tissue: Benign Prostatic Hyperplasia (BPH) and Prostate Cancer

Benign prostatic hyperplasia (BPH) is a common and well-known cause of lower urinary tract symptoms (LUTS) in men. The treatment options for symptomatic BPH include oral alpha-blockade alone or in conjunction with 5-alpha reductase inhibitors, surgical resection of the obstructing adenoma (either open prostatectomy or transurethral prostatectomy), or minimally invasive procedures such as transurethral needle ablation, transurethral microwave treatment, laser prostatectomy which is available in a variety of forms, and prostatic stent placement [6,7]. Minimally invasive procedures are generally used in patients who are unfit for surgery because serious comorbidities place them at greater anesthetic risk [3,8,9]. Another potential indication for prostatic stent insertion is in the patient with serious comorbidities and a greater anesthetic risk with locally advanced prostate cancer resulting in bladder outlet obstruction.

Urethral Stricture

Urethral strictures can be classified according to their location (proximal or distal) or their etiology, such as iatrogenic or secondary to other pathology. Iatrogenic causes are related to previous surgical urethral manipulation including cystoscopy, ureteroscopy, transurethral prostatectomy or resection of bladder tumor, catheter manipulation, pelvic irradiation, and any surgery involving the urethra. Secondary urethral strictures may be due to previous infection such as sexually transmitted diseases (especially gonoccocal urethritis); malignancies such as prostate, bladder, or urethral cancer, or pelvic trauma with pelvic bone fracture. Urethral strictures can be also idiopathic. The treatment for urethral strictures is generally surgical and involves urethral dilatation, direct visual internal urethrotomy or open urethroplasty. The recurrence rate of strictures is 50%–75% within 2 years after endoscopic treatment [10]. Transurethral treatment of urethral strictures is not suitable for every type of stricture, particularly long strictures, strictures in conjunction with spongiofibrosis, or patients that have had recurrent urethral strictures and prior failed treatments. For these patients, open urethroplasty offers the highest success rate of over 90% and is considered the gold standard of therapy [11]. Patients with serious comorbidities who are at great anesthetic risk with recurrent or long urethral strictures are good candidates for urethral stent placement.

Detrusor Sphincter Dyssynergia (DSD)

Traumatic suprasacral injury to the spinal cord can cause neurogenic bladder associated with DSD, leading to elevated bladder pressure, voiding dysfunction, vesicoureteral reflux, nephropathy, and even loss of renal function. The primary goal in the treatment of DSD is to lower bladder pressure to preserve renal function using either medical or surgical therapies. The standard surgical solution for patients with DSD has been transurethral sphincterotomy, which is irreversible. Permanent sphincter stenting can be considered as an appropriate alternative, which would improve symptoms and preserve bladder and renal function.

Types of Urethral Stents

A variety of urethral stents is available and can be broadly classified as temporary or permanently implantable.

Temporary Stents

Temporary urethral stents maintain urethral patency and are not incorporated into the wall of the urethra. The aim of such stents is to provide an alternative to an indwelling urethral or suprapubic catheter for the short-term relief of bladder outlet obstruction [7]. Temporary urethral stents enable normal micturition with a success rate ranging from 50% to 90% [12]; however, cystoscopy or urethral catheterization cannot usually be carried out with these stents in place due to the small luminal size. Temporary stents are made of stainless steel, biodegradable polymers [13], or a nickel titanium alloy (Table 2). Temporary urethral stents are replaced every 6–36 months depending on the manufacturer's recommendations. Other temporary stents consist of poly-D/L-lactic acid, which is biodegradable and dissolves spontaneously over time [14]. Such stents are used postoperatively in conjunction with minimally invasive surgery involving the urethra or prostate such as transurethral microwave therapy (TUMT) [15] and visual laser ablation of the prostate (VLAP) [16] to provide temporary drainage and slowly dissolve thereafter, thus precluding the need for an indwelling urethral catheter or a subsequent procedure to remove the prostatic stent.

