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REVIEW

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Semirigid *vs* Flexible Ureteroscopy in the Management of Ureteral Stones – Review

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ABSTRACT

Ureteral stones are a major clinical problem in urology that require effective and safe therapeutic options. Semirigid and flexible ureteroscopy ar two well-established procedures for treating these stones. The present review provides an outline of the advantages and disadvantages of these approaches. Semirigid ureteroscopy, which uses a rigid straight instrument, provides excellent stone visualisation and successful fragmentation. It is especially useful for proximal and bigger stones, frequently resulting in high stone-free rates and reduced procedure times. Nonetheless, its stiffness can make it difficult to navigate the delicate ureteral anatomy and increase the risk of mucosal injury. On the other hand, flexible ureteroscopy employs a more adjustable flexible scope, allowing access to complicated ureteral configurations while reducing the risk of ureteral trauma. It excels at treating distal and difficult stones but has a lower efficacy with larger stones and often requires longer procedure times. The choice between semirigid and flexible ureteroscopy is determined by patient-specific factors such as stone characteristics or anatomical considerations and the surgeon's skill. A customised approach that uses the capabilities of both treatments as needed can improve stone management outcomes while reducing potential problems. The continued advancement of technology and methodological modifications is predicted to improve the field of ureteroscopic stone management.

Keywords: semirigid, flexible, ureteroscopy, kidney stones.

INTRODUCTION

Nephrolithiasis represents a common finding in middle-aged adults, with pick between the third and fifth decade of life (1). The most incriminating risk factors in the occurrence of urinary stones include various metabolic conditions, environmental factors, socioeconomic status and genetic predisposition (2). The management of nephrolithiasis ranges from conservative (active monitoring, including expulsive therapy using various drugs) to extra-corporeal shock wave lithotripsy (SWL) or multiple sur-

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gical approaches, the choice of treatment being directly connected to the stone size, degree of obstruction, symptom severity, stone location, kidney function or urinary tract infections (3).

During the last decades, ureteroscopy (URS) has significantly changed the perspective of ureteral calculi management by improving major technical aspects such as endoscopes miniaturization, enhanced tools or improved optical quality. Apart from general considerations regarding general anesthesia or redundant urinary tract infections (UTI), the European Association of Urology (EAU) guidelines recommend that URS can be performed in all patients with no specific contraindications (4); various aspects such as ureteral strictures may impede ureteral retrograde approach. Different techniques are available for ureteral stone fragmentation such as laser, pneumatic, ultrasonic or electrohydraulic lithotripsy (5). For many years, pneumatic lithotripsy (PL), which uses vibrating mechanical forces for fragmentation, has activated as a safe, practical and cost-effective method for stone surgical management; thus, the Lithoclast has acknowledged worldwide recognition as a popular treatment modality for ureteral calculi. However, higher retrograde stone migration represents its disadvantage (6). Introducing laser technology in endourological practice marked an important milestone in the management of nephrolithiasis, with the promises of increasing effectiveness for proximal and impacted stones, fewer intraoperative complications and overall better outcome for both surgeon and patient, but at a higher cost (7); laser lithotripsy, and especially Holmium:yttrium-aluminum-garnet [Ho(YAG)] is nowadays a well-established method of intracorporeal lithotripsy with escalating popularity (8), especially in flexible instruments. In the past 30 years, flexible ureteroscopy (fURS) has been considerably improved, bringing multiple technological upgrades, being successfully used for a wide range of diseases of the upper urinary tract, but mostly for lithiasis.

There are many ways to treat ureteral stones, including open surgery, laparoscopic methods, antegrade ureterolithotripsy, extracorporeal shock wave lithotripsy and ureterorenoscopy with semirigid or flexible devices. Many elements are taken into account when choosing the treatment method, among which the most important are represented by the size and location of the calculus, anatomical and functional considerations such as the degree of dilatation and last but not least, the surgeon's expertise and patient's preference (9). According to the EAU recommendation (4), flexible and semirigid ureteroscopy (URS) are now the most popular methods for treating urolithiasis, although there is no conclusive proof of any benefit from treatments. The goal of this study is to assess the most recent data that have been published and translate them into comparative terms in an effort to highlight the benefits and drawbacks of each distinct treatment.

