Review

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Update on Flexible Ureteroscopy

Key Words
Endourology · Laser · Ureteral stent · Ureteral stone · Ureteroscopy

Abstract
Objective: An update on ureteroscopy with focus on current technology and newer instrumentation is presented. ***Methods:*** A literature search through Medline-indexed journals as well as personal comments are included in this review. Topics such as new semirigid and flexible ureteroscopes, lasers, ureteral access sheats, wires and stone extraction devices are outlined. ***Results:*** Thanks to the continuous advances of technology and miniaturization of instruments, ureteroscopy is an ever-expanding field. A clear outline of the available instruments and techniques with reference to published results catches the status of this dynamic field. ***Conclusions:*** Urologists are faced with a host of new products related to ureteroscopy every year. This review serves to identify the most useful and proven advances in the field and helps in selecting the equipment needed for a successful minimally invasive approach to upper urinary tract pathologies.
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Introduction

Ureteroscopy has become the treatment of choice for a growing number of urological conditions. Ureteroscopy is still a relatively new procedure that continues to undergo significant advancements. Technological improvements in urologic instrumentation have advanced through the cooperation of engineers and surgeons. These are most evident within the area of ureteroscopy, medical lasers, and miniaturized working instruments. These improvements have expanded the possibilities to diagnose and treat a number of abnormal conditions in the upper urinary tract. This update will describe the most recent advances in ureteroscopic instrumentation.

History

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

Marshall [2] in 1964 and later Takagi et al. [3] and Bush et al. [4] reported the first flexible ureteroscopic procedures which actually predated the first reports of routine rigid ureteroscopy. These early experimental flexible ureteroscopes could be used for visualization of the upper urinary tract but had no integrated deflecting mechanism or working channel. Although they could be used diagnostically, little could be done therapeutically with these endoscopes. Because of these limitations, as well as

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the introduction of shock-wave lithotripsy, flexible ureteroscopy for the treatment of stones was not widely utilized until much later.

Ureteroscopic treatment of renal calculi could not be possible without the recent evolution in flexible ureteroscopes. Current flexible ureteroscopes allow access to the entire intrarenal collecting system in 94–100% of patients [5, 6]. Likewise, an efficient means of destroying the stone once reached is necessary. Although electrohydraulic lithotripsy could be used in the past, the introduction of the holmium:YAG laser for use as an intraluminal lithotripsy device in the early 1990s greatly improved the precision and effectiveness of ureteroscopic lithotripsy [7–10].

Flexible Ureteroscopes

The basic components of flexible ureteroscopes include the optical system, deflection mechanism, and working channel. The optical system consists of the flexible fiberoptic image and light bundles. These fiberoptic bundles are created from molten glass that has been pulled into small diameter fibers. 'Cladding' each fiber of glass with a second layer of glass of a different refractive index improves the internal reflection and light transmission. This cladding also improves the durability of the image bundles. The mesh-like appearance of the image from flexible ureteroscopes is due to the lack of light transmission through this cladding. These fibers uniformly transmit light from one end of the fiber to the other proportional to the light input. When the fibers are bundled randomly, such as those within the light bundle, they provide excellent light transmission for illumination, but no image. When the fibers are bundled with identical fiber orientation at each end (i.e., coherent), the light from each fiber within the bundle will coalesce to transmit images. Small lenses attached to the proximal and distal ends of the image bundle create a telescope with image magnification, increased field of view, and focusing ability. Improvements in image bundle construction have allowed closer packing of more fibers, resulting in improved images, smaller outer diameters, and larger working channels in both rigid and flexible ureteroscopes. Another recent design modification of the light bundle is the splitting of this bundle distally into more than one point of light transmission. This permits a more centrally placed working channel as well as better distribution of the light within the working field of view [11].