Urospiral and Prostakath

The Urospiral (Porges, Paris, France) is a 21 Fr stainless steel coil that is constructed in three segments including a proximal portion in the prostatic urethra extending up to 10 mm into the bladder, a midsection at the sphincteric level, and a distal end positioned in the bulbar urethra distal to the external sphincter. The Urospiral was one of the first temporary stents that was designed for the relief of urinary obstruction in patients with BPH. The Prostakath (Engineers &

TABLE 2. Temporary prostatic and urethral stents

Stent name	External caliber (Fr)	Length (mm)	Composition	Maximum indwelling time (months)	Location	Notes
Spiral stents						
Urospiral (Porges, Paris, France)	21	40–80	Stainless steel	12	Prostate	(1) Inserted with 21 Fr Endoscope under direct vision or over a catheter with ultrasound guidance (2) High complication rates
Prostakath (Engineers & Doctors, Copenhagen, Den-mark)	21	35–95	Gold-plated stainless steel	12	Prostate	
Memokath (Doctors & Engineers, Kvistgaard, Denmark)	22	35–95	Nitinol	36	Prostate	(1) Heat expandable (2) Mounted on a delivery catheter under ultrasound or using flexible endoscope under direct vision (3) Permits the passage of flexible cystoscopes
ProstaCoil (Instent, Eden Prairie, MN)	24–30	40–80	Nitinol	36	Prostate	(1) Self-expanding (2) Mounted on a delivery catheter under fluoroscopy (3) Permits the passage of flexible cystoscopes
Urethrospiral (Porges, Paris, France)	21	40–70	Stainless steel	12	Urethra	
UroCoil (Instent Israel, Haifa, Israel)	24	40–80	Nitinol	36	Urethra	

Table 2. *Continued*

Stent name	External caliber (Fr)	Length (mm)	Composition	Maximum indwelling time (months)	Location	Notes
Polyurethane stents						
Intraurethral Catheter	16–18	25–80	Puroflex	6	Prostate	(1) Inserted under topical anesthesia using 22 Fr cystoscope
Barnes stent (Angiomed, Bard, UK)	16	50	Polyurethane	3	Prostate	(1) Inserted using a curved introducer and a cystoscope
Trestle stent (Boston Scientific Microvasive, Natick, MA)	22	75	Polyurethane	6	Prostate	(1) Consists of two tubes and an interconnecting string (2) Suitable for prostates of less than 80 ml (3) The connecting string lies across the sphincter (maintains continence) (4) Inserted under topical anesthesia (5) Positoned under transrectal ultrasound control
Biodegradable stents						
Biofix (Bionx Implants, Tampere, Finland)	21	45–85	Polyglycolic acid, polylactic acid	6	Prostate	(1) Degrades with time—does not require removal (2) Used short term after minimally invasive procedures in the prostate or urethra

Doctors, Copenhagen, Denmark) is similar to the Urospiral but is coated with gold in an attempt to prevent encrustation. These stents are inserted using a 21 Fr endoscope either under direct vision or using ultrasound guidance over a catheter.

Memokath

The Memokath (Engineers & Doctors, Hornbaek, Denmark) is a nickel-titanium alloy stent mounted on a polyurethane insertion catheter with an inflatable balloon that is used to expand and deploy the stent within the urethra. The shaft is 24 Fr, and the lower cone expands to 44 Fr when heated to 55°C and has "shape memory" due to its nickel-titanium alloy construction (Fig. 1).

Deployment can be performed under ultrasound guidance or flexible cystoscopy using a 22 Fr insertion stent. Removal takes an average of 11 min, even in patients who have had the stent for a mean indwelling time of 12.9 months [17]. Removal involves flushing the stent with cool water (10°C or less), which alters the spiral to become soft and pliable to facilitate transurethral removal.

