Review Article

Status study of clinical application of ureteral access sheath in urology: a narrative review

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Background and Objective: As one of the effective minimally invasive methods for upper urinary tract stone treatment, ureteroscopic lithotripsy has gradually become the mainstream surgical approach. The routine use of ureteral access sheaths (UAS) during ureteroscopic lithotripsy has plenty of advantages. Although many concerns have emerged in the clinical practice of the UAS, the clinically improved devices have addressed these issues. This article reviews the advantages, existing issues, and current improvements of UAS in clinical practice, aiming to provide references for better clinical application and further improvements of UAS.

Methods: We searched in PubMed database using the terms: "ureteral access sheath", "ureteroscopic lithotripsy" or "flexible ureteroscope". Articles were independently evaluated for inclusion based on predetermined criteria.

Key Content and Findings: The routine use of UAS during ureteroscopic lithotripsy facilitates the entry and exit of the ureteroscope, improves intraoperative visibility, and reduces postoperative complications. However, concerns over ureteral wall injury, difficulty in controlling renal pelvic pressure, lack of reduction in operation time, failure to increase stone free rates, and controversies regarding the ratios of endoscope-sheath diameter have limited the clinical application of UAS. The emergence of clinically improved devices such as intelligent pressure controlled, tip bendable, and rigid ureteroscope aided UAS has addressed these issues, laying a foundation for their further clinical application.

Conclusions: The clinical improvement of the UAS can serve as a bridge for the widespread usage of the ureteroscopic lithotripsy. In the future, we anticipate more innovative advancements in UAS, making their clinical use even more practical and convenient.

Keywords: Upper urinary tract stones; ureteroscopic lithotripsy; ureteral access sheath (UAS); stone free rate

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Introduction

Urolithiasis is a common disease in urology. In recent years, with changes in lifestyle and improvements in living standards, the incidence and the prevalence rate of urolithiasis has gradually increased. Over the past 50 years, the incidence of this disease has sharply risen in industrialized countries, affecting 2–20% of the global population (1). The higher prevalence imposes significant burdens on countries and healthcare systems.

Ureteroscopic lithotripsy is a widely used method for stone fragmentation in clinical practice, with broad indications. Guidelines (2,3) suggest that ureteroscopic lithotripsy can treat kidney stones ≤2 cm in diameter and is a primary treatment option for upper ureteral stones. While it is recommended as an alternative treatment for kidney stones >2 cm in diameter (3), the European Association of Urology (EAU) guidelines (2) indicate that its efficacy in treating these stones can achieve a stone free rate of up to 91%.

However, traditional ureteroscopic lithotripsy has its limitations. During procedures, issues such as elevated renal pelvic pressure and urinary tract infections are common. To address these challenges, ureteral access sheaths (UAS) have been introduced. They provide a pathway for the entry of the ureteroscope and drainage within the ureter (2), aiding in resolving the aforementioned issues. EAU guidelines (2) also affirm the safety and benefits of using UAS, particularly for multiple, larger stones, and prolonged surgeries.

But there are still concerns regarding the use of UAS in clinical practice. Numerous studies have confirmed that during the use of UAS, there may be issues such as causing damage to the ureteral wall, insufficient reduction of renal pelvic pressure, no reduction in surgical time, no improvement in stone clearance rates, and controversies regarding the sheath-to-scope ratio. A series of technological advancements, such as new laser lithotripsy techniques, smaller ureteral soft scopes, and the introduction of renal pelvic pressure measurement devices, have also posed new challenges for the future use of UAS. Currently, several literature reviews have systematically discussed these concerns, highlighting the clinical applications and future prospects of UAS amidst these issues and challenges (4,5). However, the progress in the development of the UAS itself has been overlooked. The introduction of flexible-tip UAS, pressure-controlled UAS, visually guided UAS, and force-sensing devices has largely addressed these issues, adding hope for the widespread clinical use of UAS. This article will review the latest improvements in UAS, summarize the current advantages and problems, discuss the issues solved by these improvements and their limitations, and look forward to the further development and future clinical applications of UAS. We present this article in accordance with the Narrative Review reporting checklist (available at https://tau.amegroups.com/article/view/10.21037/tau-24-557/rc).

Methods

Our search was performed on July 22, 2024 by both authors. The inclusion and exclusion criteria were determined prior to the literature search.

