Basic and advanced technological evolution of laser lithotripsy over the past decade: An educational review by the European Society of Urotechnology Section of the European Association of Urology

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ABSTRACT

Laser disintegration of urinary stones is a cornerstone of urolithiasis treatment in the modern era. Despite the wide clinical use of stone lasers, basic and advanced technological achievements and developments are difficult to comprehend and interpret by the average urologist. A descriptive analysis of laser production and stone disintegration mechanisms was performed. We focused on physics of modern types of lithotripters, the construction of laser fibers, laser parameters, new modes, settings, and lithotripsy techniques. The main principle of laser emission remains the same since the first emitting laser was produced. Peak power density and short interaction time lead to photothermal effects responsible for stone disintegration. Modern lithotripters such as Holmium: YAG (low/high power, Moses technology) and thulium fiber laser show basic construction differences with the physical properties of the latter being superior, at least in in vitro studies. By adjusting lasing parameters, a wide spectrum of stone ablation from fragmentation to dusting can be achieved. New technology allows for the production of real dust. Knowledge of laser fiber construction and physical properties are useful in marketing and clinical use. Urologists should understand the physical and physiological background of the lasers used in their everyday practice for stone fragmentation.

Keywords: Laser, lithotripsy, Holmium laser, Thulium fiber laser, settings, technique

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Introduction

Since 1968, when Beck and Mulvaney introduced the ruby laser,[1] a lot of advances have been made regarding laser technology and its use in the field of urology. A lot of research has currently resulted in upgrades and more effective and equally safe lithotripsy for stone disease.[2] In this study, we aimed to highlight the evolution of the basic and advanced laser technology that every urologist should be familiar with.

Material and methods

We underlined the theoretical aspects of laser production used in lithotripsy and focused on physics, laser parameters, new laser modes, settings, disintegration techniques, and consumables. The review article was based on a search of MEDLINE, EMBASE, Cochrane Controlled Registry of trials, and Google Scholar. We searched for English language studies using the keywords, "laser," "lithotripsy," "lasertripsy," "Ho: YAG," "TFL," "power," "settings," and "technique" using the Boolean operator (AND , OR) to refine research. Because of the heterogeneity of technological parameters, a meta-analysis was not possible, and a narrative synthesis has been carried out.

LASER production and stone disintegration mechanisms

Light amplification by stimulated emission of radiation (LASER)[3] is the mainstay of calculi disintegration during ureteroscopy and the recently implemented minimally invasive percutaneous surgery. The main principle of laser emission remains the same since the first working laser emitter was constructed. A stimulated

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source, enclosed in an optical chamber with opposing mirrors, emits white light that passes through a solid, liquid, gas, or plasma active medium. As the medium absorbs energy from the light, electrons are raised into a higher energy state. On coming down to a lower energy level, photons are emitted, which are reflected along the optical chamber with opposing mirrors generating the laser beam. The light is eventually amplified by a repeated stimulated emission of photons.[4]

Lasers used for stone disintegration differ based on the light source generator and the absorptive active media they are constructed of. It is of paramount importance to understand that the heat produced by various light generator sources and active media differs as does the wavelength of the laser. The former requires cooling and determines the wall plug efficiency of the laser: how much of the main power supply is converted into laser power.[5, 6] The latter is based on the material the active medium is structured of and the doping that covers it, and mainly determines, along with various tissue properties, the depth of tissue penetration of the beam. The extinction length, the depth at which 90% of the incident laser energy is absorbed and converted into heat, measures the laser's penetration.[4] Taking into consideration the water component of urinary calculi and its surrounding environment, the laser wavelength necessary for stone disintegration and safety of the surrounding tissues should be very near the absorption peak of water (1940 nm).[4, 6]