ProstaCoil

The ProstaCoil (Instent, Minneapolis, MN, USA) is designed to be inserted under fluoroscopic guidance. Retrograde urethrography is used to measure the prostatic urethra and mark the bladder base and urethral sphincter. The stent is then inserted with the patient conscious and able to cooperate. Before the end of the procedure, the patient is asked to voluntarily stop the urinary stream during micturition to ensure that the stent is not interfering with sphincteric function. Antibiotic coverage is started 2–3 days before the procedure and continued for 2 weeks after stent placement. To remove the ProstaCoil stent, a 21 Fr

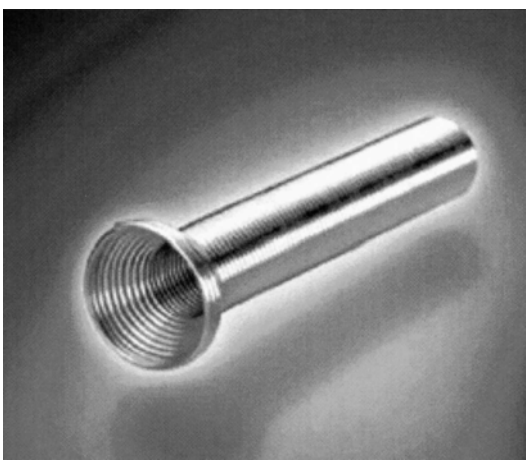


Fig. 1. Memokath

cystoscope and endoscopic grasper are inserted transurethrally. The distal end of the stent is grasped and pulled out of the urethra atraumatically. A second established method for ProstaCoil stent removal is via insertion of a 12–14 Fr Foley catheter through the stent lumen to its proximal end. The balloon is inflated with 2–3 ml saline and pulled out of the urethra under fluoroscopic guidance. Removal of the ProstaCoil stent is typically atraumatic to the anterior urethra.

Polyurethane Stents

Three main types of temporary stents are made from polyurethane, including the IntraUrethral Catheter (IUC), the Barnes stent, and the Trestle Catheter.

The intraurethral catheter (IUC) is a 16–18 Fr device that has a similar shape to a double-Malecot catheter and is available in lengths of 25–80 mm. The device is inserted under local anesthesia and direct vision using a 22 Fr, cystoscope. The removal of the IUC is easily achieved by pulling a nonabsorbable nylon string attached to its distal end.

The Barnes stent (Angiomed, Bard, UK) is a 16 Fr urethral device with a length of 75 mm. The proximal end of the stent is similar to a regular urethral catheter and the distal end resembles a Malecot catheter that is positioned proximal to the verumontanum. Insertion is accomplished by using a special introducer that advances the stent into the bladder, and then a cystoscope is used to retract the stent into the urethra to its correct position using nylon threads attached to the distal end of the device. Removal of the Barnes stent is easy and achieved under local anesthesia by pulling the strings.

The Trestle Catheter (Boston Scientific Microvasive, Natick, MA, USA) has two 22 Fr tubes that are connected by a compressible thread which is positioned across the sphincter, thus maintaining continence. The catheter is inserted under local anesthesia and positioned under transrectal ultrasound control.

Permanent Stents

Permanent urethral stents are manipulated into the urethral lumen and become incorporated into the wall of the urethra as urothelium covers the device. Permanent stents are used to alleviate bladder outlet obstruction in cases of urethral stricture, DSD, or anastomotic stricture after radical prostatectomy [18,19]. The initial enthusiasm for the use of permanent stents has waned in recent years [20]. The common permanent stents are detailed in Table 3.

UroLume

One of the most widely used permanent stents is the UroLume, which is constructed as a nickel superalloy wire mesh configured as a flexible expandable tube. Originally reported in the use of bulbar urethral strictures [21], it rapidly found use in patients with BPH [22] and DSD [23].