PubMed database was searched using the terms "ureteral access sheath", "ureteroscopic lithotripsy" or "flexible ureteroscope". A detailed search of further relevant literature was conducted in the bibliography of the selected papers.

Articles published from 2011 to 2024 were included. A total of 115 articles were identified, with 53 articles being excluded because they are retrospective studies, out of dated, duplicated or no English versions are found. No automation tools were used.

Finally, 62 articles were included in this review, as shown in *Figure 1*. The summary of the search strategy is shown in *Table 1*.

Advantages of UAS

With the increasing clinical application of UAS, their variety continues to expand, each type offering distinct characteristics as shown in *Table 2*.

The application of UAS in ureteroscopic lithotripsy brings numerous advantages. Firstly, using UAS facilitates easy entry and exit of the ureteroscope during procedures (2). Simultaneously, continuous irrigation and drainage improve visibility, lower the incidence of postoperative infections (17,18), and minimize kidney damage (7). Research also indicates that the use of ureteral access significantly improves postoperative pain levels (19).

Issues with the clinical use of UAS

Although the use of UAS has provided significant convenience for ureteroscopy procedures, several problems have been identified during clinical application. These issues have become limiting factors for the clinical use of UAS.

Ureteral wall injury

Several studies have observed that the use of UAS during ureteroscopic lithotripsy can cause damage to the ureteral wall. In a study by Traxer and Thomas (20), 167 out of 359 participants (46.5%) experienced ureteral wall injury. Several meta-analyses have also pointed out that the use of UAS can lead to ureteral wall injury. One meta-analysis, which included 5 randomized controlled trials and 466 patients (21), indicated that the use of UAS did not reduce the incidence of ureteral injury [relative risk (RR) =1.29, 95% confidence interval (CI): 0.95–1.75]. However, this study had a small sample size, which may reduce the reliability of the findings. Another meta-analysis,

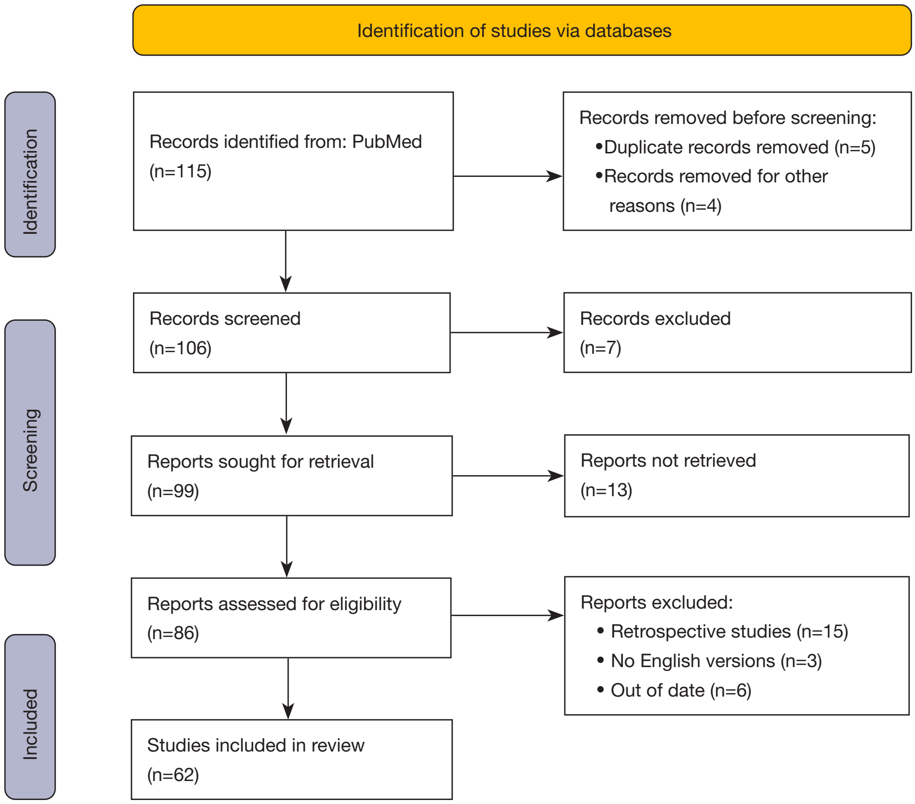

Figure 1 Article screening and selection flowchart (6).

