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REVIEW

Laser Lithotripsy in Renal Lithiasis – 2023 Update – a Narative Review

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ABSTRACT

Introduction: *Urolithiasis is a serious health issue that is constantly getting worse around the world. In relation to laser lithotripsy, new techniques and technological advancements have emerged, giving urologists a wide range of choices for treating stone disease. The objective of the present review is to provide an overview of the most current developments and show how effective they are for reducing complications and boosting surgical effectiveness.*

Material and method: *In October 2023, we performed a comprehensive search of the literature, including relevant articles using the PubMed international database to identify related publications concerning ureteroscopic laser stone lithotripsy in renal lithiasis. Both review and original articles were selected. Searches were limited to studies written in English which involved human and adult subjects.*

Results: *All eligible studies concerning ureteroscopic laser lithotripsy were published in 2022 and 2023. They were conducted in Asia (5/10), the North America (3/10) and Europe (2/10), and totalized 1570 patients with an age range between 18 and 85 years. Regarding the primary efficacy outcome, all studies focused on stone free rates (SFRs), complications and average operative time.*

Conclusion: *The rising frequency and incidence of stone disease has led to ongoing breakthroughs in endourology through technological advancements and ongoing developments. Unlike the relatively well-known Holmium laser, which has several uses in the field of stone lithotripsy, Thulium fiber laser (TFL) is a brand-new technological arrangement.*

Keywords: Holmium laser, laser lithotripsy, Thulium laser.

INTRODUCTION

Urolithiasis is a major health concern that is becoming more common worldwide (1, 2). Shockwave lithotripsy and ureteroscopic fragmentation and retrieval are commonly used for stones with a diameter of 1-2 cm; ureteroscopy has a greater stone-free rate (SFR) and requires fewer treatments than shockwave lithotripsy (3, 4). The European Association of Urology (EAU) guidelines for 2023 (5) stated that renal calculi with a diameter lower than 2 cm should be treated with retrograde intrarenal surgery or extracorporeal shockwave lithotripsy, while those with a diameter greater than 2 cm should be treated with percutaneous nephrolithotomy (PCNL).

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For the treatment of stone illness, urologists today have many options due to advanced technology and new approaches. Many years have passed since Marshall (6), Fernstrom and Johansson (7) invented PCNL and flexible ureteroscopy (f-URS). Over the past ten years, ureteroscopy has been the most commonly used treatment for treating upper urinary tract stones, as opposed to shock wave lithotripsy (8). Technological developments in scope size, design and optics have been instrumental in this shift. The use of ureteroscopy has witnessed a significant increase, which is explained to a large extent by the availability of a wide range of instruments that have made it possible to treat stones with ever-increasing precision and efficiency due to the novel technologies and instrumental miniaturization. Saline solution is still a crucial irrigation fluid in many endoscopic treatments.

The progress of laser technology was a significant advancement in the development of this surgical specialty. Despite the development of many other possibilities, the Holmium:yttrium-aluminum-garnet (Ho:YAG) laser, which is referred to as Holmium laser in our article, has been the cornerstone laser platform for intracorporeal endoscopic stone lithotripsy for more than 20 years (8, 9). Consequently, it has been recommended as the "gold standard" among a number of distinct international guidelines (10). A novel laser cannot be accepted as a practical solution and implemented widely until it proves that it possesses a number of critical attributes, including longevity, safety, a high SFR and clinical efficacy. Delivery *via* a small fiber can limit retropulsion, support better manipulation of a flexible scope and enhance irrigation – especially if pulse energy (PE, the total energy delivered by the fiber in a single pulse) is not compromised (11). Thulium fiber laser (TFL) is the most current development in laser technology, that was initially reported to be used for stone lithotripsy in 2005 as part of an *in vitro* investigation (12). Since it was originally described for use in stone lithotripsy, it has drawn more attention for this function. Ever since, there have been a growing number of studies looking into its potential for use in both preclinical and clinical settings. Besides its efficiency for stone lithotripsy, TFL demonstrated its applicability for tissue surgery, like brain, soft tissue and prostate. ❑

MATERIAL AND METHOD

In October 2023 we performed a comprehensive literature search in PubMed database in order to identify relevant articles concerning flexible ureteroscopic treatment using laser lithotripsy. Both review and original articles were included. Searches were limited to studies written in English, which involved human and adult subjects. Relevant studies, which were published between 2022 and 2023, were found using the following search terms: 'laser lithotripsy' OR 'ureteroscopic laser lithotripsy' OR 'renal stone laser treatment' OR 'laser ureteroscopic lithotripsy'.