Table 3. Permanent prostatic and urethral stents

Stent name	External caliber (Fr)	Length (mm)	Composition	Location	Notes
UroLume (American Medical Systems, Minnetonka, MN, USA)	42	20–30	Biocompatible superalloy woven tubular mesh	Prostate or urethra	(1) Inserted with 21 Fr endoscope under direct vision (2) Gradual epithelization over the wires of the mesh
Memotherm (Bard, Covington, GA, USA)	42	15–80	Nitinol woven single wire	Prostate or urethra	(1) Heat expandable (2) Inserted with endoscope under direct vision
Ultraflex (Boston Scientific, Natick, MA, USA)	42	20–60	Nitinol	Prostate or urethra	(1) Heat expandable

The UroLume is inserted using an introducer that resembles a cystoscope. The procedure is performed under general, regional, or local anesthesia. The correct length of stent is chosen by measuring the urethra from the bladder neck to the distal urethral sphincter under direct vision. The stent is placed under direct vision distal to the bladder neck and proximal to the distal urethral sphincter so that the patient maintains urinary continence.

Although it is meant to be permanent, removal of the UroLume stent is possible when necessary. To remove the UroLume stent, a standard resectoscope and loop cautery or Colling's knife is used to resect the overlying urothelium and push the stent into the bladder, after which it is extracted transurethrally through a larger sheath.

Memotherm

The Memotherm is a 42 Fr coil-shaped stent made of nickel-titanium alloy (NiTinol). The Memotherm is positioned within the urethra using an endoscope and insertion catheter under direct vision. The stent is heat expandable with the ability of changing from one configuration to another at different temperatures. After the stent is positioned in the desired location, it is flushed with 45°C water, causing the NiTinol stent to expand. Removal of the Memotherm stent is achieved by irrigating with 15°C water, which softens the metal, causing it to uncoil.

Clinical Results with Urethral Stents

Stents for the Treatment of Benign Prostatic Hyperplasia (BPH)

The prostatic stent was first described by Fabian in 1980, who named it the "partial catheter" [24]. The use of prostatic stents for the treatment of bladder outlet obstruction is known to be safe and effective [8], offers immediate relief, and has 7-year follow-up data [6].

Several stent types have been investigated in patients with bladder outlet obstruction from BPH. Poulsen et al. investigated the use of the Memokath stent and report an 83% success rate in 30 patients with BPH without problems of stent migration, but stent encrustation occurred [25]. Most patients, however, were satisfied with this minimally invasive outpatient procedure for BPH. The first use of the UroLume stent in urology was to treat bulbar urethral strictures in patients who had failed internal urethrotomy [21]. Since then, the indications for UroLume stent insertion have widened to include patients with symptomatic BPH [26–28] and in particular those patients who are unfit for anesthesia and surgical treatment [22].

Urethral Stricture

Several trials have reported the utilization of stents for urethral stricture disease. Shah et al. reported the long-term results of the UroLume endourethral prosthesis in the treatment of recurrent bulbar urethral strictures in a multicenter North American trial [29]. The study included 24 patients with recurrent bulbar urethral strictures treated with a UroLume stent and 11 years of follow-up. Preoperative evaluation included uroflowmetry (peak and average urinary flow rates), a urinary symptom questionnaire, and cystoscopy to determine the length and location of the stricture. They found a dramatic improvement in the mean flow rates after stenting (9.5 to 20.8 ml/s) and in the mean urinary symptom scores. Complete epithelialization of more than 90% of the surface area of the stent was seen in the majority of patients (90%) at 1 year follow-up and was persistent through 11 years. The authors recommend this stent for patients with bulbar urethral strictures of less than 3 cm and after at least two recurrences following endoscopic dilation or incision. The distance from the external sphincter should be at least 10 mm to conserve urinary continence.

Badlani et al. reviewed the long-term results of the North American Multicenter UroLume Trial for the treatment of recurrent bulbar urethral strictures [30]. This multicenter prospective controlled trial included 175 patients with a bulbar urethral stricture who failed prior treatment attempts including urethral dilatation, visual internal urethrotomy, or urethroplasty (25%). Etiology of the strictures was attributed to prior instrumentation (21.6%), urethral catheterization (14.9%), trauma (18.9%), inflammation/congenital problems

(8.1%), or idiopathic (36.5%). The mean stricture length was 2.34 cm. Follow-up was undertaken at 6 weeks, 6 months, 1 year, and annually after urethral stent insertion.