In addition, stone disintegration requires a pulsed laser excitation.[7] When excitation is effected in a single pulse or in on-line pulses (free-running mode), peak power densities of 10^5 W/cm^2 can be developed for duration of 10 ms to 100 μsec. Storing the excitation energy and releasing it suddenly (q-switch mode or mode-locking) leads to a peak power density increase of up to 10^{10}–10^{12} W/cm^2, and pulse duration of 100 nsec to 10 psec. It is this high effective power density and the short interaction time that leads to photothermal (1 msec–100 sec; 1–10^6 ^{W}/cm^2) and photomechanical (10 psec–100 nsec; 10^8–10^{12} W/cm^2) effects of the laser beam necessary to destroy urinary calculi in different laser types.[7] The long-pulse Holmium:YAG (Ho: YAG) laser is not known to produce shock waves owing to plasma expansion at the onset of laser irradiation;[4] and as so it is unlikely a photomechanical mechanism to be the dominant stone disintegration mechanism. The most important optical parameter that determines the complex photothermal effect, the principal lithotripsy mechanism, is the laser wavelength. The heat accumulated by the laser radiation is absorbed by the stone surface inside the calculus and generates an immediate build-up of pressure that causes chemical decomposition of the calculi.[8]

Main Points:

- Laser production principle remain stable since its invention.
- Laser peak power density and lasing interaction time determine the photothermal phenomenon.
- TFL lithotripter seems to be superior to Ho:YAG lithotripters at least in in vitro studies.
- Take into advantage the wide spectrum of laser settings and individualize patient and stone treatment.

Modern Types of Laser Lithotripters

Holmium: YAG Laser

Ho: YAG laser is produced by a flash lamp generated light, emitted onto an Yttrium-Aluminum-Garnet crystal doped by chromium, thulium, and holmium ions. Chromium absorbs white light and transfers energy to thulium ions, whereas thulium ions share low energy levels among each other, thus increasing the final energy level reaching the holmium ions. The interaction between thulium ions allows better temperature control of the crystalline laser rod and enables the Holmium laser to keep lasing in a repetition mode and operate at room temperature.[4]

Ho: YAG laser operates at a wavelength of 2120 nm, is highly absorbed by water, and disintegrates calculi through a photothermal effect.[4, 6, 8] The physical properties of Ho-YAG laser allows for fragmentation of all stone compositions and densities.[6] Concurrently, the pulsed mode of laser excitation runs so quickly that thermal conductivity and thus thermal effects on urinary tract wall have almost no impact. In addition, the depth of tissue penetration is 0.4 mm, which means no significant harm is done when the laser fiber tip brushes the urothelium accidentally and occasionally.[9] The last two characteristics underline the high safety profile of the Ho: YAG laser during stone intracorporeal lithotripsy.

Ho-YAG laser devices were initially marketed with a power output of 15–20 W. Recently, devices with multiple laser producing cavities and outputs of 120 W are available for lithotripsy, which will decrease the procedural time.[10] However, the low wall-plug Ho: YAG machines' efficiency of 1%–2% equals the 98%–99% wasted energy transformed into heat within the device necessitating massive water cooling systems. As a consequence, the size, weight, and cost of the device increase significantly having a negative impact on operating room ergonomics.[6]

Thulium: YAG and Thulium fiber laser

Thulium: YAG laser is produced by high-power, diode-laser generated light, emitted onto an Yttrium-Aluminum-Garnet crystal that is doped by thulium metals.[5] The solid-state design of the Thulium: YAG laser operates at 2010 nm in a continuous mode and is not suitable for stone treatment.[5] Recent advances have resulted in the diode laser produced energy to be entirely generated in a chemically Thulium-ion doped small laser fiber, hence the term “fiber laser.”[5, 11] The energy is then transferred to another thin silica fiber through which it is delivered to the stone.[11] Over the past two decades, studies on thulium lithotripsy were performed with a modulated 100 W continuous wave TFL.[12] The new fiber laser provides five times higher peak power (500 W), hence the term “superpulse.”[12]

TFL operates at wavelengths of either 1908 or 1940 nm and thus has a four to five times higher absorbed peak in water compared to Ho: YAG lasers.[5, 9] As current thulium technology is capable of pulsed laser emission, TFL is suitable for lithotripsy. Calculi are disintegrated mainly through a photothermal effect and lesser through a photomechanical effect[13] and because of increased water absorption, the TFL ablation threshold is lower and as such, stone fragmentation is superior to Ho: YAG lasers.[5] Similar to holmium lasers, the physical properties of thulium laser radiation allows for fragmentation of all stone compositions and densities.[14, 15] In addition, the safety profile of TFL may be more favorable than Ho: YAG lasers as the vaporization of water by thulium laser leads to smaller bubble formation with lower collapse pressures.

