

Advances in ureteroscopy

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Abstract: Ureteroscopy (URS) is a procedure which has been constantly evolving since the development of first generation devices 40 years ago. Progress towards smaller and more sophisticated equipment has been particularly rapid in the last decade. We review the significant steps that have been made toward improving outcomes and limiting morbidity with this procedure which is central to the management of urolithiasis and other upper urinary tract pathology.

Keywords: Ureteroscopy (URS); laser; urinary calculi; digital imaging

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Introduction

Ureteroscopy (URS) is a well-established diagnostic and therapeutic modality in urological practice. Advances in technology and surgical techniques have broadened the range of urologic conditions that can be addressed by URS including: renal and ureteric calculi, urothelial carcinoma (UC) and ureteral strictures. The use of URS for the treatment of stones is increasing relative to shockwave lithotripsy (SWL) (1). In this article we aim to summarise the pertinent developments in the field of URS.

Discussion

Ureteroscopes can be classified as rigid, semi-rigid, or flexible. Rigid ureteroscopes use a non-flexible optical lens system. The most significant advance in the field of endourology is the recent development of flexible ureteroscopes. These scopes are smaller than their rigid and semi-rigid counterparts and have increased capability for deflection and instrumentation. Semi-rigid ureteroscopes are usually housed in a pliable metallic sheath, whereas flexible ureteroscopes do not have a rigid outer layer. This manoeuvrability allows instrumentation of the entire urinary tract including upper ureters and pelvic calyces. Development of instrumentation has included the addition of working channels, narrower shaft diameters, greater

distal tip active deflection and secondary deflection (2).

Flexible ureteroscopes

Fibre-optic flexible ureteroscopes were primarily developed due to concerns with the rigid ureteroscope causing damage to the urothelium when accessing the upper ureter.

The deflection capacity (flexion of the tip from a straight to an angled position) in digital ureteroscopes varies in each model (*Table 1*). Primary deflection is the initial degree of deflection achieved from a neutral straight position of the scope tip, whereby secondary deflection is a further degree of deflection in relation to an already curved or 'flexed' ureteroscope tip. Secondary deflection is necessary in up to 29% of cases, particular lower pole calculi (3). The DUR[®]-8 Elite ureteroscope (Gyrus ACMI, USA) is the only model that offers secondary deflection. Secondary deflection of 130° up or down allows the surgeon to achieve a total deflection angle up to 270° (4). The wide range of deflection capabilities and 'S' shape allows an experienced urologist to access virtually any area of the intrarenal collecting system (5).

Other ureteroscope advances include a laser-resistant chip composed of a proprietary Laserite[™] (5), minimization of distal tip [<6 francium (Fr)] and a tapered 'evolution' tip to facilitate ureteral cannulation, as seen in the Olympus URF-P5 flexible ureteroscope (Olympus, USA). Some limitations of fibre-optic based ureteroscopes include:

Table 1 Currently available flexible ureteroscope models

Model	Manufacturer, country	Optical/digital	Tip diameter (Fr)	Proximal shaft diameter (Fr)	Primary deflection up/down (degrees)	Instrument channel diameter (Fr)	Special features
DUR-8 Elite	Gyrus ACMI, USA	Optical	8.7	9.3	170/180	3.6	Secondary deflection
URF-P5	Olympus, Japan	Optical	5.3		180/275	3.6	Evolution tip
Flexvision U500	Stryker, USA	Optical	6.9		275/275	3.6	
Invisio DUR-D	Gyrus ACMI, USA	Digital	8.7		250/250	3.6	
Viper	Wolf, Germany	Optical	6.0	8.8	270/270	3.6	
Flex-X2	Karl Storz, Germany	Optical	7.5		270/270	3.6	Photodynamic diagnosis enabled
DUR-8 Ultra	Olympus	Optical	8.6		270/270	3.6	
Flex-Xc	Karl Storz, Germany	Digital	8.5		270/270	3.6	
URF-V	Olympus, Japan	Digital	8.5		180/275	3.6	NBI enabled
Cobra	Richard Wolf, Germany	Optical	6.0	9.9	270/270	3.3*	*Two instrument channels
11274AA	Karl Storz, Germany	Optical	7.5	8.7	170/120	3.6	

Fr, francium; NBI, narrow-band imaging. *, refers to the quoted Fr gauge 3.3 for a 'dual channel' configuration-the Cobra ureteroscope has 2 separate channels each of size 3.3 Fr.

damage to optic fibres leading to reduced image quality, overall 'grainy' picture and potential water infiltration onto optical lens.