The study demonstrated a continuous improvement in symptom score values and peak and mean urine flow rates. Fifteen percent of the patients required further treatment for recurrent stricture within (44%) or adjacent (56%) to the stent. Only seven patients (4%) required stent removal, and 14.3% required adjuvant treatment after 1 year compared to 75.2% of controls. There was no significant difference in the rate of urinary tract infection before and after stent insertion, and the only predictive factor of postinsertion infection was a positive preoperative urine culture. Stent migration occurred in 4% of patients and occurred predominantly in the first 6 weeks after insertion. Pain and discomfort in stented patients decreased progressively with time from 62% after 6 weeks to 11% at 2 years of follow-up. Severe urinary incontinence was found in 4.3% and 2.5% of the patients after 6 weeks and 2 years of follow-up, respectively. Mild hematuria was noted postoperatively in 26% of the patients but improved to 4% at 2 years. Five patients (3%) had urinary retention after stent insertion. One of these patients developed hyperplastic tissue between two previously placed stents and was treated by insertion of a third stent to bridge the gap between the two existing stents. The other episodes of urinary retention occurred as a result of a new or preexisting urethral stricture adjacent to the stent.

Patients with longer urethral strictures or those that have failed a previous stent insertion may require the placement of more than one stent. Tillem et al. reported on the use of multiple UroLume stents in complex bulbar urethral strictures in 41 patients from the 175 (23%) patients enrolled in the UroLume endourethral prosthesis study for recurrent bulbar urethral strictures [31]. Patients who required multiple stents generally had longer strictures with a mean length of 3.6 cm (range, 1.5–6.0). Of the 41 subjects, 32, 6, and 3 patients required two, three, and four stents, respectively. Multiple stents were inserted either simultaneously during the primary procedure (61%) or in a subsequent procedure (39%). Peak urine flow rates and symptom scores were significantly improved in these patients, who showed a similar benefit to other patients in this study who underwent single stent insertion. Patients with urethral strictures longer than 2.5 cm are more likely to require the insertion of multiple stents. Furthermore, patients with multiple stents are more likely to require retreatment, but fortunately the success rate after retreatments is equal to those patients with a single stent. Indications for multiple stent insertion includes strictures longer than 2.5 cm, strictures that were underestimated in length, malpositioned stents, stent migration, recurrent stricture separate from the previously stented region, or simple urethral narrowing adjacent to the stent.

Wilson et al. reported on a small series where all DSD patients ($n=4$) stented with a UroLume suffered urosepsis within 10 months and required hospitalization [20]. All six patients with urethral strictures had recurrences, and required subsequent surgery, and stent removal was not always straightforward.

Detrusor Sphincter Dyssynergia (DSD)

The use of urethral stents for DSD was reported in 1990 [23], and a subsequent study demonstrated equivalent long-term results compared to surgical sphincterotomy [32].

Shah et al. assessed 14 male patients with suprasacral spinal cord injury and documented DSD with elevated detrusor pressures and postvoiding residual (PVR) volumes [33]. Patients underwent Memokath stent insertion and were reviewed at 1 month and every 3 months thereafter to assess for urinary tract infection (UTI), autonomic dysreflexia, erectile function, PVR volume, bladder stones, and signs of upper tract obstruction. They found a significant reduction in the PVR volume and improvement in hydronephrosis and autonomic dysreflexia after stent insertion. Six of eight (75%) patients who had a history of recurrent UTIs experienced a decrease in UTI occurrence following stent insertion, presumably from improved PVR volumes.

Denys et al., in a study of 47 consecutive male patients with DSD secondary to a spinal cord lesion, reviewed the efficacy of the Ultraflex urethral stent (Boston Scientific, Boston, MA, USA) [34]. The stent was inserted endoscopically under local, neuroleptic, or general anesthesia. Twenty-one patients (44.6%) with a history of recurrent symptomatic infections had significantly fewer UTIs postoperatively ($P=0.001$). Improvement in autonomic dysreflexia occurred in 5 of 8 stented patients, as well as an improvement in preoperative hydronephrosis in 7 of 8 patients ($P=0.005$).