Most of the evidence on TFL relies on preclinical studies showing some promising advantages compared with holmium lithotripters.[12, 15-17] TFL shows a symmetrical, focused, and near-single mode beam compared with Ho: YAG’s non-uniform, multimodal beam.[5] This is expected to show important clinical benefits as fibers of smaller diameter, 50/100/150 μm are tested for TFL and cannot fit into the Ho: YAG laser.[5] Smaller fibers may allow better irrigation and scope maneuverability during flexible ureteroscopy. In addition, compared with Ho: YAG laser, TFL emits in pulse energies as small as 25 mJ (versus 200 mJ) and frequency as high as 2000 Hz (recently, 2400 Hz[18]) (versus 80 Hz), with a longer and more uniform shape pulse width. As the pulse energy (PE) may go up to 6 J, peak power of 500 W could be achieved with TFL.[13]. The very low pulse energies, the higher frequencies, and the longer pulse durations are features that Ho: YAG lasers do not have. These characteristics may prove beneficial for urinary calculi dusting with the TFL.[5, 11]

Using diode lasers instead of flash lamps to emit light, less heat is produced within the TFL device compared with Ho: YAG lasers, resulting in greater wall-plug efficiency (12% vs 1%–2%). As a consequence, fan ventilation seems to be adequate for TFL even when operated in high frequencies. Moreover, owing to a lack of mirrors inside the beam-producing cavity, the TFL system is less sensitive to vibrations. All these advantages are incorporated into small, tabletop devices with power outputs of 50 W, compared with the tabletop versions of Ho: YAG that reaches up to 20 W.[19-21]

Laser Parameters, New Modes, Settings and Techniques of Lithotripsy

Laser parameters

Modern laser devices provide the possibility to intraoperatively modify various parameters depending on the clinical need.

PE, the energy of each laser pulse, is considered to be the most important parameter for stone disintegration. Ho: YAG lasers allow PE settings of 0.2–6.0 J[22] and TFL between 0.025–6.0 J[23]. Higher PE leads to greater fragmentation but at the expense of higher stone retropulsion and fiber-tip degradation.[24, 25]

Pulse frequency, the number of pulses produced per second, is less important for fragmentation but plays a significant role in stone dusting. Newer Ho: YAG lithotripters function up to 80 Hz[11], whereas TFL devices can reach up to 2400 Hz,[18] although frequencies up to 500 Hz are reported for experimental lithotripsy.[26]

Laser power, as determined by multiplication of frequency and energy, define the energy delivered per unit of time. Ho: YAG lasers units can be either low power (20–30 W) or high power (80–120 W). TFL devices currently operate at 50 W. It seems that power per se is not the most important parameter for the actual effect on the stone during the lithotripsy procedure. It is the modification of the equation parameters, energy, and frequency that lead either to stone fragmentation or dusting.[24] Traditionally, the preferred initial laser settings were 0.6–0.8 J at 6–8 Hz.[4, 27]

Pulse mode (pulse width [PW], pulse length, and pulse duration) defines the length of time during which the same amount of energy is delivered. Ho: YAG laser PW ranges from 150 to 1300 μS, whereas TFL ranges from 200 to 12000 μS.[11] With most initial Ho: YAG laser devices, the pulse duration was mainly driven by the activating discharge tube and could not be adjusted by the operator. As such, most of the machines were set at a fixed short pulse (SP) mode ranging from 150 to 350 μS.[4] Modern laser devices allow lengthening the PW during the lithotripsy process and promotes a more “dusting” technique.[4] As such, long pulse (LP) mode seems to be more effective on softer stones (up to 60% more ablative).[28] Reduction in retropulsion of 30%–50% have been reported when using LP mode.[29] At equal pulse energies, the stone retropulsion threshold is up to four times higher with TFL.[30] Moreover, LP also reduces laser fiber tip degradation.[31]

Despite the aforementioned evidence of greater stone ablation with SP lithotripsy, there is still great controversy on the topic as some studies showed equal efficiency for both LP and SP modalities and less retropulsion for SP mode compared with the high-power LP mode.[32]

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Table 1. Comparison of Ho: YAG and TFL lasers