The deflection mechanism of flexible ureteroscopes permits complete maneuverability within the intrarenal collecting system. Most deflecting mechanisms consist of control wires running down the length of the ureteroscope attached on the proximal end to a manually operated lever mechanism. Distally the wires run through moveable metal rings to the distal tip where they are fixed. Moving the lever up or down will pull the control wire and move the tip. When the tip moves in the same direction as the lever, the deflection is said to be 'intuitive' (i.e., down is down and up is up). Modern flexible ureteroscopes allow both up and down deflection in a single plane. This plane of deflection is marked by the reticle seen as a notch within the field of view of the ureteroscope. Modern flexible ureteroscopes permit down deflection of approximately 180°. A study investigating the angle between the major axis of the ureter and the lower pole infundibula (ureteroinfundibular angle) in 30 patients reported the average angle to be 140° with a maximum of 175° [12]. Active deflection of the ureteroscope of 180° should allow visualization of the lower pole in most patients. However, reaching into the lower pole calyx with the tip of the ureteroscope can still be difficult. The secondary, passive deflection mechanism permits this. All flexible ureteroscopes have a more flexible segment of the ureteroscope due to a weakness in the durometer of the sheath, located just proximal to the point of active deflection. The ability to engage the passive secondary deflection depends upon the ability to passively bend this portion of the ureteroscope off of the superior portion of the renal pelvis. This can be difficult or impossible in patients with significant hydronephrosis. Additionally, once the tip of the ureteroscope has been extended into the lower pole calyx, the ability to manipulate working instruments and work within the calyx, using active primary deflection, can be challenging.

Two new innovations to the standard deflecting mechanism address this problem. The DUR-8 Elite (Gyrus ACMI, Stamford, Conn., USA) is the first flexible ureteroscope to incorporate active secondary deflection [13]. In addition to the active primary deflection (185° down, 175° up) the secondary deflection is now active, 165° down. It is controlled with an additional lever opposite the existing primary deflection lever and can be locked in place. Secondary deflection is not dependent upon passive manipulation of the scope off of the upper portion of the renal pelvis. The degree of secondary deflection is not dependent upon the position of the scope or how hard you advance the scope but is controlled with the deflecting lever. Severe hydronephrosis will not prevent the use

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Table 1. Characteristics of the currently available flexible ureteroscopes

Characteristics	Gyrus ACMI			Olympus	Karl Storz	Richard Wolf		
	DUR-D (digital)	DUR-8	DUR-8 Elite	URF-P5	Flex-X2	7330 0.072	7325 0.172	7325 0.071
Tip diameter, Fr	8.7	6.75	6.75	5.3	7.5		6.8	6.0
Shaft diameter, Fr	9.3	8.6	8.6	8.4	8.4	9.0	7.5	8.8
Working length, cm	65	65	65	70	70	70	70	68
Channel size, Fr	3.6	3.6	3.6	3.6	3.6	4.5	3.6	3.6
Active deflection up, °	250	175	175	180	270	130	130	270
Active deflection down, °	250	185	185	275	270	160	160	270
Active secondary deflection, °	0	0	165	0	0	0	0	0
Angle of view, °	9	12	12	0	6	0	0	0
Field of view, °	80	80 ± 5	80 ± 5	90	90	65	65	65
Depth of field, mm		2–40	2–40	2–50	2–50	2–40	2–40	2–40
Magnification	Zoom capabilities	30 ×	30 ×	52 ×	40 ×	50 ×	50 ×	50 ×

of secondary deflection. Locking the secondary deflection in place can simplify manipulation of the primary deflection within the lower pole calyx. The usefulness of this active secondary deflection of the DUR-8 Elite has been evaluated by Ankem et al. [14]. In a series of 54 patients, they found the dual deflecting DUR-8 Elite ureteroscope helpful in cases in which the single deflection-flexible instruments fail to access and treat upper urinary tract pathology.

Karl Storz Endoscopy (Tuttlingen, Germany) has introduced 'exaggerated deflection' with their Flex-X model flexible ureteroscope [15]. This modification of the deflection mechanism permits active primary deflection to >300°. When approaching the lower pole calyx, the tip will extend out as it is deflected against the lower pole infundibulum. This improvement of the deflection mechanism results in easier lower pole access and improved deflection when using working instruments.

Hudson et al. [16] investigated the effect of the diameter of the flexible ureteroscope on its successful passage up an undilated ureter. This was a retrospective series of 115 consecutive patients at two different institutions. Flexible ureteroscopes from several different manufacturers and with different shaft diameters were used for ureteroscopy in adults. An initial attempt was made to pass one of the larger diameter flexible ureteroscopes; if this was unsuccessful, the smaller 7.5-Fr flexible ureteroscope was used. These authors found that the ability to pass the flexible ureteroscope with no formal dilatation was directly related to the flexible ureteroscope diameter. The rate of failing to pass with no formal dilatation was 37% for the 9.0-Fr, 8.5% for the 8.6-Fr, 5% for the 8.4-Fr and 0.9% for the 7.4-Fr ureteroscope. Based on this study, the ability to pass flexible ureteroscopes is directly related to their outer diameter. When only the ease of introduction is considered, the ideal ureteroscope outer diameter is 7.4 Fr.