Table 1 The search strategy summary

Items	Specification
Date of search	July 22, 2024
Database searched	PubMed
Search terms used	"ureteral access sheath", "ureteroscopic lithotripsy" or "flexible ureteroscope"
Timeframe	2011–2024
Inclusion and exclusion criteria	Randomized controlled trials, clinical trials, case reports and systematic reviews concerning ureteral access sheaths are included
	Retrospective studies, out-of-date studies, duplicated studies and studies without English versions are excluded
Selection process	The search was performed by both authors. The inclusion and exclusion criteria were determined prior to the literature search

which included 8 studies and 3,099 patients on the use of UAS (22), found that the incidence of postoperative ureteral injury in the UAS group was significantly higher than in the non-UAS group (RR =1.46, 95% CI: 1.06–2.00). The EAU guidelines (2) suggest that preoperative stent placement might improve the success rate of sheath insertion in ureteroscopic lithotripsy. However, inserting a double-J stent increases the number of procedures a patient undergoes and may raise hospitalization costs. Additionally, stent-related symptoms during the indwelling period need to be considered. Currently, the guidelines do not recommend preoperative double-J stent placement (2,3). Therefore, identifying the causes of ureteral injury and finding solutions is crucial.

Table 2 Classification and characteristics of ureteral access sheaths

Ureteral access sheath classification	Advantages	Drawbacks
Traditional ureteral access sheath (2,7)	Provides a pathway for the entry of the ureteroscope and irrigation fluid drainage, offering a clearer view and reducing postoperative complications	Easily cause ureteral wall injury, insufficient reduction of renal pelvic pressure, no shortening of surgical time, no improvement in stone clearance rate, and controversy regarding the ratios of endoscope-sheath diameter
Negative pressure ureteral access sheath (8,9)	Equipped with negative pressure suction device, capable of aspirating, removing stone fragments, better controlling renal pelvic pressure, improving stone clearance rate, and reducing postoperative infections	There is still room for improvement in the stone clearance rate, as it cannot completely aspirate stones from the renal calyces. The control of surgical time is not ideal, and the efficiency of stone aspiration is insufficient, requiring repeated withdrawal of the scope for stone retrieval
Tip bendable ureteral access sheath		
Passive flexible ureteral access sheath (10,11)	Tip can passively bend to follow the scope into the renal calyx, and can completely aspirate the stones from the calyx, reducing postoperative complications	The control of surgical time is not ideal, and the extended length of the sheath affects the speed of stone aspiration. The tip of the sheath can only passively bend along with the ureteroscope, requiring constant adjustment of the angle to aspirate the stones. It is difficult to clear stones from the lower renal calyx
Active flexible ureteral access sheath (12)	Tip can actively adjust bending, and the sheath body can rotate coaxially, allowing it to actively grasp stones, making the operation more flexible	More clinical randomized controlled trials are needed to validate its clinical effectiveness
Intelligent pressure-controlled ureteral access sheath (13,14)	Includes a pressure monitoring platform; controls renal pelvic pressure through irrigation and negative pressure adjustment	There have been no significant improvements or increases in stone clearance rate, surgical time, and other aspects. It requires an experienced surgeon to operate
Rigid ureteroscope aided ureteral access sheath (15,16)	Placed under direct vision of ureteroscope during ureteroscopy, shortening the surgical time, reducing damage to the ureteral wall, and minimizing radiation exposure	There has been no significant improvement or increase in stone clearance rate and renal pelvic pressure control. The larger diameter of the sheath makes it suitable only for patients with a large ureteral caliber and wide ureteral lumen

Clinically, the following factors are considered to cause ureteral wall injury due to the use of UAS. First, to ensure a smaller sheath-to-scope ratio, UAS with an outer diameter of up to 14-Fr are commonly used, while the upper limit of the normal ureteral diameter is only 3 mm (9-Fr), which is significantly smaller than the sheath's outer diameter (20). Under such conditions, the insertion of the sheath exerts considerable shear force on the ureteral wall, leading to injury. An animal study conducted on rabbits (23) showed that an oversized sheath and prolonged insertion time can cause histological damage to the rabbit's ureteral wall. Additionally, the UAS can compress the ureteral wall's blood vessels, impeding blood flow and causing ischemia in the ureteral wall. After the procedure, removing the sheath can lead to an ischemia-reperfusion phenomenon in the ureteral wall, and the resulting free radicals may further damage the ureteral wall (20). This process is related to the activation of transforming growth factor-β1 (TGF-β1) by reactive oxygen species (24). TGF-β1 can activate fibroblasts, promoting collagen secretion and scar formation, which is a fundamental cause of postoperative ureteral stricture (25). Currently, some studies have reported the incidence of ureteral stricture after the use of UAS. A prospective study that included 56 patients (26) indicated that the incidence of ureteral stricture was 1.8% among patients who experienced high-grade ureteral injury after UAS use. A meta-analysis published in 2024 (27) showed that the incidence of ureteral stricture after UAS was 0.5%.