Parameter	Ho: YAG Low Power	Ho: YAG Medium Power	Ho: YAG High Power	Ho: YAG High Power (Moses)	TFL Superpulse
Wavelength	2,120				1,940
Light source	Flash lamp				Diode laser
Active Medium	Yttrium Aluminum Garnet Crystal				Thulium Fiber Crystal
Doping	Chromium Thulium Holmium Metals				Thulium Metals
Laser Cavity	1		➢1		1
Beam	Multimode 3-5 mm				Single mode 18 μm
Electrical efficiency	Low (<1%)				High (>5%)
Electrical requirements	220 V outlet				110 V outlet
Cooling system	Water cooling				Air cooling
Sensitivity to vibration	High				Low
Mode of emission	Pulsed				Pulsed
Maximum Power Output	20 W	30-60 W	80-100 W	120 W	50 W
Pulse energy (J)	0.2-1.2	0.2-1.2	0.2-6	0.2-6	0.025-6
Pulse frequency (Hz)	5-15	5–25	5-50	5-80	1-2000
Pulse width (μs)	350	350-1300[1]	350-1300	350-1300	200-1200
Mechanism of action - Effect	Photothermal				Photothermal Photomechanical
Penetration	0.4 mm				0.4 mm
Optical fiber	Low-OH Silica				Low-OH Silica
Core laser fiber size (μm)	>200				>50

[1]May not be available
Ho: YAG: Holmium: Yttrium-Aluminum-Garnet: TFL: Thulium fiber laser;

New Laser Modes

Moses technology

Irrespective of short or long pulse length, laser energy during Holmium laser emission is delivered in one pulse. Most of the energy is consumed to create the vapor bubble that in turn transfers its energy onto the stone. Moses technology recently modulated the energy to be delivered over two pulses through a high-power 120 W device. The vapor bubble is created by the energy consumed during the first pulse, whereas the rest of the energy, which is delivered with the second pulse, reaches the stone through the already formed vapor channel.[33, 34] In theory, this technology, whether it is applied in contact with the stone or from a 1–2 mm distance, delivers more energy to the stone compared with the single pulse mode technique[34]. Elhilali et al.[33] and Ibrahim et al.[35] have shown reduced stone retropulsion and greater ablation rates using this technology. However, Mullerad et al.[36] have failed to achieve statistical significance for shorter lithotripsy duration, whereas Stern et al.[37] have not shown cost effectiveness of this method because of expensive software and special fibers used.

Burst ithotripsy

In accordance with the two pulses technology, burst laser lithotripsy delivers deescalating energy through three pulses of increasing length emitted in rapid succession one after another. Improved ablation rates of 60% have been reported compared with standard lithotripsy at similar power and energy settings.[28]

Lasing Settings and Techniques of Lithotripsy

The ideal goal of lithotripsy is to completely destroy the stone without leaving residual stone fragments of any size.[38] Contact laser lithotripsy is the first and often the only step needed to complete urinary stone disintegration. Contact lithotripsy is achieved through two ways: stone fragmentation and removal of pieces with a basket or stone dusting until the formation of tiny particles that will spontaneously pass through the urinary system. As the surgeon approaches the stone, a strategic plan of how to proceed should be made on the basis of their experience and preference, the stone size, location, and hardness, the instruments and consumables available as well as the laser type and device provided.[11, 39]

Table 2. Techniques and settings of Ho: YAG Laser Disintegration

Technique	Energy (J)	Frequency (Hz)	Pulse width	Uses
Fragmentation	High (0.8-1.4)	Low (6-10)	Short	Hard stones Creates fragments UAS needed Increased retropulsion Increased fiber tip degradation Increased OT Bladder stones and PCNL
Dusting	Low (0.2-0.5)	High (10-70)1	Long	Soft stones Creates fine dust Decreased retropulsion Less need for UAS Increased OT in hard stones Decreased fiber tip degradation Preferred initial technique
Pop-Corning	High (1.0-1.5)	High (15-40)1	Long	Larger residual fragments Use in 2 mm distance from the bulk Use in an non-dilated calyx High fiber tip degradation
Pop-Dusting	Low (0.2-0.5)	High (50-80)1	Long	Smaller residual fragments Effect of pop-corning Low fiber tip degradation

[1]Frequency settings depend on the availability of the machine and the location (ureteral/kidney) of the stone
Ho: YAG: Holmium: Yttrium-Aluminum-Garnet: UAS: ureteral access sheath; PCNL: percutaneous nephrolithotomy; OT: operation time