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

Durability

The miniaturization of flexible ureteroscopes has significantly enhanced their effectiveness. Due to the high cost of purchase and repair, and the broadening of indications for flexible ureteroscopy, the durability of these fragile instruments has become a major issue. One of the most common causes of flexible ureteroscopes failure is damage to the working channel by working devices. Seto et al. [17] developed an experimental model to study the physical damage to the working channel of flexible ureteroscopes caused by insertion of various accessories. They found that insertion of 3-Fr biopsy forceps or a 2.4-Fr nitinol (nickel-titanium) stone-retrieval device caused only slight damage to the model channel, even when the deflection angle was 120°. However, the tips of 200- or 250-μm holmium laser fibers shaved the inner surface of the channel at 60° of deflection. At 120° of deflection, the

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laser fiber either penetrated the channel or could not be advanced because of resistance by the channel wall. When the laser fiber was inserted within a protective tube, the channel was never damaged, even when the deflection angle was 120°. These authors concluded that when devices are inserted into the working channel of a flexible ureteroscope, damage to the wall depends on the kind of device and deflection angle and that harm could be avoided by inserting the devices, especially laser probes, within a protective tube. This problem can effectively be avoided by simply insuring the ureteroscope is straight (on the fluoroscopic image) prior to insertion of the laser fiber.

Several groups have evaluated and compared the durability of the initial generation of smaller diameter – less than 9 Fr – ureteroscopes. Bratslavsky and Moran [18] presented data on the Wolf (Vernon Hills, Ill., USA) 7325.17 and Storz 11274AA, and found they needed repair after an average of 12 procedures. Afane et al. [19] prospectively evaluated four devices less than 9 Fr, including the Storz 11274AA, the Circon ACMI AUR-7, the Olympus (Lake Success, N.Y., USA) URF-P3 and the Wolf 7325.172. They found that these ureteroscopes needed repair after 6–15 cases, that is after 3–12.8 h of use.

The latest generation of flexible ureteroscopes seems to be more durable than previous generations. Traxer et al. [20] performed 50 flexible ureteroscopies using the Karl Storz Flex-X ureteroscope. Postoperatively, they evaluated the maximal active ventral and dorsal deflection, irrigation flow at 100 cm H_2O, and the number of broken optical fibers. The maximal ventral deflection deteriorated from 270° initially to 208° following the last procedure. The maximal dorsal deflection similarly decreased from 270 to 133°. The irrigation flow at 100 cm H_2O decreased from 50 ml/min initially to 40 ml/min following the last procedure. One repair was necessary at the 50th procedure because of a laser perforation of the working channel. These authors concluded that the need for repair occurred less frequently with the new generation of ureteroscopes, especially when they are used by an experienced endourologist.

In 2001, ACMI released the DUR-8, a ureteroscope less than 9 Fr designed for improved durability. Specific modifications to the DUR-8 included a larger shaft tapering from 8.7 to 10.1 Fr, patented nitinol shaft construction to provide durability and torque stability, and a patented cable compensation system to prevent cable breakage. Monga et al. [21] reported that the DUR-8 required major repair after 25 procedures. A randomized, prospective, multi-institutional evaluation of ureteroscope durability, including ureteroscopes that had not previously been analyzed for durability (ACMI DUR-8 Elite and Storz Flex-X) found that currently available flexible ureteroscopes require repair after only 3–14 cases or 105–494 min of use. Accordingly, the fragile nature of these endoscopes results in a significant financial commitment on the part of the hospital for both repairs and the need to purchase and maintain 2 or 3 backup ureteroscopes. Substantial differences in durability among the different makes and models available for purchase were noted. The DUR-8 Elite and URF-P3 models demonstrated improved durability. The URF-P3 also proved to be durable, particularly when surrogate measures of complexity of the procedure were considered, such as minutes of use in the lower pole and minutes of use with an instrument in the working channel.