Semirigid ureteroscopy in ureteral stone treatment

Semirigid ureteroscopy is by far the most used current method of treating ureteral lithiasis worldwide. For many decades, this procedure has successfully managed the minimally invasive treatment of a very widespread pathology, with very good results and minimal perioperative complications (10-12). Multiple types of ureteroscopes have been developed in the last three decades, coming from many reputable manufacturers in the medical devices market, all being successfully used in these types of treatments. Among them, Karl Storz Endoskope (Germany) (13), Richard Wolf (USA) (14) and Olympus (Japan) (15) are the most famous manufacturers. There are many technical varieties between them, from the working channel with one or two channels, their thickness or the way in which the constituent elements are arranged – working channel, light source, optics (16). Intraoperative aspects of ureteroscopic stone treatment are illustrated in Figure 1.

Lithotripsy is one of the most important elements of the success of ureteroscopy in the management of ureteral lithiasis. Classically, the most commonly used methods include pneumatic (ballistic) and ultrasonic energy, both with satisfactory results for different types of urinary stones.

Urinary stone treatment is continually changing in endourology. There are several types of intracorporeal lithotripters, including ultrasonic, pneumatic and laser lithotripters (Figure 2).

Mulvaney provided the initial description of lithotripsy using ultrasonic (US) waves (17). The primary disadvantage of US lithotripsy is the requirement for large diameter devices with

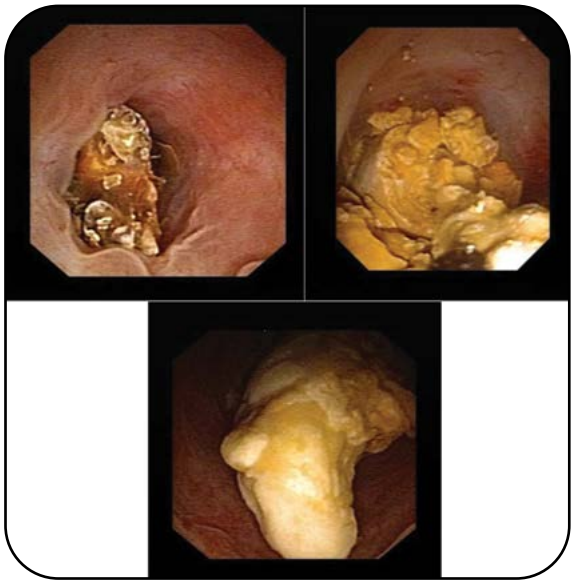

FIGURE 1. Different intraoperative images of ureteroscopic stone treatment (authors' collection)

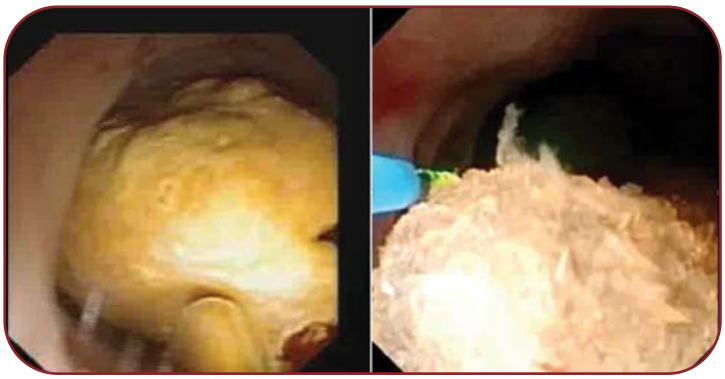

FIGURE 2. A (left): pneumatic lithotripter; B (right): laser fiber (authors' collection)

straight working channels; as a result, the intramural portion of the ureter must be dilated, which significantly lengthens the surgery and exposes the patient to more radiation (18). Pneumatic ureteral lithotripsy is one of the oldest methods of fragmenting stones embedded in the ureter; it is cheap and perhaps one of the most effective procedures when it comes to the fact that it can fragment any type of stone, regardless of its hardness. A study following over 250 patients with large ureteral stones (>30 mm^2) treated with pneumatic lithotripsy resulted in very good outcomes with promising stone-free rates (SFRs) (around 90%) with no major complications and very low minor complications (around 10%); it concluded that pneumatic lithotripsy combined with semirigid URS was a safe and extremely effective treatment for stones larger than 30 mm^2, especially in the distal ureter (19). A study published in the *Arab Journal of Urology* followed 95 semirigid ureteroscopies using pneumatic and laser energy for fragmenting ureteral stones, which resulted in up to 95% of SFRs after any of the procedures. The main commonly encountered complications included hematuria (1%), colic pain (2%), fever (2%), mucosal injury (7%) and access failure (8%). The main limitation of pneumatic lithotripsy was retrograde stone migration (7%), which was limited in laser technology (20).