The occurrence of stricture is associated with factors such as stent placement duration, stone impaction, and advanced age. Although the incidence of stricture is not high, there is still a risk, which requires clinical attention. The insertion technique is also an important factor in ureteral wall injury. A prospective randomized controlled study by Loftus *et al.* (28) indicated that prolonged sheath placement time and subjective difficulty in sheath insertion are associated with high-grade postoperative ureteral injury. Currently, UAS placement is mainly performed under X-ray guidance. This method exposes both the surgeon and the patient to uncertain radiation, and its safety remains under evaluation (16). A clinical survey study (29) showed that urologists' compliance with radiation protection measures during surgery is poor, with the usage rates of thyroid protection shields, dosimeters, lead glasses, and gloves being only 68%, 34.3%, 17.2%, and 9.7%, respectively. A study using real-time dosimetry (30) indicated that the exposure to scatter radiation during surgery is substantial, posing a risk to occupational health. These studies suggest that radiation protection during the sheath placement process is also a significant safety concern.

Insufficient decrease of renal pelvis pressure

Renal pelvic pressure is an important issue to monitor during ureteroscopic procedures. When the renal pelvic pressure is excessively high, it can cause the renal pelvic safety valve to open, leading to reflux (31). An *in vitro* study on the safety threshold of renal pelvic pressure during ureteroscopy (32) indicates that the safe threshold for intraoperative renal pelvic pressure is 30 mmHg. When the renal pelvic pressure exceeds 35 mmHg, renal pelvic-tubular reflux occurs, and noticeable reflux can be observed when the pressure reaches 40 mmHg. The presence of renal pelvic reflux not only damages the kidneys (31) but also poses a risk of pathogenic bacteria from the irrigation fluid being absorbed by the body, leading to severe postoperative urinary tract infections (33). Therefore, controlling renal pelvic pressure during ureteroscopy is crucial for managing postoperative infections. The use of a UAS provides a channel for the drainage of irrigation fluid and effectively controls renal pelvic pressure. A prospective clinical study (34) indicated that after using UAS, the pressure in various renal calyces was significantly reduced compared to when UAS was not used. However, in clinical practice, it is not uncommon for renal pelvic pressure to exceed the safe threshold even with the use of UAS. A clinical study by Croghan *et al.* (35) found that fluctuations in renal pelvic pressure exceeding the safety threshold are frequently observed during ureteroscopic lithotripsy, and there is no correlation between the use of a UAS and the average renal pelvic pressure during the procedure. This indicates that even with the use of a UAS, it is still challenging to ensure that renal pelvic pressure remains below the 30-mmHg safety threshold.

Surgical time is not reduced and may even be extended

The duration of ureteroscopic lithotripsy is an important factor in controlling the occurrence of postoperative complications, as longer surgical times are associated with a higher incidence of such complications (2). However, numerous clinical trials have found that the use of a UAS does not reduce surgical time and may even prolong it. A clinical randomized controlled trial by Singh *et al.* (36) found no difference in surgical time between using a UAS and not using one. Another clinical trial on UAS (37) even showed that the surgical time was shorter in the group that did not use a UAS.

The extension of surgical time may be related to many factors. The duration of surgery can be influenced by the surgeon's proficiency (38). Even for surgeries performed by the same surgeon, if the surgeon is more skilled in the technique without using a UAS, the procedure may take less time. Therefore, training the surgeon in operative techniques is an essential aspect of controlling surgical time. The UAS itself can also contribute to the extension of surgical time. An additional step of sheath placement is required compared to not using a sheath, and the time taken for sheath insertion becomes a factor affecting the overall surgical time.