Digital Ureteroscopes

Recently, rigid (Olympus) and flexible (Gyrus ACMI) digital ureteroscopes have been developed and released. These ureteroscopes integrate the endoscope, the digital camera and the light source. This obviates the need for a separate camera head since the scope has a digital camera chip (CCD or CMOS) mounted on the tip of the ureteroscope. Since these devices do not require a separate light cord or camera head, there is a potentially prolonged lifespan. These 'digital' ureteroscopes may help miniaturization, optimize digital resolution, and improve durability. We anticipate further refinements in this technology, and it will likely become routine in future ureteroscopes.

Holmium Laser

The holmium laser has dramatically improved intraluminal lithotripsy and has become the intraluminal lithotripsy energy of choice for most urologists. It has a wavelength of 2,100 nm, which is absorbed in 3 mm of water and 0.4 mm of tissue, making it very safe for use in urology. Fragmentation of calculi is produced by a photothermal reaction with the crystalline matrix of calculi. By not relying upon shock-wave generation for stone fragmentation, the photothermal reaction produces stone dust rather than fragments, effectively removing a moderate volume of the stone. The flexible quartz fibers can be used with both rigid and flexible ureteroscopes, and are reusable. These fibers are available in various sizes. The smallest fiber has a diameter of 200 μm, and will limit the deflection of the ureteroscope less than the larger fibers.

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The holmium laser will fragment any composition of calculi [10].

In a recent study comparing it with Lithoclast (Boston Scientific, Natick, Mass., USA) lithotripsy, holmium:YAG lithotripsy was associated with shorter operation time and postoperative hospitalization period [22]. These data also suggest that holmium:YAG lithotripsy was safe and more effective than Lithoclast lithotripsy in the aspect of immediate stone-free rate.

Other laser energy sources have recently been investigated for intraluminal lithotripsy. The frequency-doubled double-pulse neodymium:YAG (FREDDY) laser has been developed for endoscopic lithotripsy and combines the characteristics of solid and dye lasers with a thin flexible optical fiber, enabling it to be used with flexible ureterorenoscopy. It is reportedly less expensive and easier to maintain than other lasers. Recently, Dubosq et al. [23] evaluated its efficacy and role in the ureteroscopic treatment of urinary stones. At 3 months, 69% of the patients were stone-free, and 72.4% of the stones had been treated completely. Although it is an effective lithotripsy energy for most calculi, its limited ability to fragment calcium oxalate monohydrate, ineffectiveness for cystine stones, and inability to incise or ablate tissue, make this laser less attractive than the holmium.

Stone Retrieval Devices

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

Important basket properties for stone extraction include the ability to open with enough radial force in the ureter, and to capture, retain, or (if necessary) disengage a stone. Stone baskets are available in the usual helical and flat-wire designs. Helical baskets are most useful when used in the ureter where they are opened above the stone and pulled down and rotated to engage the stone. The helical design is not particularly useful when working within the intrarenal collecting system. Perhaps the most useful basket design for use with the flexible ureteroscope is the tipless, nickel-titanium (Nitinol) basket. The soft Nitinol wires have memory, and resist kinking, and therefore open safely and reliably. These baskets are particularly useful for percutaneous applications, but because they may permit safer disengagement of larger calculi, can also be used within the intrarenal collecting system through the flexible ureteroscope. During ureteroscopic stone basket extraction, stones that are too large to withdraw or release may be entrapped. The 1.9-Fr Escape stone basket (Microvasive/Boston Scientific) has a unique cage design that transforms from 4 wires (11 mm) at its base to 2 wires (15 mm) to assist in freeing stones. The Dimension stone basket (Bard Urology, Covington, Ga., USA) can be articulated by turning a wheel on the handle, resulting in an increase in basket size on one side, which improves the ability to release a stone [24]. Another recent innovation in basket design is the ability to rotate the entrapped stone during lithotripsy. The novel 1.5-Fr Halo tipless basket (Sacred Heart Medical, Minnetonka, Minn., USA) allows rotation of an engaged stone via a rotary wheel on the basket handle. The small size of the Halo basket allows passage of a 200-μm laser fiber alongside it, permitting simultaneous laser lithotripsy and stone rotation. Average irrigant flow rates with and without a laser fiber were significantly higher with the Halo 1.5-Fr basket than with the 1.9-Fr ZeroTip basket (Boston Scientific) or the 3-Fr Laser Flat-Wire Stone Extractor (Cook Urological, Spencer, Ind., USA) [25]. It is important to emphasize that stone capture with subsequent laser lithotripsy should be considered the exception. Usually, laser lithotripsy prior to stone capture is advocated as a safer approach.