Ultrasonic lithotripsy was one of the first methods utilized to treat renal and ureteral stones, but more contemporary methods, such laser lithotripsy with both rigid and flexible ureteroscopes, have largely supplanted it. A study carried out in Rabin Medical Center, which studied 340 ureteroscopies performed with ultrasonic lithotripsy, reported very good results regarding the degree of stone fragmentation by using this method and concluded that patients undergoing ultrasonic lithotripsy (UUL) were generally complicated stone patients. The special characteristics of UUL, which combine stone fragmentation and effective removal of small fragments, are utilized in the application of ultrasonic lithotripsy as a follow-up procedure or in conjunction with laser or ballistic devices (21).

A study conducted over a long period of time (12 years) evaluated over 400 ureteroscopies performed by using ultrasonic lithotripsy (Swiss Lithoclast) for ureteral calculi. Its authors used the 9.5 Fr and 10 Fr semirigid ureteroscopes from Storz Medical, encountering ureteral lithiasis located both proximally (80.3%), middle (93.8%), and distally (96.9%). After careful data analysis, the final results showed a total success rate of approximately 91.6% in male patients and 96.9% in female patients. The authors came to the conclusion that ureter stone treatment using Swiss Lithoclast and pneumatic lithotripsy was efficient and secure. Due to a greater likelihood of stone fragment migration during lithotripsy, its effectiveness is diminished in cases of big upper ureter stones with obvious hydronephrosis (22). A comprehensive comparison of both methods of endoscopic lithotomy in the case of semirigid ureteroscopy (pneumatic and ultrasonic) are compared in Table 1.

TABLE 1. Comparison between the main types of contact lithotripsy used in semirigid ureteroscopy (23)

Principle	Mechanism	Probes	Advantages	Disadvantages
Ultrasonic	Ultrasonic generator that produces sinusoidal vibrations (20-27 kHz)	Rigid	Cheap, efficient (especially for calculations of reduced hardness). It allows simultaneous aspiration of fragments. It reduces the time of surgical intervention in the case of bulky stones.	Reduced efficiency for ureteral stones. The sample may frequently freeze. Cannot be used with flexible tools.
Pneumatic	Compressed air that actuates the test	Rigid	Cheap and efficient. It allows the destruction of any type of calculation.	Rigid samples. It can cause the retropulsion of stones

Flexible ureteroscopy in ureteral stone treatment

The primary goal of ureteral stone treatment is to achieve a high SFR with minimal morbidity. The most important therapeutic options for renal lithiasis include shock wave lithotripsy (ESWL), semirigid/flexible ureteroscopy and percutaneous nephrolithotomy (PCNL). According to the EAU guidelines (4) extracorporeal lithotripsy with shock waves has lower rates of morbidity and fewer associated complications, as well as the fact that it can be performed in outpatient conditions, but ureteroscopy has better SFRs and poses a lower risk of necessary subsequent interventions.

Flexible ureteroscopy is effective in the treatment of ureteral lithiasis at any level, regardless of the hardness of the stone. It uses laser lithotripsy which can destroy any calculus no matter how hard it is. Data from the literature suggest the use of flexible ureteroscopy for proximal ureteral lithiasis, because when stone fragments migrate retrograde they can be approached to achieve a stone-free status (24, 25). A large study published in *European Urology* (26) showed that semirigid ureteroscopy could be successfully used at any ureteral level – proximal, middle and distal. However, when this fails due to residual fragments or the impossibility of accessing the stone, fURS is an indisputable help with significantly higher success rates and improved stone-free status. A number of 9 681 patients underwent ureteroscopy, resulting in 95% SFR at the level of the distal ureter, 89% in the middle ureter and 84% in the proximal ureter. For the proximal ureter, reintervention rates were higher, resulting in greater success when the fURS was used. Another study published in the *International Brazilian Journal of Urology* (27) that compared the use of flexible and semirigid ureteroscopes in the treatment of ureteral lithiasis, both in men and women, showed clearly improved results in the case of fURS (SFRs 91%) compared to semirigid ureteroscopy (SFRs 68%). It concluded that treatment for ureteral stones may be possible with either flexible or semirigid URS. Because fURS is also available, semirigid URS should only be used selectively in the case of ureteral stones. Flexible URS is the most advantageous method for treating ureteral stones due to its better success and lower complication rate. Another study published in 2018 in the *Egyptian Journal of Hospital Medicine* compared the outcome of semirigid ureteroscopy to that of fURS in the treatment of ureteral lithiasis. There was a 90.0% SFR in group A (who received semirigid ureteroscopy) and 93.3% in group B, with both groups having similar rates of complications and operative time (28). On the other hand, a study published by Sadi Turkan in *SpringerPlus* (29) highlighted the use of the semirigid ureteroscope in ureteral lithiasis as the first treatment option in favor of the flexible ureteroscope in a cohort of 137 patients, of whom 124 were stone-free at the end of treatment. The semirigid ureteroscope was used for 80 patients and the flexible ureteroscope for 44 patients, but only when the semirigid ureteroscopy failed to completely treat the lithiasis. The authors emphasize the importance of both instruments in the retrograde treatment of ureteral lithiasis, but specify the fact that flexible ureteroscopy has the main complementary role, more than the alternative to semirigid ureteroscopy.