Digital imaging

The recent development of digital ureteroscopic imaging has led to higher quality ureteric and renal pelvis imaging compared to traditional fibre-optic ureteroscopes (4). Digital ureteroscopes transmit images from a digital sensor on the tip to a proximal point via a single wire, with processing occurring at a proximal sensor. This new generation of "chip on the tip" digital ureteroscopes avoid the use of fibre-optics for the transmission of images. Light can be provided from a distal LED source or transmitted via the scope from a proximal source. Digital ureteroscopes offer high-definition imaging, autofocus capabilities and digital magnification. As a result the moiré (honeycomb) effect is eliminated with digital scopes, overall improved image quality and up to 2.5 times larger image on a standard monitor compared to fibre-optic ureteroscopes (6). Digital video URS eliminates the need to attach a camera allowing for less cables, quicker set-up and less weight, which is advantageous in long cases (5).

The first digital ureteroscope was the Invisio® DUR®-D (Olympus) which was introduced in 2006. All digital

ureteroscopes currently available are summarised in *Table 1*. Although the new digital technology is more expensive than the traditional fibre-optics, they have been reported to be more durable and require less frequent repairs (7). In addition, the elimination of the need for fibre-optics allows for larger working channels in these new digital ureteroscopes (8). However, these all-in-one digital scopes are often larger than fibre-optic scopes (9). A randomised control trial (RCT) by Bach *et al.* (10) compared the Invisio® DUR®-D (Gyrus ACMI, USA) digital scope to the DUR®-8 Elite (Gyrus ACMI, USA) fibre-optic flexible ureteroscope and the use of ureteral access sheaths. The use of ureteral access sheaths was significantly higher ($P < 0.005$) for the digital scope DUR®-D (25%) compared to the fibre-optic DUR®-8 (7.5%). This study quoted differing sizes compared to the manufacturer brochure: 6.75 instead of 8.7 Fr and 8.7 instead of 9.3 Fr for the DUR®-8 and DUR®-D scopes respectively (11).

Shah *et al.* (12) compared the Invisio® DUR®-D to the URF-V (Olympus, Japan) digital ureteroscope in a prospective RCT. Overall the URF-V scope offered better maneuverability. A smaller fibre-optic ureteroscope was required in 11% and 7% of cases for the URF-V and DUR®-D scopes respectively. Multescu *et al.* (13) compared the URF-V digital to the Storz 11274AA fibre-optic flexible ureteroscope in 44 diagnostic retrograde procedures.

The URF-V digital ureteroscope displayed superior maneuverability, durability and visibility.

Advanced imaging

Endourology has seen a number of technical advances in imaging to aid with the diagnosis of upper tract UC. Conventional white-light imaging is sufficient for the diagnosis of medium to large upper tract UC lesions however, visualising smaller lesions can be difficult. Narrow-band imaging (NBI) and photodynamic diagnosis (PDD) are imaging advances that aid in the diagnosis of upper tract UC.

NBI is an optical image enhancement technique which filters white light into two narrow bandwidths, 415 nm (blue) and 540 nm (green), which are strongly absorbed by haemoglobin. This enhances the contrast between mucosal surfaces and micro-vascular structures in real-time, without the use of dyes (14). In the presence of UC, which is highly vascular in nature, NBI increases the colour contrast between superficial tumours and normal mucosa. Currently the only scope with NBI capability is the URF-V (Olympus, Japan) digital ureteroscope and has been shown to improve tumour detection rates by 23% compared to white-light imaging (15).