Voiding function is also improved in DSD and spinal cord injury patients [35]. Patients who used an indwelling urinary catheter or intermittent catheterization for urinary drainage were able to void spontaneously into a condom catheter after stent placement. These results were also accompanied by a significant decrease in the occurrence of autonomic dysreflexia, symptomatic UTIs, and hydronephrosis. Hamid et al. evaluated the Memokath urethral stent, in 25 patients with DSD [36] with a mean age was 45.5 years (range, 32–65 years). Preoperatively, the majority of patients (80%) were draining their bladder using a reflex voiding with a condom drainage system, and the remaining patients used an indwelling suprapubic catheter or clean intermittent urethral self-catheterization. After stent insertion, the patients demonstrated a significant reduction in maximum detrusor pressure, duration of detrusor contraction, and residual urine volume. In fact, bladder function and urinary drainage improved to the point that preexisting hydronephrosis in 4 patients resolved.

Not all studies have found beneficial effects using urethral stents. Mehta et al. reviewed 29 patients with 33 Memokath stents who suffered from spinal cord injury patients and DSD [37]. These authors found the working life of the stent to be 21 months, with a high complication rate. Their overall experience with Memokath stents was disappointing, which has led them to abandon the use of this stent. Moreover, removal is necessary when there is extensive mucosal proliferation leading to lumenal obstruction [38]. Chronic infection and migration

have been other issues limiting the indwelling time of this stent in DSD patients [39].

Complications

The use of urethral stents in urology is not free of complications. Patients who require cystoscopy to treat and follow certain urological conditions such as urinary stone disease, transitional cell carcinoma, or any other problems that require recurrent endoscopic manipulations should be precluded from stent insertion with certain stent types. Urethral stents are a foreign body and may cause irritative urinary symptoms such as frequency, urgency, dysuria, or urge incontinence. Other potential complications include encrustation, stent fracture, migration, UTI, hematuria, and clot retention [2,35].

Stent positioning is important, and complications may occur when a stent is placed distal to the bulbous urethra, resulting in incontinence or pain while sitting or during intercourse [40]. Shah et al. reviewed the data related to the explantation of UroLume urethral stents in the North American Study Group, which included 465 patients [41]. A total of 73 stents (15.6%) were removed from 69 patients (14.8%). Characteristics of the patients that underwent stent removal were examined: the explantation rate was 23%, 5%, and 22% from patients with BPH, bulbar urethral stricture, and DSD, respectively. Thirty-two stents (44.4%) were removed during the first year after insertion, with stent migration being the primary reason in 38.4% of explantations. Other reasons for stent removal included worsening symptoms, stent encrustation, and incomplete luminal epithelialization.

Conclusions

There are several possible indications for urethral stent placement, including urethral stricture disease, BPH, and DSD. Much progress has been made during the last decade in the field of urethral stenting. Currently, one can choose an appropriate stent from a wide variety of temporary and permanent urethral stents. Although it is often not considered a definitive treatment, urethral stenting offers an alternative minimally invasive procedure to relieve the symptoms of bladder outlet obstruction in high surgical risk patients and as an alternative to open urethroplasty in select populations.

References

1. The American Heritage Dictionary of the English Language, edn (2006) Houghton Mifflin, Boston
2. Badlani GH (1997) Role of permanent stents. J Endourol 11:473–475