There are limited data comparing stone fragmentation to dusting. The level of evidence is low as there is only one randomized controlled trial and a few prospective comparative studies. They reveal no superiority for stone-free rate (SFR), complication, and re-intervention rates through any of these methods.[40-42] However, unplanned hospital visits were higher when fragments were left for spontaneous passage.[40] There are several drawbacks of the aforementioned studies, including treating different stone sizes among the two groups, lack of documentation of settings in the dusting group, and limited use of computed tomography (CT) scan to document stone-free status, and underline the cautious interpretation of their results.[40, 41] Hardy et al.[13] performed a preclinical study to compare dusting modes of Ho: YAG laser and TFL and observed higher ablation rates and smaller residual fragments with TFL using the same settings. Another study underlining the use of dusting comes from Pietropaolo et al.[43], who used dusting and pop-dusting for large stones≥15 mm and achieved SFR>90% with a low complication rate.

The stone can either be fragmented or dusted depending on the laser settings. High energy and low frequency results in stone fragmentation, whereas low energy and high frequency results in stone dusting.[41] When stone fragmentation and basketing of the fragments is done, the surgeon has to create small pieces, preferably starting at the periphery of the stone, by placing the fiber in contact focused on one point until the stone breaks. Fragmentation occurs with high PE (0.6-1.2 J), low pulse frequencies (6–10 Hz), and short pulse durations (<500 μs).[4, 22, 24, 44] With fragmentation settings, the TFL ablates twice as fast as Ho: YAG laser.[45] Care should be taken to fragment the stone in pieces small enough to remove through a ureteral access sheath or a percutaneous sheath. The bigger the stone being treated, the higher the number of removable fragments.[11] In addition, fragmentation has inherent disadvantages such as the need to use access sheaths and baskets, which are not devoid of potential pelvicalyceal or ureteral trauma. In addition, having to remove numerous fragments increases the operative time (up to 20%–40%).[46]

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Stone dusting bypasses the aforementioned drawbacks but is more time consuming. Dusting requires low PE (0.2–0.5 J), high frequencies, and preferably long pulse lengths.[47] A recent survey showed that the settings most commonly used by urologists are around 10 Hz and 0.8 J.[27] Modern high-power holmium lithotripters provide high frequencies of up to 80 Hz and when used in an LP mode, increases the speed of the lithotripsy procedure.[10] With dusting settings, the TFL ablates four to five times faster than the best Ho: YAG lasers.[45] Although there is a lack of strong evidence, it seems that increased frequency does not affect stone retropulsion, provided that energy levels and pulse modes are kept constant during lithotripsy.[10, 48]

Although stone dusting should result in dust, it is common to end up with small fragments of 2 mm or less. These small fragments are difficult to focus and laser and take time to disintegrate or completely remove. Non-contact lithotripsy techniques are used to further pulverize these small particles. Non-contact infers to placing the tip of the fiber in a small (<2mm) distance from the bulk of the fragments. Longer distance and working in a dilated calyx disperse energy and makes lithotripsy less effective.[49] Traditionally, the so called "pop-corn" technique is applied by using high PE (1.5 J), associated with a high frequency (20–40 Hz), LP mode, as well as a small-diameter laser fiber.[39, 42, 50] Alternatively, the "pop-dusting" technique applies low PE (0.5 J), in association with high frequency (40–80 Hz) and LP mode, a combination that creates finer fragments without compromising fiber tip burn-back.[10, 25, 49] TFL produces at least twice as much dust even when compared with Moses technology.[51] The resulting mean stone particle sizes are significantly smaller in all size categories of less than 1 mm or 0.5 mm.[13, 52]

In summary, we recommend starting the lithotripsy session with lower PE levels and longer pulse lengths to achieve small fragments and minimize stone retropulsion and fiber degradation, in association with very high frequencies to speed up the procedure. The laser fiber should be moved uniformly over the stone without chipping or fragmenting the stone. During the procedure, adjustments of the settings may be needed according to the resulting fragment size, and pop-corn technique may be required to finish the procedure.

Lasing speed

Lasing speed depends on many parameters, namely the type and settings of the laser and the speed of fiber move.