PDD is an optical enhancement for URS utilising fluorescence, which enhances the contrast between benign and malignant tissue. The urinary tract tissues is photosensitised by the administration of an agent either delta-aminolevulinic acid (ALA) or its derivative, hexaminolevulinate (HAL, Hexvix). These prodrugs initiate a series of biochemical reactions that results in an end-product (photoactive porphyrins) that accumulates and emits red fluorescence (693 nm) in malignant tissues in the presence of blue light (380-470 nm) (14,16). Normal bladder mucosa appears blue-green allowing the surgeon to identify potentially malignant tissue. A prospective pilot study for detecting upper tract UC using PDD and the administration oral 5-ALA supported it as a feasible and useful technique with additional advantages of detecting lesions not seen on conventional white-light URS (17).

Guidewires and ureteral access sheaths

Alongside a wide variety of endoscopic instruments that have been introduced to treat renal stones, there are many different guidewires commercially available. In essence the guidewire remains a useful tool in navigating past an impacted calculus and maintaining a "safety-line" to the renal pelvis during URS. Despite debate about the necessity

of this safety technique (18,19) the general consensus is that a safety guidewire should be still used in all cases (8).

There are many different guidewires with differing properties that gives each one their own unique advantages. The Glidewire[®] by Boston Scientific (USA) aka a 'slippery' guidewire is extremely flexible and therefore relatively atraumatic but often has a tendency to bend if faced with an obstruction (9). The Amplatz Super Stiff[™] guidewire (Boston Scientific, USA) is more resistant to bending and can be used to pass instruments successfully (20).

A development in this field is the introduction and adoption of hybrid guidewires that offer both the flexibility of a hydrophilic wire at the tip and a stiff body to maintain rigidity (9). Two examples of hybrid wires currently on the market include the Sensor[™] (Boston Scientific, USA) and U-Nite[™] (Bard Medical, USA) wires. A systematic evaluation by Sarkissian and colleagues (21) concluded that the Sensor[™] wire has a greater friction force and should be the choice for a safety wire amongst hybrid wires. The hydrophilic tip of the Sensor[™] wire is more flexible compared to the U-Nite[™] and is likely a better choice for bypassing an obstructing ureteric calculus. The rounder tip of the U-Nite[™] wire is less likely to cause ureteral mucosal tunnelling (9).

The use of ureteral access sheaths in URS allow for lower irrigation pressures and therefore reduced ureter rupture risk, reduced operating time and improved scope longevity (22). Digital ureteroscopes often require the use of a ureteric access sheath. Ng *et al.* (23) found that the size of ureteric access sheaths (10 to 16 Fr) had minimal impact on irrigation flow whilst the working channel was occupied. They also demonstrated that better flow dynamics could be achieved by using a concurrent ureteral access catheter (4 or 5 Fr) alongside a normal ureteral access sheath purely for irrigation inflow.

Two studies favour the 12/14 Fr Cook Flexor[®] access sheath (Cook Urological, USA) with regards to placement, instrument passage, stone extraction, a low failure rate and less propensity to buckle whilst in situ (24,25).

Intracorporeal lithotripsy

In current practice lasers are the most popular devices for intracorporeal lithotripsy. Other lithotripters that are available include electrohydraulic (EHL), pneumatic and ultrasonic. The Holmium: yttrium-aluminium-garnet (YAG) is the gold-standard for laser lithotripsy during URS, which is effective against all stone composites and produces smaller fragment sizes (26). This laser energy

has superior complication and stone-free rates compared to EHL or pneumatic lithotripsy (9). Results from several studies using the Holmium: YAG laser reported stone-free rates for ureteric stones (upper, mid and distal) ranged from 89-100% and 77-99% in the kidney (27-30). A meta-analysis by Aboumarzouk *et al.* (31) looked at stones >2 cm treated by flexible URS and laser lithotripsy and this technique was effective for large stones. This technique had a stone-free rate of 96% from stones 2-3 cm and 85% for those >3 cm, with a minor complication rate of 14% and 15% respectively. Major complication rate was 11.5% for stones >3 cm with no major complications for stones 2-3 cm.