3. Slutzker D, Richter S, Lang R, Nissenkorn I (1994) The use of a prostatic stent in high risk patients over 80 years old with benign prostatic hyperplasia and chronic retention. J Am Geriatr Soc 42:1004–1005
4. Juma S, Niku SD, Brodak PP, Joseph AC (1994) Urolume urethral wallstent in the treatment of detrusor sphincter dyssynergia. Paraplegia 32:616–621
5. Soni BM, Vaidyanatham S, Krishnan KR (1994) Use of Memokath, a second generation urethral stent for relief of urinary retention in male spinal cord injured patients. Paraplegia 32:480–488
6. Kapoor R, Liatsikos EN, Badlani G (2000) Endoprostatic stents for management of benign prostatic hyperplasia. Curr Opin Urol 10:19–22
7. Ogiste JS, Cooper K, Kaplan SA (2003) Are stents still a useful therapy for benign prostatic hyperplasia? Curr Opin Urol 13:51–57
8. Lam JS, Volpe MA, Kaplan SA (2001) Use of prostatic stents for the treatment of benign prostatic hyperplasia in high-risk patients. Curr Urol Rep 2:277–284
9. Nagae H, Mugiya S (2002) Other less invasive surgical therapy for BPH (urethral stent). Nippon Rinsho 60 (suppl 11):408–412
10. Steenkamp JW, Heyns CF, de Kock ML (1997) Internal urethrotomy versus dilation as treatment for male urethral strictures: a prospective, randomized comparison. J Urol 157:98–101
11. Santucci RA, McAninch JW, Mario LA, Rajpurkar A, Chopra AK, Miller KS, Armenakas NA, Tieng EB, Morey AF (2004) Urethroplasty in patients older than 65 years: indications, results, outcomes and suggested treatment modifications. J Urol 172:201–203
12. Fitzpatrick JM, Mebust WK (2002) Minimally invasive and endoscopic management of benign prostatic hyperplasia. In: Walsh PC, Retik AB, Vaughan ED, Wein AJ (eds) Campbell's Urology, 8th edn. Saunders, Philadelphia, p 1381
13. Isotalo T, Nuutinen JP, Vaajanen A, Martikainen PM, Laurila M, Tormala P, Talja M, Tammela TL (2005) Biocompatibility and implantation properties of 2 differently braided, biodegradable, self-reinforced polylactic acid urethral stents: an experimental study in the rabbit. J Urol 174:2401–2404
14. Talja M, Valimaa T, Tammela T, Petas A, Tormala P (1997) Bioabsorbable and biodegradable stents in urology. J Endourol 11:391–397
15. Djavan B, Ghawidel K, Basharkhah A, Hruby S, Bursa B, Marberger M (1999) Temporary intraurethral prostatic bridge-catheter compared with neoadjuvant and adjuvant alpha-blockade to improve early results of high-energy transurethral microwave thermotherapy. Urology 54:73–80
16. Petas A, Talja M, Tammela TL, Taari K, Valimaa T, Tormala P (1997) The biodegradable self-reinforced poly-DL-lactic acid spiral stent compared with a suprapubic catheter in the treatment of post-operative urinary retention after visual laser ablation of the prostate. Br J Urol 80:439–443
17. Barber NJ, Roodhouse AJ, Rathenborg P, Nordling J, Ellis BW (2005) Ease of removal of thermo-expandable prostate stents. BJU Int 96:578–580
18. Zivan I, Stein A (2001) New modality for treatment of resistant anastomotic strictures after radical prostatectomy: UroLume urethral stent. J Endourol 15:869–871
19. Elliott DS, Boone TB (2001) Combined stent and artificial urinary sphincter for management of severe recurrent bladder neck contracture and stress incontinence after prostatectomy: a long-term evaluation. J Urol 165:413–415
20. Wilson TS, Lemack GE, Dmochowski RR (2002) UroLume stents: lessons learned. J Urol 167:2477–2480