Stone-free rate not improved

The postoperative stone-free rate is an important indicator for evaluating the effectiveness of lithotripsy. However, numerous clinical randomized controlled trials have shown that there is no difference in the postoperative stone-free rate between using a UAS and not using one. Studies by Abdelfatah Zaza *et al.* (37), Singh *et al.* (36), and Ecer *et al.* (7) all demonstrated that the use of a UAS did not improve the postoperative stone-free rate. For stones larger than 2 cm in diameter, Geraghty *et al.* (39) also confirmed that using a UAS did not enhance the stone-free rate. A multicenter prospective study by Traxer *et al.* (40), which included 2,239 patients, indicated that the stone clearance rate was lower in the UAS group (0.739 *vs.* 0.828). An Inverse Probability Weighted Regression Adjustment (IPWRA) analysis was conducted on 1,827 patients, and although the stone clearance rate improved after using UAS (0.753 *vs.* 0.504), the difference was not statistically significant (P=0.60). The unsatisfactory improvement in stone-free rate may be due to the fact that, when using a UAS, stone fragments still need to be retrieved using a stone retrieval basket after lithotripsy. For some smaller, powdery stones, complete clearance is still not achievable (10).

Controversy over the ratios of endoscope-sheath diameter

The ratios of endoscope-sheath diameter have been a widely studied topic in recent years. The ratios of endoscope-sheath diameter refer to the ratio of the outer diameter of the flexible ureteroscope to the inner diameter of the UAS. To ensure adequate irrigation and drainage during surgery and prevent excessive renal pelvic pressure, a smaller ratio of endoscope-sheath diameter is recommended. An *in vitro* study (8) found that when the ratios of endoscope-sheath diameter is smaller, it is easier to maintain renal pelvic pressure within the safe range of 30 mmHg. For traditional UAS, keeping the ratio at or below 0.75 is considered safer. Lower renal pelvic pressure also helps protect the kidneys. A randomized controlled clinical trial (41) showed that using a 12/14 Fr UAS is more likely to cause acute kidney injury postoperatively compared to using a 9.5/11.5 Fr UAS. A smaller ratio of endoscope-sheath diameter provides a wider channel for stone extraction, making stone removal more convenient. An *in vitro* study (42) showed that a smaller ratio of endoscope-sheath diameter in UAS facilitates stone clearance during flexible ureteroscopy.

However, a smaller ratio of endoscope-sheath diameter does not imply that a larger inner diameter of the UAS is always better. As mentioned earlier, the outer diameter of commonly used UAS is larger than the inner diameter of the ureter, creating shear forces on the ureteral wall during insertion, which may lead to histological and hemodynamic changes, potentially causing ureteral injury. The EAU guidelines (2) also indicate that increasing the sheath diameter directly increases the risk of ureteral injury. Therefore, using a UAS with a smaller inner diameter during surgery is more beneficial for protecting the ureter and reducing postoperative complications. A randomized controlled clinical trial (43) found that using a 9.5/11.5 Fr UAS significantly reduces the severity of ureteral injury compared to using a 12/14 Fr UAS.

Thus, there is a conflict between the requirements for the inner diameter of the UAS during insertion and surgery. During insertion, a smaller inner diameter is preferred to minimize ureteral injury and improve the success rate of sheath placement. However, during the ureteroscopic lithotripsy procedure, a larger inner diameter is needed to ensure good irrigation, control renal pelvic pressure, and facilitate the removal of stones through the sheath.

Clinical improvements to UAS

To address the aforementioned issues with UAS, numerous improvements have been made in clinical practice. Each improvement method has its own merits and has effectively resolved different problems.

Negative pressure UAS

Negative pressure UAS utilize negative pressure suction to better drain irrigation fluid and attract stones, thereby reducing renal pelvic pressure (8). In a clinical randomized controlled trial involving 122 patients (13), researchers randomly assigned patients to either a negative pressure UAS group or a traditional UAS group, comparing stone clearance rates and complication indicators postoperatively. They found that the negative pressure UAS group achieved higher stone free rates and fewer postoperative fevers. Moreover, a series of *in vitro* studies also demonstrate that negative pressure sheaths can achieve lower renal pelvic pressures compared to traditional UAS (8), facilitating the expulsion of stones from the UAS (42).

