Future perspectives of flexible ureteroscopy

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Purpose of review
In the recent past, there were numerous and promising technological developments in the field of endourology leading to tremendous changes in the management of urolithiasis. This review will try to weave ancient stone therapy with the very modern advent of flexible ureteroscopy and recent developments in robotic systems.

Recent findings
In the broad field of flexible ureteroscopy for stone surgery, new disposable scopes have been developed and established. The use of robotic instruments is also a new and interesting concept. Additionally, clinical research on the understanding of laser features leads to a specific and appropriate use of lasers for lithotripsy, both holmium, and nowadays also interestingly thulium.

Summary
Disposable, digital flexible ureteroscopes for the treatment of both ureteric and kidney stones are taking an essential role in the medical field. Until recently, the clinically relevant laser systems for stone surgery during ureteroscopy are mainly based on Holmium laser YAG (Ho:YAG) devices, but a new thulium variant with promising features is giving interesting results. Additional research in laser features will guide to a better, more effective and safer treatment algorithm. Robotic technologies are promising but their definitive role still needs to be determined.

Keywords
disposable digital devices, endourology, flexible ureteroscopy, laser features, robotic instruments

INTRODUCTION

One of the oldest surgical practices undertaken by physicians is stone surgery. Hippocrates preferred to let lithotomists, instead of physicians, treat patients suffering from bladder stones. Somewhat more than 200 years ago, it was the Emperor Napoleon Bonaparte I who suffered from a bladder stone and febrile infection during the battle of Waterloo. One of the reasons why the French troops lost this battle might have been that simple but to this day most important bladder stone. His nephew Napoleon Bonaparte III also suffered from a bladder stone and died because of postinterventional complications, which was the case in almost up to 30% of treated persons. In the last century, modern stone treatment became a well tolerated and effective strategy. It was only in 1980 when the first human study of extracorporal shock wave lithotripsy on a kidney stone was performed with measurable success. As a result of this finding, a new era in minimally invasive treatment was established. In this new 'Stone Age,' although minimally invasive therapies remain the mainstay of treatment, there has been a notable increase in the use of ureteroscopes (URS), so that URS is now the most common surgical therapy for upper tract stones in most western countries [1,2]. One understandable reason for the shift in practice toward URS has been the widespread availability of the holmium laser, which permits lithotripsy in all stone locations. As a result of advances in laser technology, therapeutical options available to surgeons have expanded. The introduction of digital flexible scopes with their chip-on-the-tip technology with outstanding image quality and visibility changed the effectiveness of retrograde intrarenal surgery (RIRS) tremendously. In 1987, Bagley [3] published the first clinical study of disposable flexible ureteroscopes. The further evolution of these disposables was encouraged because reusable scopes had some

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Curr Opin Urol 2019, 29:113–117

DOI:10.1097/MOU.0000000000000575

KEY POINTS

- Laser features as pulse energy, frequency and pulse width are of great importance whenever defining optimal treatment of urolithiasis; in addition to the known holmium systems, a new thulium system seems to be promising.
- Disposable ureteroscopes are comparable with reusable scopes, analysis of local microcosting is useful whenever planning the right strategy.
- Robot-assisted surgery in urology is well established, additionally there is an interesting system for robotic ureteroscopy.

unfavorable particularities as availability, sterilization or partly high costs of repair. But retrograde intrarenal surgery is limited by ergonomic deficiencies during stone management, laser lithotripsy or basketing fragments. The surgeon usually stands and has to control the laser device by a foot pedal, while holding the position of the endoscope fixed with one hand and using a basket or laser fiber with the other [4]. On the basis of positive experiences with master–slave systems in laparascopic surgery, several groups focused on the usefulness of such devices for fURS trying to overcome most of these methodological obstacles [5–10].

LASER FEATURES NOW AND IN THE FUTURE

Laser systems for stone surgery during ureteroscopy are mainly based on Holmium laser YAG (Ho:YAG) devices. There are numerous laser fibers available for Holmium use for lithotripsy. There are reusable and disposable fibers in different sizes mainly from 200 up to 600 μm in diameter. The tip of the laser fibers, especially with reusable ones, can be sharp and cause damage to the expensive scopes. Therefore, ball-tip fibers have been developed. At the very tip of those fibers, industry put a ball of glass to allow a safe passage through the working channel of the ureteroscopes.

Aldoukhi *et al.* [11] distinguish between contact laser lithotripsy and noncontact laser lithotripsy. Contact laser lithotripsy leads to fragmentation when using high pulse energy or dusting when using low power with high frequency. Noncontact lithotripsy can pulverize small stones in a calyx into fine fragments, which some authors also call 'dustmenting.' Furthermore, Kronenberg and Somani [12▪▪] points out the importance of the movement of the laser fiber itself by the surgeon in order to treat the stone fast and effectively with low energy and high frequency. Modern consoles allow users to modify pulse energy, pulse frequency and pulse width to carry out the desired fragmentation technique.