21. Milroy EJ, Chapple CR, Cooper JE, Eldin A, Wallsten H, Seddon AM, Rowles PM (1988) A new treatment for urethral strictures. Lancet 1:1424–1427
22. Williams G, Jager R, McLoughlin J, el Din A, Machan L, Gill K, Asopa R, Adam A (1989) Use of stents for treating obstruction of urinary outflow in patients unfit for surgery. BMJ 298:1429
23. Shaw PJ, Milroy EJ, Timoney AG, el Din A, Mitchell N (1990) Permanent external striated sphincter stents in patients with spinal injuries. Br J Urol 66:297–302
24. Fabian KM (1980) The intra-prostatic "partial catheter" (urological spiral) (author's transl). Urologe A 19:236–238
25. Poulsen AL, Schou J, Ovesen H, Nordling J (1993) Memokath: a second generation of intraprostatic spirals. Br J Urol 72:331–334
26. Anjum MI, Chari R, Shetty A, Keen M, Palmer JH (1997) Long-term clinical results and quality of life after insertion of a self-expanding flexible endourethral prosthesis. Br J Urol 80:885–888
27. Masood S, Djaladat H, Kouriefs C, Keen M, Palmer JH (2004) The 12-year outcome analysis of an endourethral wallstent for treating benign prostatic hyperplasia. BJU Int 94:1271–1274
28. Milroy E, Chapple CR (1993) The UroLume stent in the management of benign prostatic hyperplasia. J Urol 150:1630–1635
29. Shah DK, Paul EM, Badlani GH (2003) 11-year outcome analysis of endourethral prosthesis for the treatment of recurrent bulbar urethral stricture. J Urol 170: 1255–1258
30. Badlani GH, Press SM, Defalco A, Oesterling JE, Smith AD (1995) Urolume endourethral prosthesis for the treatment of urethral stricture disease: long-term results of the North American Multicenter UroLume Trial. Urology 45:846–856
31. Tillem SM, Press SM, Badlani GH (1997) Use of multiple urolume endourethral prostheses in complex bulbar urethral strictures. J Urol 157:1665–1668
32. Chancellor MB, Bennett C, Simoneau AR, Finocchiaro MV, Kline C, Bennett JK, Foote JE, Green BG, Martin SH, Killoran RW, Crewalk JA, Rivas DA (1999) Sphincteric stent versus external sphincterotomy in spinal cord injured men: prospective randomized multicenter trial. J Urol 161:1893–1898
33. Shah NC, Foley SJ, Edhem I, Shah PJ (1997) Use of Memokath temporary urethral stent in treatment of detrusor-sphincter dyssynergia. J Endourol 11:485–488
34. Denys P, Thiry-Escudie I, Ayoub N, Even-Schneider A, Benyahya S, Chartier-Kastler E (2004) Urethral stent for the treatment of detrusor-sphincter dyssynergia: evaluation of the clinical, urodynamic, endoscopic and radiological efficacy after more than 1 year. J Urol 172:605–607
35. Juan Garcia FJ, Salvador S, Montoto A, Lion S, Balvis B, Rodriguez A, Fernandez M, Sanchez J (1999) Intraurethral stent prosthesis in spinal cord injured patients with sphincter dyssynergia. Spinal Cord 37:54–57
36. Hamid R, Arya M, Wood S, Patel HR, Shah PJ (2003) The use of the Memokath stent in the treatment of detrusor sphincter dyssynergia in spinal cord injury patients: a single-centre seven-year experience. Eur Urol 43:539–543
37. Mehta SS, Tophill PR (2006) Memokath stents for the treatment of detrusor sphincter dyssynergia (DSD) in men with spinal cord injury: The Princess Royal Spinal Injuries Unit 10-year experience. Spinal Cord 44(1):1–6
38. Vaidyanathan S, Soni BM, Oo T, Sett P, Hughes PL, Singh G (2002) Long-term result of Memokath urethral sphincter stent in spinal cord injury patients. BMC Urol 2:12

39. Low AI, McRae PJ (1998) Use of the Memokath for detrusor-sphincter dyssynergia after spinal cord injury—a cautionary tale. Spinal Cord 36:39–44
40. Chapman SM, Wemyss-Holden GD, Clarke NW (1994) Urinary incontinence following urethral Wallstent insertion. Br J Urol 73:586
41. Shah DK, Kapoor R, Badlani GH (2003) Experience with urethral stent explantation. J Urol 169:1398–1400

Index