The final studies were selected based on the following inclusion criteria: no limitations on the quantity or location of stones; only English language content; treatment of renal stones using laser lithotripsy. Furthermore, at least one of the following outcomes for fURS is reported in the original comparison studies: SFR, treatment session, duration of surgery, total complications, or Clavien grade complication. However, we did not include studies that met any of the subsequent exclusion criteria: (1) patients under the age of 18; (2) research submitted as conference abstracts or presentations; and (3) neoplastic patients featured in studies. ❑

RESULTS

The literature search turned up 248 papers, of which 238 were disregarded due to a lack of relevance as determined by their titles and abstracts, which did not specifically mention ureteroscopy or laser lithotripsy. Studies were also excluded if they investigated patients either aged under 18 years or suffering from neoplasia. Table 1 shows plots for all studies reported on the variables listed in the data extraction section (13-24).

All selected studies regarding ureteroscopic laser lithotripsy were published in 2022 and 2023. They were conducted in Asia (5/10), North America (3/10) and Europe (2/10), and totalized 1570 patients with an age range between 18 and 85 years. Regarding the primary efficacy outcome, all studies explored SFRs, complications and average operative time.

Three studies revealed that the use of Thulium-laser lithotripsy results in shorter operative time and a better SFR than Holmium-laser lithotripsy (14, 18, 24). Two studies showed com-

TABLE 1. Patients' demographics

Author	Journal	Center (country)	Year	Number of patients	Age
Shrestha A.	*World J Urol*	Nepal	2022	120	Not mentioned
Ulvik O.	*Eur Urol*	Norway	2022	120	18-84
Kristian M Black	*World J Urol*	USA	2022	Not mentioned	Not mentioned
Chen Bo-Han	*J Clin Med*	Taiwan	2022	421	20-80
Ryan J	*World J Urol*	USA	2022	152	Not mentioned
Pietropaolo A	*Ther Adv Urol*	UK	2022	284	18-85
Nikoufar P	*Journal Endourol*	Canada	2023	111	Not mentioned
Xu LW	*Zhonghua Yi Xue Za Zhi*	China	2023	76	45.7±14.1
Hui Xie	*Altern Ther Health Med*	China	2023	106	Not mentioned
Vaddi Chandramohan	*Urol Ann*	India	2023	180	38.4±12.2 and 40.3±10.4

parable results between TFL and pulse-modulated Holmium MOSES laser (21, 22). In a study using a Holmium laser to treat renal stones, the total energy used and J/mm^3 were lower in the low-power group than the high-power group with similar lasing duration, operative duration, ablation speed and SFR (13). In contrast, another study found that when using a high-power laser to treat lower-pole stones, ureteral access sheath (UAS), postoperative stent and procedural time were significantly reduced when compared to the low-power group. ❑

DISCUSSION

Since the introduction of Holmium laser – which supplanted earlier lasers such as the pulsed dye laser – in urological practice, in 1992, it has quickly emerged as the industry standard (21). Its method of operation rather depends on a photothermal effect than on a photoacoustic effect to cause stone fragmentation, in contrast to the latter and the neodymium:YAG laser (22). An ongoing study has spurred the progress that has led to its current condition (23). These days, a variety of hybrid tactics can also be used based on the ability to combine high frequency (40–50 Hz) and low energy (0.2–5 J) in contact mode. This has resulted in the phenomena known as "dusting," in which the stone breaks down into submillimeter particles that naturally escape (24). Using non-contact lithotripsy, also referred to as "pop-dusting" or "popcorn" lithotripsy, can boost stone clearance even further. This eliminates the possibility of a basket retrieval requirement, which may shorten operating times and eliminate the necessity for a UAS, both of which may result in more problems (25).

Technology advancements have made it possible to employ a large range of power sources for ureteroscopic lithotripsy. Chen and colleagues (16) found that, at their institution, laser lithotripsy outperforms pneumatic lithotripsy in terms of the stone-free rate and the secondary intervention rate for stones of all sizes. In addition, Yin *et al*.'s meta-analysis revealed that laser lithotripsy outperformed pneumatic lithotripsy with a high SFR and a low migration rate (26). When utilized appropriately, the laser generator offers a very useful instrument for fragmenting stones in the urinary tract with very few extra safety risks.

Because of its exceptional safety profile and capacity to shatter stones of any composition, Ho:YAG is the most widely used laser source for f-URS. Given that Ho:YAG has a modest penetration depth and high absorption capacity in water, the surrounding tissue is not severely damaged. The fiber's tip is where the laser is created and releases its energy. After that, stones break down into dust or fragments. Depending on the manufacturer and the type of laser console being used, the pulse energy and frequency settings of the Holmium laser typically vary from 0.2 to 2.0 Joules and 4 to 80 Hertz, respectively. While variations in frequency had little impact on retropulsion when the energy and fiber diameter were held constant, stone retropulsion increases with increasing pulse energy.