Laser lithotripsy requires a laser fibre through a working channel on a rigid or flexible ureteroscope. The size and type (single versus reusable) of fibre can affect deflection capabilities, irrigation flow and potential for scope damage (8). The sizes of laser fibres vary from small (150 to 300 μm) to medium (300 to 400 μm). In general, a smaller fibre is more flexible and less traumatic to scopes, but have more degradation and are slower at defragmenting compared to larger fibres (9). It is estimated that a Holmium: YAG laser fibre of 365 μm can cause a loss in deflection of 24° to 45°, and for a 200 μm fibre this loss is smaller at around 9° to 19° (32). It is generally recommended that a medium to large fibre ($\geq 300 \mu\text{m}$) is reserved when using a rigid ureteroscope and during flexible URS a smaller fibre ($\leq 200 \mu\text{m}$) is used to preserve scope deflection and therefore access to upper tracts (32,33).

One limitation of lasers is the potential for ureteroscope damage from the introduction of the laser fibre, particularly in a deflected scope, or activation of the laser whilst the tip is within the working channel. There are a few products that aim to prevent scope damage during laser lithotripsy that include: endoscope protection system (EPS) (Gyrus ACMI, USA, Massachusetts), Flexguard™ (Lisa Laser Products, Germany) and the TracTip fibre (Boston Scientific, USA). The EPS is available with the DUR®-D flexible ureteroscope and immediately terminates the Holmium: YAG laser energy upon the fibre being retracted into the ureteroscope (9). This device is successful *in vitro* but *in vivo* results of successful laser termination rates range from 50% to 100% (34,35), therefore further studies and evaluation is needed to evaluate the efficacy of EPS. Flexguard™ is a protective laser sheath with mixed results showing that it offers protection to ureteroscopes from laser fibre damage after 40 to 50 uses but led to a loss in deflection capability (36). The TracTip fibre is small (200 μm) and round tipped therefore can be advanced even during scope deflection.

Instruments for stone retrieval

Baskets ideally should be durable, flexible, easily deployed, atraumatic and have low resistance properties in order to preserve adequate irrigation flow during URS. There are several baskets on the market, with the newer, often smaller (<1.5 Fr) nitinol (nickel titanium) baskets replacing stainless steel (9). This new metal alloy allows for increased flexibility and memory, and smaller diameter has less impact on irrigation flow. Current baskets on the market vary in design from the simple Cook NCircle® nitinol basket (Cook Inc. USA) to the more complex configuration such as Sur-Catch (ACMI). Other models include the OptiFlex™ (Boston Scientific, USA) and the Halo™ (Sacred Heart Medical, USA) baskets (37). *Ex vivo* studies conclude that smaller diameter baskets (<1.5 Fr), such as the OptiFlex™ (1.3 Fr) have less detrimental effect on irrigation flow and ureteroscope deflection (38). Porcine studies have shown no advantage in complex wire configuration in stone retrieval (39). The Escape™ basket (Boston Scientific, USA) is unique in design as it allows the surgeon to grasp and simultaneously laser a stone, with a 200 μm holmium laser fibre transmitted through the inner channel within the basket wiring (9).

Devices to prevent stone migration

During URS, proximal migration of a stone or fragments can be an issue. This is particularly problematic during lithotripsy and is influenced by many factors including irrigation pressure, location of the stone and degree of proximal hydronephrosis. There are numerous specific devices available which aim to prevent this occurrence. In general this technique is recommended after primary lithotripsy has been performed and a stone fragment is too large to be removed via basket (8). In addition, many anti-retropulsion devices have to be deployed alongside the ureteroscope, whilst the working channel is occupied by a lithotripsy fibre (e.g., laser), and therefore can be problematic in a narrow ureter (9).

The Stone Cone™ (Boston Scientific, USA) is made from an inner coiled nitinol wire covered with an outer radio-opaque 3 Fr polytetrafluoroethylene cover, which aims to prevent the migration of fragments larger than 2 to 3 mm (8). It is available in two sizes: 7 or 10 mm. Eisner *et al.* (40) analyzed a case-series of 133 ureteroscopies over 3 years and reported only two patients with stone fragments larger than 2 mm following the use of the Stone Cone™ device.