The European Association of Urology recommends the use of ESWL or fURS for proximal ureteral lithiasis, which is also emphasized in the literature, considering these procedures as the most commonly used for this situation (4). It is generally considered that ESWL has lower success rates and that in many cases retreatment is necessary for a complete resolution (30). Addi-

Specifications	Parameter	High-power Ho:YAG	Thulium fiber laser (TFL)
Technology specifications	Laser wavelength	2 100 nm	1 940 nm
	Pulse profile	Spikes irregular energy pulses	Constant symmetrical wave energy pulses
	Patient laser fiber core diameter	200 µm or higher	50 µm or higher
Machine specifications	Pulse energy	0.2 – 6.0 J	0.025 – 6.0 J
	Pulse frequency	5-80 Hz	5 – 2 200 Hz
	Maximum average power	120 W	50-55 W
	Energy efficiency	1%	12%
	Energy consumption	9 000 W	1 000 W
	Cooling system	Water cooling system	Air cooling system

TABLE 2. High-power Ho:YAG and Thulium fiber laser technology and machine specifications

tionally, Pace *et al* (31) showed that retreatment of ureteral stones by SWL following a failed initial treatment resulted in a considerable reduction in the SFR. On the other hand, early findings using fURS and laser lithotripsy for the treatment of proximal ureteral stones showed a high SFR of more than 95% (32). A prospective, multicenter trial with 71 patients who had solitary proximal ureteral stones (33) recently re-demonstrated the high success rate of fURS in the treatment of proximal ureteral stones, with an overall SFR of 95% and a SFR of 100% for stones less than 1 cm. In *Journal Urology*, a study conducted by Kijvikai *et al* pointed out a better success rate of URS for proximal ureteral lithiasis, especially for stones larger than 10 mm (34). However, the evaluation incorporates a variety of data from fURS and semirigid URS research. In the literature there is still little available data comparing both ureteroscopic procedures for ureteral stones.

Laser lithotripsy in ureteral stone treatment

Laser technology is extremely important in modern endourology, facilitating multiple types of endoscopic interventions, but especially in urinary lithiasis. This type of lithotripsy is the only way to fragment ureteral or renal calculi in the case of fURS or it can also be used in semirigid ureteroscopy, other than pneumatic and ultrasonic lithotripsy; this kind of lithotripsy can fragment all types of urinary stones (35, 36). For many years now, holmium (Ho:YAG) laser is the current lithotripsy standard. With the new technological advances and development of new technologies, the Thulium laser is gaining more and more popularity. Thulium fibre laser (TFL) outperforms Ho:YAG in terms of absorption coefficient by a factor of four when emitting pulsed infrared light at a wavelength that is near the water absorption peak. For stone lithotripsy, this correlates to a low threshold (37). Compared to Ho:YAG, cavitation bubble dynamics are also different, and TFL generates a stream of smaller bubbles. Thulium fibre laser is therefore anticipated to be quite effective at removing stones in clinical settings. When using the same energy settings, TFL lithotripsy may be up to four times faster than Ho:YAG, according to earlier laboratory experiments (38).