More recently, Moses technology, which employs a 120 W generator (Lumenis Pulse P120H) and the Vapor TunnelTM (Quanta System, Samarate, Italy), has been presented as a fresh potential solution to this problem. This technique was developed by Quanta System and it has been adapted on the basis of "Moses effect" theory that was previously mentioned (27). The remarkable pulse-shaped modulation of this method allows energy to be provided in two separate stages.

In a study using Moses technology, Kristian M. Black found that pulse modulation led to more fragmentation at lower frequency and power level settings through true non-contact laser lithotripsy (15).

Furthermore, in a study on 120 patients Anil Shrestha *et al* concluded that the total energy used and J/mm^3 were lower in the low-power group than the high-power group with similar lasing duration, operative duration, ablation speed and SFR for renal stones less than 2 cm (13).

A study conducted by Amelia Pietropaolo *et al* demonstrated that the use of a high-power laser for lower-pole stones resulted in a considerable reduction in the need for UAS, postoperative stent and procedural time. Even with relatively larger stone sizes, the SFR was greater in the high-power group, albeit not statistically significant; this was also reflected in a lower rate of sepsis-related complications with these lasers (19). Their study shows how a high-power laser can shorten the operative time, which translates into a reduction in infectious complications and urosepsis, in addition to treating larger stones as compared with low-power lasers. This is one of the first studies in the literature looking at the role of different laser power settings for the treatment of lower pole stones. Their results were achieved with 'dusting and pop-dusting' techniques using the higher power laser. Despite treating significantly larger stones ($p < 0.001$), the employment of UAS was significantly lower ($p = 0.001$) as was the postoperative stent usage ($p < 0.001$).

The light source for TFL is rather a diode than a system of flash bulbs, which means that hardly much energy is lost as heat and a basic built-in air-cooling system is all that is needed. High-power settings are possible with this kind of cooling system (up to 500 W in super pulse mode).

In a study comparing the use of thulium laser and Holmium laser fiber on 120 patients, Øyvind Ulvik *et al* found that, when using TFL instead of Ho:YAG, a considerably higher number of patients with kidney stones reached a stone-free status and fewer had intraoperative problems (14).

In a study including 111 patients, Parsa Nikoufar *et al* observed that, while TFL laser systems and MOSES laser systems were equally effective for lithotripsy of renal calculi during f-URS, TFL lasing times were longer for calcium phosphate stones (21).

Vaddi Chandramohan *et al* showed that TFL was faster and more effective than Holmium:Yag laser, with comparable side effects in both groups. While Xu LW *et al* demonstrated that TFL lithotripsy was a safe and effective surgical procedure for the treatment of upper urinary tract stones, with a shorter laser action time compared to Holmium laser lithotripsy, SFR was also similar between the two groups (24).

Moreover, in a meta-analysis of clinical studies contrasting TFL against Holmium:YAG laser, Michael Chua found no inter-group difference for SFR. However, TFL was found to produce a higher SFR than Ho:YAG without pulse modulation, with shorter operation and laser use periods, less retropulsion and a higher ablation rate being observed in favor of TFL use. For the composite postoperative complication rate, ablation efficiency, total energy expenditure and hospital stay, there was no overall inter-group difference (28).

In a trial on 50 patients, Alba Sierra *et al* used low pulse energy and low pulse frequency and found that the novel TFL laser was a safe and effective approach for lithotripsy during RIRS (17).

Furthermore, James R. Ryan demonstrated that TFL was substantially less expensive and requires less time in the operating theater when compared to the conventional Ho:YAG for URS with laser lithotripsy for comparable size of kidney stones and patients' characteristics (18). Their study showed that, with no discernible difference in surgical time depending on stone location, composition, ureteral access sheath use, pre-stenting, obesity, or laterality, it was discovered that the use of TFL reduced operative time by around 20%. Notably, when endourologic fellowship training, the presence of a resident, or the resident experience was considered, there was no statistically significant difference in number of cases performed between the Ho:YAG and TFL groups. In total, 11 distinct attending surgeons executed laser lithotripsy within each group, with residents participating in almost 60% of cases. Since there are so many different treating providers, it is highly improbable that the TFL technology is to blame for the observed reduction in treatment times, even if it were due to the method or ability of a subset of surgeons. ❑

CONCLUSION

As a direct result of the increased incidence and prevalence of stone disease, endourology is always being advanced through continuous developments and technological advancements. Unlike the relatively well-known Holmium laser, which has several uses in the field of stone lithotripsy, the TFL is a brand-new technological arrangement. ❑

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