This device is resistant to EHL and pneumatic lithotripsy, however, one limitation is that it can be damaged by the Holmium laser.

The Cook NTrap[®] device (Cook, USA) is a 2.6 Fr deployable nitinol mesh. In a meta-analysis including 456 patients by Ding *et al.* (41) they showed a significant advantage in the NTrap[®] cohort versus controls in terms of stone-free rates (odds ratio OR =3.08, P=0.003). The incidence of stone migration was also significantly lower using the NTrap[®] (OR =0.23, P=0.0006) but operative time was not prolonged compared to controls (P=0.62). A comparison study by Lee *et al.* (42) compared the NTrap[®] and Stone Cone[™] in an *in vitro* model but found no difference between either device. The Accordion[®] (Percutaneous System, USA) is a 2.9 Fr urethane film ureteral occlusion device, which has also been found to be an effective anti-migration device compared to controls (P=0.0064) (43). Fogarty balloons used for ureteral occlusion during lithotripsy have been found to be ineffective (44).

Recently a temporary ureteral occlusion gel BackStop[™] (Boston Scientific, USA) has become available which is thermosensitive and can be dissolved easily by an induced temperature change (45). Rane *et al.* (46) performed a RCT including 68 patients to evaluate the effectiveness of BackStop[™] ureteral occlusion gel and found a significantly reduced rate of retropulsion of stone fragments using the gel compared to control (P=0.0002).

New techniques

Lower pole kidney stones can be difficult to access and treat with URS. Anatomically the lower pole infundibulopelvic angle, which averages 140° (from ureter to lower pole), restricts deflection of flexible ureteroscopes. In addition, the use of a laser fibre within the working channel further impedes scope flexibility. Ghani *et al.* (47) describe a surgical technique whereby evacuating the collecting system with a syringe can draw the stone closer to the scope and maximise angle of deflection. They also describe a nitinol basket deployment technique whereby a smaller calibre basket is used to reposition the stone into a middle or upper calyx, requiring a smaller degree of scope deflection and a larger laser fibre (e.g., 365 µm) can be used for fragmentation.

Bostanci *et al.* (48) describe a double wire technique for difficult ureteroscopic access in order to prevent the impact on patient quality of life (QoL) and potential anaesthetic risk from a secondary URS procedure. Anatomical

variation, ureteral oedema, muscular spasm or prostatic hyperplasia can distort the vesicoureteric junction. They describe a method using a secondary guidewire through the ureterscope's working channel, which is inserted into the ureter alongside the safety wire. This facilitates dilatation of the vesicoureteric junction and safe passage of the ureterscope.

Special considerations

Urolithiasis is the second most common cause of abdominal pain in pregnancy and affects 0.5% of pregnancies, with 80-90% of patients in their 2nd or 3rd trimester (49). Clinical guidelines from the European Association of Urology suggest that URS is reserved for failed conservative management or temporising measures (e.g., JJ uterine stent or nephrostomy) and only performed in specialist centres (50). A systematic review of the literature by Laing *et al.* (49) analysed 116 URS procedures and reported a complete stone clearance rate of 86%. Clavien complications (grades I to III) occurred in nine patients. The most significant was a ureteral perforation (Clavien III) and premature uterine contraction (Clavien II). URS in pregnancy is an effective and potential first-line treatment for urolithiasis in pregnancy but should be reserved to high volume centres.

Conclusions

Over recent years we have witnessed many advances in URS. The most significant advance is the development of flexible ureteroscopes, which have revolutionised access to the upper urinary tract and therefore the treatment of proximal and intrarenal calculi. Digital ureteroscopes and imaging allow for better quality visualisation. There are many instruments available to assist with lithotripsy, including baskets, ureteric access sheaths and anti-retropulsion devices. Laser lithotripsy still remains the most popular method for stone fragmentation.

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Footnote

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