Of course, the negative pressure sheath also faces many clinical challenges. First, the improvement in stone clearance rate with the negative pressure sheath is still not ideal. When using a negative pressure UAS during surgery, the sheath's distal end can only be placed at the renal pelvis-ureter junction (44), and cannot reach the renal calyx, preventing it from fully aspirating the stones from the calyces, which limits the improvement in stone clearance rates. Secondly, the use of a negative pressure sheath has not been shown to reduce surgical time. A randomized controlled trial on negative pressure sheaths (11) showed that there was no difference in surgical time between patients using a tip bendable negative pressure UAS and those using a traditional UAS. For negative pressure UAS, the extension in surgical time mainly occurs during the stone suction stage (11). Due to the relatively long length of the UAS, the speed of stone extraction using vacuum suction may not be faster than using a stone retrieval basket (11). If the stones cannot pass through the gap between the ureteroscope and the sheath, the scope needs to be withdrawn to retrieve the stones, further extending the surgical time. Since negative pressure sheaths have good stone clearance and reduce the risk of infection, the surgeon may deliberately extend the surgical time to ensure thorough stone removal.

Tip bendable UAS

To address the issues with traditional negative pressure sheaths, which struggle to enter renal calyces and fully remove stones, the tip bendable UAS was developed. The last 10 cm of this sheath is made of soft, flexible material, allowing it to follow the ureteroscope past the ureteropelvic junction and enter the target calyx, getting closer to the stones and facilitating their removal (10). Additionally, the flexible tip can use negative pressure to attract and hold the stones in place, preventing them from moving and improving stone clearance efficiency (10).

In ureteroscopic lithotripsy, using a tip bendable UAS significantly improves immediate postoperative stone-free rates. In a prospective, international multicenter randomized controlled trial conducted by Zhu *et al.* (11), 320 patients were randomly assigned to the tip bendable sheath group or the traditional sheath group, and postoperative stone clearance was observed. The results showed that the tip bendable sheath had a clear advantage in stone free rates compared to the traditional sheath.

Moreover, compared to the traditional UAS, the tip bendable sheath also has advantages in controlling postoperative complications. Clinical randomized controlled trials (11) have demonstrated that using a tip bendable sheath reduces the incidence of postoperative complications, decreases postoperative bleeding and pain, and lowers inflammation markers and infection rates. These improvements may be related to better control of renal pelvic pressure. Traditional sheaths can only be placed at the ureteropelvic junction (45), forcing the irrigation fluid from the ureteroscope to pass through this narrow junction, which can lead to high renal pelvic pressure if the irrigation flow is too high or the drainage is insufficient (44). However, the tip bendable sheath can follow the scope into the target calyx, allowing irrigation fluid to exit directly from the sheath at the calyx, shortening the drainage path and preventing blockage by the ureteropelvic junction's mucosa. This helps control renal pelvic pressure and reduces the incidence of postoperative complications (11,44,46). An *in vitro* study (44) showed that using the tip bendable UAS reduces renal pelvic pressure and, by adjusting the negative pressure values, keeps the pressure within a safe range at different irrigation flow rates.

However, there are still limitations with the tip bendable sheath in controlling surgery duration. Zhu *et al.*'s study (11) showed no significant difference in surgery time between the tip bendable and traditional sheaths. In the current clinical research, the tip bendable sheath they used passively bends along with the ureteroscope, requiring frequent angle adjustments to better fragment and suction the stones, which affects surgery time. At the same time, due to the limitations in the bending angle, stone fragments in the lower renal calyx still require the use of a stone retrieval basket for more thorough clearance (11). Currently, there is also a lack of assessment regarding the cost and training difficulties of this type of UAS in clinical practice, and more clinical trials are needed to confirm its feasibility for widespread clinical application (11).

Intelligent pressure-controlled UAS

To address the issue of high renal pelvic pressure during ureteroscopic lithotripsy, the intelligent pressure-controlled UAS has been introduced. This sheath, equipped with a pressure feedback infusion-suction platform and a renal pelvic pressure monitoring device, not only allows real-time monitoring of renal pelvic pressure but also enables the regulation of suction from the negative pressure device to keep it within a range set by the surgeon (47). An *in vitro* study using porcine kidneys demonstrated that the intelligent pressure-controlled sheath could maintain renal pelvic pressure within a safe range under different irrigation flow rates (48). This improvement reduces the occurrence of renal pelvic reflux and decreases the absorption of irrigation fluid through the renal calyces. Several studies on irrigation fluid absorption (14,33) have shown that patients using the intelligent pressure-controlled sheath absorbed significantly less fluid during surgery. The reduction in renal pelvic pressure and reflux also led to a decrease in the incidence of infectious complications. A study by Du *et al.* (13) found that for ureteral stones below the L4 level, the intelligent pressure-controlled sheath significantly reduced the postoperative incidence of infectious complications compared to traditional ureteral sheaths.