There is a new technology for laser lithotripsy called the 'Moses effect.' The theory is that this lithotripsy mode emits a modulated laser pulse whose first part divides the water between laser fiber tip and the stone, allowing the second part of the pulse to hit the stone unobstructed, more efficiently and with less retropulsion. However, on a closer look at the official high-speed videos, it reveals to be made of two separate laser pulses with a short time interval between them, rather than a single 'modulated' laser pulse. Surgical opinions and in-vitro experiments have indeed shown that this 'Moses effect' reduced retropulsion [13,14] and is significantly more ablative; however, in-vivo experiments did not show any significant differences in terms of lasing and procedural times between regular and Moses lithotripsy techniques [13].

Another interesting perspective in the field of laser lithotripsy is the use of a thulium laser. Traxer [15▪▪] studied the SuperPulse thulium fiber laser and concluded that the wide range of settings (0.05–6 J; 5–2000 Hz) available for this laser allows efficient destruction of stones of any composition and location in both dusting and fragmentations modes. Also real dusting into sand-like particles is described to be possible as a totally new strategy being safe and extremely fast. In another, study Hardy *et al.* [16] analyzed thulium fiber laser-induced bubble dynamics for ablation of kidney stones. High-speed imaging of laser-induced bubbles was performed at 105 000 frames per second and 10 nm spatial resolution to determine influence of these laser parameters on bubble formation. The author concluded that thulium fiber laser bubble dimensions were four times smaller than for holmium laser due to lower peak power and smaller fiber diameter used. These interesting findings were also presented by Platonova *et al.* [17]. In this clinical study with 56 patients treated for urolithiasis, one of the results showed that thulium fiber laser can not only increase by several times the stone fragmentation speed, but also minimizes the risks of surgical complications because of less retropulsion and lower energy used for treatment. A well known disadvantage of thulium:YAG devices in terms of lithotripsy is laser fiber burnback as it might be enormous. Hutchens *et al.* [18] tested a 'fiber muzzle brake' for reducing both fiber burnback and stone retropulsion by manipulating vapor bubble expansion. Results were promising, clinical evaluation is still missing, however.

Laser can be dangerous when using it without the appropriate care. As laser energy is converted into enormous heat (at the very end of the Holmium

Table 1. Laser types, fibers, settings and safety profile

Laser lithotripter modification	Long pulse width	Short pulse width	Moses effect	SuperPulse Thulium
	Dusting	Fragmenting	Decrease in retropulsion	Small fibers/low energy
Laser fibers	**Ball tip**	**Diamond cutter**	**Steel scissors**	
	Safe passage through working channel	Allows precise cut	Allows precise cut	
Laser settings	**Fragmenting**	**Dusting**	**Pop-dusting**	
	Short pulse width/high energy (>1000 mJ)	Long pulse width/low energy (>500 mJ)	Medium pulse width – medium energy	
Laser safety and complications	**Local thermal damage**	**Collateral scope damage**		
	For example, long-lasing time/low irrigation flow	For example, firing laser within the inner sheath		

laser tip more than several thousand degree Celsius), irrigation fluid around the laser fiber can absorb this heat and consecutively harm the urothelial mucosa resulting into stenosis of, for instance, the ureter. Not only can laser energy induce thermal lesions, also an incorrect use of the fiber can damage or destroy the inner sheath of the fragile flexible scopes (when firing the laser with the tip within the working channel for instance).

In Table 1, different laser lithotripter modifications, laser fiber features and laser settings are described for clinical use in stone surgery.

REUSABLE AND DISPOSABLE FLEXIBLE URETEROSCOPES

The first disposable flexible ureteroscope for accessing the upper urinary tract was developed by Bagley in 1987 [3]. In recent years, the innovative technical evolution in the expanding field of endourology has been highlighted by a variety of single-use flexible ureteroscopes that are now commercially available [19▪,20,21]. Davis *et al.* [22] concluded in their review of 11 clinical and laboratory studies on 466 patients that single-use fURS demonstrate comparable efficacy and their selective usage in low-volume centers may limit the costs for repair of the reusable scopes. Deininger *et al.* [23] compared in a laboratory model, two single-use ureteroscopes (LithoVue, Boston Scientific Corporation, Marlborough, Massachusetts, USA; Pusen Uscope UE3011, Pusan Medical Technology, Guangdong, China) and one reusable ureterorenoscope (FlexXc, Karl Storz, Tuttlingen, Germany). Both single-use scopes showed measurable lower light emission, the reusable scope appeared favorable in terms of optical and technical characteristics. Interestingly, the intrarenal pressure was the highest with the Pusen Uscope, which might have a clinical impact on patient's safety. Emiliani *et al.* [24] tested the Pusen Uscope in a clinical scenario in 10 procedures concluding that the image quality, deflection and maneuverability decreased during the procedures. In a human cadaveric model LithoVue (Boston Scientific) seemed to be comparable with conventional ureteroscopes in terms of visibility and manipulation within the collecting system [25]. A recent and similar study compared two commonly used reusable digital ureteroscopes (Olympus and Karl Storz) to LithoVue in an ex-vivo experiment. The disposable LithoVue was analogous to the reusable digital scopes in regard to standard technical metrics and appropriate use of it may also represent cost effectiveness [26].