Ureteroscopic lithotripsy of proximal ureteral calculi can be complicated by stone migration into the renal pelvis and calices. An instrument that can prevent this migration, functioning as a 'backstop', may be an important tool in the ureteroscopic armamentarium [26]. Several studies sought to assess the role of just such an instrument, the Stone Cone (Boston Scientific), in proximal-ureteral lithotripsy. This device consists of a nitinol wire configured into expandable tapered cone, which is deployed cephalad to the stone. After the initial report by Dretler et al. [31] who treated the first 25 patients with no stone migration and 100% success rate, Maislos et al. [26] treated 19 consecutive patients with proximal ureteral stones using semirigid ureteroscopy, a Stone Cone, and holmium:YAG laser lithotripsy [17, 18]. No migration and successful fragmentation in all cases was reported. Similar findings were reported in 23 patients by Gonen et al. [27] using pneumatic lithotripsy instead of the laser. In an

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Table 2. Ureteral access sheaths

Name (manufacturer)	Dilator/sheath, Fr	Lengths, cm	Unique features
Navigator™ (Boston Scientific)	11/13; 13/15	28; 36; 46	
Forte™ (Applied)	10/12–16; 12/14–18; 14/16–18	20; 28; 35; 55	
Forte Plus™ (Applied)	10/14–18	35; 55	Active deflecting mechanism
AquaGuide™ (Bard)	10/12–14; 11/13–15	25; 35; 45; 55	Dual lumen design
Flexor™ (Cook)	9.5/11; 12/13.7; 14/16	13; 20; 28; 35; 45; 55	
Flexor™ DL (Cook)	9.5/14; 12/16.7	13; 20; 28; 35; 45; 55	Dual lumen design

interesting ex vivo study, Holley et al. [28] compared the Stone Cone with a new occlusion device built by Cook Urological, the Ntrap. The Ntrap was successful at preventing retrograde migration of beads ≥1.5 mm within the experimental ureter. The Stone Cone blocked the retrograde migration of beads ≥2.5 mm. In our experience, these backstop devices may be useful in the ureter, but are space consuming, and are in general unnecessary as stones that migrate can be easily treated within the kidney where they can be immobilized within a calyx.

Ureteral Access Sheaths

Several companies have developed ureteral access sheaths to facilitate repeated ureteroscopic access to the intrarenal collecting system. These 12- to 14-Fr sheaths allow repeated passage of the ureteroscope without requiring passage of the ureteroscope over a guidewire. Several commonly used sheaths are the Flexor (Cook Urological), the Access Forté XE (Applied Medical, Rancho Santa Margarita, Calif., USA), the Navigator (Boston Scientific), and the AquaGuide (Bard Urology). The primary disadvantage is related to their size and the (small) potential for ureteral injury [21, 22]. Ureteral access sheaths are useful when multiple fragments of stone require ureteroscopic removal.

A prospective, randomized comparison of the 12F/14F Flexor and the 12F/15F Access Forté XE demonstrated that the Flexor sheath was easier to use and had a 0% failure rate (vs. 44% for the Access Forté XE) [29]. In vitro studies have demonstrated that the Flexor and the UroPass (Gyrus ACMI) have the largest inner diameters in the most common bending positions (straight and 30° bend) and are the most resistant to buckling during insertion [30]. The Aquaguide sheath (Bard Urology) and the Cook Flexor DL are available with a built-in second channel that permits irrigation of small fragments of stone out of the kidney during the procedure. This can improve visibility and may facilitate treatment of larger stone burdens within the kidney. The majority of stones treated within the upper urinary tract will require only a single passage of the ureteroscope to access and fully fragment the stone. For these cases, an access sheath is usually unnecessary. The characteristics of currently available ureteral access sheaths are presented in table 2.

Wires

Guidewires are essential in acquiring, facilitating, and maintaining access to the upper urinary tract. Several new wires are worthy of mention. The UroWIRE XF (Applied Medical) and the Sensor wire (Boston Scientific) each incorporate three segments: a smooth, hydrophilic distal tip for bypassing impacted ureteral stones, a kink-resistant body (nitinol alloy core, PTFE coating), and a flexible proximal tip for backloading of the wire through the working channel of the ureteroscope. The Bi-Wire (Cook Urological) is a nitinol wire with the advantages of both a straight tip on one end and an angled tip on the other. No clinical studies evaluating these new wires have been published.

Conclusions

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

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