This UAS achieves intelligent control of renal pelvic pressure and is relatively easy to operate. The main barrier to the widespread adoption of this technology lies in the insertion of the UAS, which requires the operator to have substantial experience in sheath placement (13). This limits the use of this UAS by some beginners. It suggests that clinical training for doctors on operational techniques should be strengthened.

Rigid ureteroscope aided UAS

To avoid radiation exposure for patients and medical staff during UAS insertion under X-ray monitoring, and to reduce the risk of ureteral injury during sheath placement, the rigid ureteroscope aided UAS has been developed. This sheath incorporates a rigid ureteroscope inside the ureteral sheath, allowing for the sheath to be placed under direct visualization with the ureteroscope (16).

Since the rigid ureteroscope aided sheath is guided by the ureteroscope, there is no need for fluoroscopic imaging, effectively avoiding radiation exposure for both the patient and the surgeon (16). With the assistance of the ureteroscope, both the sheath insertion time and overall surgery time can be significantly reduced, and the risk of ureteral injury is better controlled. A study by Karabulut *et al.* (15) found that compared to traditional UAS, rigid ureteroscope aided sheaths reduced insertion and surgery times, while maintaining a similar rate of ureteral injury as observed with X-ray-guided placement. Thus, the rigid ureteroscope aided UAS offers unique advantages in shortening surgery time and protecting the ureter.

However, the introduction of ureteral rigid scopes can lead to an increase in the outer diameter of the UAS, which may cause uncontrollable trauma to the ureteral wall. Therefore, the current version of this UAS is only suitable for cases with large ureteral calibers and wide ureteral lumens (15). Developing a UAS with an appropriate diameter and visual navigation is an important issue that needs to be addressed in clinical practice.

Introduction of force-sensing devices

As mentioned earlier, the shear force exerted by the UAS on the ureteral wall is a significant factor in causing ureteral injury. In recent years, the introduction of force-sensing devices has made it possible to quantitatively assess the relationship between the magnitude of this force and ureteral injury. Kaler *et al.* (49) used a UAS force-sensing device (UAS-FS) developed by the University of California and confirmed through animal experiments that, for a 14-Fr UAS, when the applied force exceeds 8.1 N, significant ureteral injury occurs, while a force below 4.84 N can prevent injury. For a 16-Fr UAS, *in vitro* experiments (50) have shown that an applied force of ≤6 N can prevent ureteral injury.

However, most urologists do not have ideal control over the force applied during the insertion of the UAS. A clinical study that included 121 urologists and residents (51) showed that 74% of participants did not control the applied force within the safe range. A simple force-sensing device made using a syringe provides a possible solution to this issue. A study by Gao *et al.* (52) showed that by using the volume change of a 1.0 mL syringe with a closed tip, the applied force could be precisely controlled to 4.00, 6.00, or 8.00 N, thus preventing ureteral injury caused by excessive force. However, the method of using a syringe for readings is still inconvenient, and clinically, there is a need for a UAS that can display the applied force in real time.

Introduction of α1-adrenergic receptor antagonists

α1-adrenergic receptor antagonists selectively bind to α1-adrenergic receptors and inhibit the contraction of ureteral smooth muscle. Recent studies have shown that the use of α1-adrenergic receptor antagonists during ureteroscopic lithotripsy can assist in the placement of the UAS. A prospective randomized controlled trial involving 147 patients (53) showed that preoperative use of silodosin is an important factor in preventing ureteral injury ($P<0.001$). Another randomized controlled trial (54) demonstrated that preoperative use of silodosin not only reduces ureteral injury but also lowers postoperative pain levels. Additionally, several randomized controlled trials (55,56) have shown that preoperative use of silodosin can reduce the time required for UAS placement. The latest meta-analysis (57) conducted a quantitative analysis of the effects of α1-adrenergic receptor antagonists and found that they are effective in reducing the need for intraoperative ureteral dilation (RR =0.48, 95% CI: 0.30–0.75), sheath insertion failure rate (RR =0.36, 95% CI: 0.23–0.57), surgical time [mean difference (MD) =−6 min, 95% CI: −8 to −3], and postoperative complication rates (RR =0.46, 95% CI: 0.35–0.59). α1-adrenergic receptor antagonists have fewer side effects, but one study (57) indicated that the use of this class of drugs might increase the risk of ejaculatory dysfunction (12.9% *vs.* 3.2%).