One important concern is the economic impact of the single-use instruments for stone surgery as their prices are in some cases remarkable. Taking this into account, Taguchi *et al.* [27▪] analyzed the microcostings for the clinical use of both reusable and disposable (LithoVue) ureteroscopes. In conclusion, total costs per case utilizing these two scopes were comparable. In another prospective matched-pair study, Mager *et al.* [28] demonstrated that costs for the disposable ureterorenoscopes exceed the costs of the reusables between 61 and 118 procedures per ureteroscope depending on the lower and upper price limits for the instruments and all devices in use.

ROBOTIC FLEXIBLE URETEROSCOPY

Keeping in mind past developments and findings, it is still a human surgeon working in an

Table 2. Comparison of two clinical studies of robotic flexible ureteroscopy

Parameters	Desai *et al.* [7]	Klein *et al.* [31■■]	Geavlete *et al.* [32]	Klein *et al.* [33]
Robotic device	Sensei (Hansen-Medical, Mountain view, California, USA)	Roboflex (ELMED Medical Systems, Ankara, Turkey)	Avicenna Roboflex	Avicenna Roboflex
Number of patients	18	266	200	395
Stone size/volume	10 (5–15) mm	14 (5–30) mm	24 (10–37) mm	1997.5 (98–13 253) mm^3
Total operating time	91 (60–130) min	96 (59–193) min	n.a.	96 (15–193) min
Robot docking	7 (4–18) min	4 (1–29) min	n.a.	3 (1–5) min
Console time	41 (21–70) min	65 (16–174) min	n.a.	65 (16–174) min
Intraoperative complications	0	2 (0.7%) failures of devices	0	0.2% (technical failure)
Complete stone disintegration	17 (94.4%)	258 (96.9%)	92.5%	n.a.

n.a., not available.

ergonomically suboptimal position, particularly in time consuming interventions with extended lasing time and significant radiation exposure. Especially in urology, robot-assisted operations as radical prostatectomy, reconstructive surgery like pyeloplasty or partial nephrectomy are of increasing importance. In the era of developing endourology, the design of a robotic device could represent an alternative to improve the ergonomic disadvantages of standard flexible ureteroscopy [6,7,29,30,31■■]. Successful clinical introduction of Avicenna Roboflex (ELMED, Ankara, Turkey) was able to show the advantages in concerns of ergonomics and to be a safe platform [4,7–9]. The system consists of an ergonomic console, integrated flat-screen and a joystick to move the scope, which is held by the manipulator of the robotic arm. Micro-motors move the steering lever of the hand-piece for deflection. Additionally, the robotic arm allows horizontal rotation, as well as forward and backward movements. Also the speed of the irrigation inflow can be adjusted. This system is until now the only robot especially developed for fURS with a CE-mark since 2013.

Up to date, Klein *et al.* published the biggest series with 395 patients treated for stones with a robotic system. Intraoperative complications are low in all the studies compared in Table 2, also Robot docking time is low. Operating time is comparable with standard fURS.

Nevertheless, future studies are necessary to evaluate the final role of robotic fURS as costs of purchase of the robotic system are still rather high.

CONCLUSION

The actual level of care in the field of stone surgery is well established and highly developed, being also a safe and effective treatment with a remarkably increasing number of patients in our hospitals. Although scientific efforts are widespread and clinical success like stone free rate and low postoperative complications like infections or postinterventional morbidity remains clearly acceptable, there are still improvements pending. Future developments in laser systems are challenging standard strategies and have promising features. Computerized, real-time identification of stone composition with automatically installed ideal laser settings, real-time measurement of extractable fragment size or geotagging of stone particles are possible upcoming scenarios. Until today, holmium laser treatment of kidney stones is the only effective and rational way in the clinical field of flexible ureteroscopy as probes for ballistic or ultrasonic lithotripsy do not match into the fragile working channels of those devices. The new SuperPulse Thulium laser seems to be a possible game changer as new strategies like real dusting the stone into sand-like particles with negligible retropulsion effect are notable. Disposable, digital flexible ureteroscopes are comparable with standard digital reusable ones in terms of image quality and maneuverability. Future developments concerning hygiene and sterilization issues will be of great interest in this expanding field of medicine, not only in urology but also, for instance, in pulmonology or gastroenterology. The use of robotic assistance in ureteroscopy remains interesting, costs are a major burden.

Acknowledgements

None.

Financial support and sponsorship

None.

Conflicts of interest

A.S. is an advisor for Boston Scientific.

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