A recent prospective study published in 2023 (39) sought to compare the results of semirigid ureteroscopy using laser lithotripsy, Holmium *vs* TFL. A total number of 80 subjects were equally assigned to two study groups comprising 40 male and female patients each. Comparable total surgical time, total lasing time and stone fragmentation rates were found for TFL technology and Holmium laser, respectively. On the other hand, TFL had somewhat higher SFRs, better endoscopic vision and less retropulsion of stones. When comparing the complication rates of the two stone treatment techniques, the literature showed that TFL had a statistically reduced complication rate and shorter hospital stay due to a faster laser procedure and improved endoscopic vision (40, 41). A recent experimental investigation that evaluated stone ablation rates and retropulsion effects, which was published in the *World Journal of Urology* in 2020 (42), revealed higher outcomes with TFL in all comparison parameters. Another study published this year in the *Journal of Clinical Medicine* (43) compared the effectiveness of the two forms of laser available for lithotripsy of urinary stones. It conclu-

ded that TFL was more effective in lithotripsy of stones, but both types of laser were equally safe in terms of complications. A comparison of detailed specifications between high power Holmium laser and TFL is presented in Table 2.

The Holmium laser has been in use for over 30 years, being currently the most commonly used for lithotripsy of stones (4). However, the apparent benefits of TFL over the Ho:YAG laser (multiple times higher efficiency, wider and more complete parameter combinations, significantly reduced retropulsion, ease of use, versatility, scope miniaturization possibilities and increased safety profile) are simply too significant to be ignored. More studies are needed to fully understand how the Thulium laser can be developed and more to become the most frequently used in the treatment of lithiasis (37).

Flexible ureterorenoscopy in the treatment of abnormal renoureteral units

A separate category of patients is the one in which the retrograde approach of the ureter and kidney is desired using ureteroscopy. When ascending the ureter is difficult to achieve with the semirigid ureteroscope, the flexible instrument remains a viable alternative, although the data in the literature are few and uneven. A 2017 study published in the *World Journal of Urology* (44) followed the outcome of fURS in the treatment of 25 patients with anomalies of renal rotation, fusion or position. It concluded that for the treatment of kidneys with anomalies of lie, fusion and rotation, primary fURS was a successful and minimally invasive method. The Basket and Laser are essential fURS attachments for kidneys with anomalies (Figure 3).

A recent Cochrane review published by Lisa Lavan (45), including a total number of 14 studies (over 400 patients), followed fURS in the treatment of lithiasis patients with various malformations such as cross fused ectopia, horse-shoe kidney, ectopic kidney or malrotation. The authors found that, although ureteroscopy in individuals with anomalous kidneys could be technically difficult, improvements in endourological procedures have made it a safe and successful treatment. There is a high likelihood that these individuals remain stone-free, with little chance of serious complications. A study published in Urolithiasis (46) that followed treatment of 25 patients with different abnormalities such as lumbar or pelvic kidneys concluded that holmium laser lithotripsy associated with fURS was a successful treatment in abnormal renoureteral units. In the *International Journal of Surgery Case Reports*, William D. Aiken *et al* published (47) the first report of a complete bilateral obstruction of a complete duplicated ureter which was successfully managed using a flexible ureteroscope and Holmium laser. An extensive work published by Yung K. in *Urologic Clinics of North America* (48), which extensively followed the idea of ureteral lithiasis cases in various situations of renoureteral malformations such as pregnancy, aberrant anatomy, kidney transplants or urinary diversions, showed that fURS was a useful tool in the armamentarium of every urologist in the management of these cases. ❑

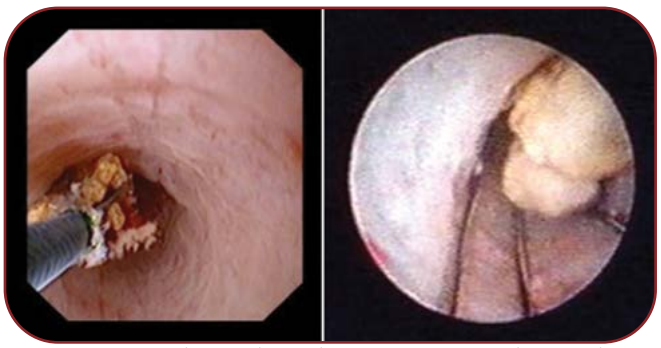

FIGURE 2. Basket probes relocating stones in abnormal kidneys (authors' collection)

CONCLUSION

The available literature data do not support the firm advantage of any of the described methods. The flexible ureteroscope is an extremely useful tool in the management of difficult cases of ureteral lithiasis and comes as a reliable adjunct in their management. However, semirigid ureteroscopy does not cease to be useful, considering that it can use any of the existing lithotripsy methods and can solve complex cases with a device that has earned its reputation in endourological lithiasis surgery. ❑

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