Discussion and outlook

As a routine tool in flexible ureteroscopy for stone fragmentation, UAS have received increasing attention and widespread use in clinical practice. Recent literature has confirmed that improvements in the UAS have effectively addressed some of the concerns regarding its clinical use. The flexible tip UAS significantly enhances stone clearance rates and reduces postoperative complications. The intelligent pressure-controlled UAS ensures that renal pelvic pressure remains within a safe range. The visual navigation UAS reduces radiation exposure during surgery, shortens the duration of the procedure, and controls ureteral injury. At the same time, force-sensing devices and α1-adrenergic receptor antagonists have also become important tools for reducing ureteral injury. The issues encountered during the clinical use of the UAS have been largely resolved, and routine use of the UAS in ureteroscopic lithotripsy for the treatment of upper urinary tract stones is highly advantageous.

However, there are still some limitations with the current improvements. First, clinical modifications to UAS often address only specific issues, without simultaneously resolving multiple problems. Therefore, more efficient improvements that can address multiple issues simultaneously are needed. One such recent development is a flexible and navigable suction (FANS) UAS (58), which allows surgeons to guide the sheath to any part of the kidney with the aid of an endoscope. A prospective, multicenter clinical trial (58) demonstrated that the use of this sheath resulted in high stone free rates and low post-operative complication rates, with a median operation time of 49 min.

At the same time, there have been no significant improvements in controlling the operation time during the stone fragmentation and extraction phases. Recently, a UAS with an actively bendable tip has been reported (12). Surgeons can manually adjust the curvature and direction of the sheath's tip via a knob on the handle, achieving favorable stone clearance results. Nevertheless, further randomized controlled trials are needed to verify its efficacy in stone fragmentation. The assistance of some new devices has also made it easier to control the surgical time with the UAS. The emergence of more compact ureteroscopes (59) and the introduction of thulium fiber lasers (60) have improved stone fragmentation efficiency, expanded the stone retrieval space, and significantly shortened the surgical duration. In recent years, robotic flexible ureteroscopy has seen considerable progress. The Avicenna Roboflex robotic flexible ureteroscope, developed by Elmed-Turkey (Istanbul, Turkey), has shown advantages in stone fragmentation time and clearance rates during flexible ureteroscopy (61). At the same time, the surgeon maintains a safe distance from the radiation source, providing space for assistants around the patient, reducing radiation exposure during the procedure, and enhancing ergonomic efficiency (62,63).

The debate over the ratio of the endoscope-sheath diameter in UAS also remains unresolved. To address this issue, it may be feasible to develop a UAS with a variable diameter. A sheath with a smaller initial diameter can be used for insertion to reduce ureteral injury, followed by expanding the sheath's diameter after placement to facilitate renal pelvic pressure control and stone removal. This approach could provide a direction for resolving this issue.

In conclusion, the widespread clinical use of the UAS holds great promise. In the future, there may be further improvements in the UAS in the following areas. First, regarding the existing improvements, clinical applications need to focus on making the device more compact, cost-effective, and easier to use, so as to accommodate different surgeons and patients, thereby expanding its applicability. Second, for some new improvements, more randomized controlled trials are needed to prove their effectiveness. For the introduction of force-sensing devices, clinical practice requires more real-time and convenient devices for measuring the advancing force, which will help clinicians control the advancing force during sheath insertion. Lastly, there is a need to strengthen the training of clinicians on operational techniques to facilitate the widespread adoption of UAS-related improvements. It is believed that in the future, the use of the UAS can be made more convenient and safer, leading to broader clinical applications.

Conclusions

At present, UAS are routinely used in flexible ureteroscopy for stone fragmentation. They offer advantages such as facilitating the insertion and removal of the ureteroscope, providing a clearer field of view, and reducing post-operative complications. However, they also present challenges, including potential ureteral wall injury, difficulties in controlling renal pelvic pressure, extended operation times, unimproved stone free rates, and controversies over the ratio of the endoscope-sheath diameter. Clinical improvements, such as intelligent pressure control, tip bendable designs, and rigid ureteroscope aided UAS, have effectively addressed these issues, promoting further clinical application of UAS. In the future, we anticipate more innovative advancements in UAS, making their clinical use even more practical and convenient.

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Footnote

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