The new high-power Holmium lasers are capable of attaining much higher PEs and very high pulse frequencies, parameters that enable the ability to dust urinary stones quicker and with more efficiency. However, the resulting dust is more like smaller fragments than true dust.[53, 54]

Recent studies demonstrate that a 50 W TFL prototype is four times more ablative for dusting and two times more ablative for fragmentation of urinary stones than the current 120 W Ho: YAG lasers.[6, 16, 55] The new TFL also produces three to four times more dust (particles under 0.5 mm or even less than 0.1 mm) than a high-power, high-frequency Ho: YAG laser at similar power levels, even if the Moses mode is used.[56]

The aforementioned characteristics along with the decreased retropulsion force of these lasers result in reduction of the operative time during endoscopic lithotripsy.[57]

Recently, Ventimiglia et al.[58] have shown that using the 35 W Holmium laser with a 273 mm fiber for stones>500mm^3, the median (interquartile range [IQR]) ablation speed was 0.7 (0.4–0.9) mm^3/s. Mekayten et al.[59] have retrospectively compared 462 patients treated with 20W Holmium laser to 169 patients treated with a 120 W laser machine for similar volume of ureteral stones. Overall and after controlling possible confounders such as stone volume, density, and location, the laser time was less than half (234.91 seconds shorter) with the 120 W machine. There was a shorter laser time to dusting (120 W=195.08 seconds vs 20 W=397.14 seconds $p<0.001$) as well as a shorter laser time per volume (120 W=0.80 seconds/mm^3 vs 20 W=1.51 seconds/mm^3; $p<0.001$). As a consequence, patients treated with the 120 W machine experienced a shorter procedure (21.13 minutes) than patients treated with the 20 W machine (31.84 minutes; $p<0.001$)[59]. Using the SuperPulsed thulium-fiber lasers for ureteral stone disintegration with a median volume of 179 (94–357) mm^3, the median (IQR) stone ablation speed was 140 (80–279) mm^3/min.[52]

Increasing the fiber speed increases stone ablation when using high frequency settings. When the fiber is fixed, there is a threshold after which increasing the pulse frequency leads to minimal gain in ablation. The exact value for threshold when the fiber is moving needs further study. If the laser fiber is moving at 1 mm/s, a hypothetical frequency threshold for ablation was calculated to be 52 Hz and 61.6 Hz for LP and Moses distance modes in contact with the stone, respectively.[60] When the laser fiber was moved at 3 mm/s, the number of pulses delivered at each stone location was less than when the fiber was moving at 1 mm/s. Thus, an optimal number of pulses (<15 pulses) were delivered at each individual location of the stone as the fiber was moved, resulting in more fragmentation.[60]

The speed of a moving laser fiber plays an important role in fragmentation. Exceeding the pulse frequency threshold at a single stone location results in minimal increase in ablation volume, wasted time, and wasted energy. Furthermore, dust ejecting from the crater following each pulse might have a shielding effect by absorbing some of the incoming laser energy during the subsequent pulses; thus, limiting the amount of energy reaching the stone.[61] This further encourages continuous movement of the laser fiber in a painting technique.[62]

Laser Fibers

Laser light is emitted in a coherent, collimated, and monochromatic fashion.[4] These characteristics make it possible to engage and transfer the light through small fibers. The fibers are constructed of an inner optical core responsible for laser transfer, a primary optical cladding responsible for laser entrapment, a secondary transparent cladding with a very low light refraction index, and an outer buffer responsible for fiber integrity.[4]

It is important to know the technical details when buying laser fibers. Holmium and thulium lasers require purified low hydroxide silica fibers. Silica is suitable for transmission of visible light, whereas the low hydroxide ions absorb the light, eliminating power loss. Fluoride-doped cladding is considered the primary choice, and fluoroacrylate cladding is preferred for transmission of shorter wavelengths and low-power applications.[4] Thulium laser emits a near-single mode beam that focuses energy up to 25 μm, which can be used with fiber cores as low as 50, 100, and 150 μm.[5, 17, 63] Holmium laser emits a multimodal and less homogeneous beam and thus is used with 200–1000μm fiber core sizes.[6, 39, 44]

Even a small diameter change can affect the lithotripsy procedure as it affects accessibility, visibility, efficiency, and surgical time.[64] As a consequence, small size fibers are used more commonly during flexible ureterorenoscopy. However, small size fibers are more susceptible to "burn-back" tip degradation and breakage.[65] Although higher power energy, shorter pulse lengths, or harder stone material are more detrimental to the fiber tip,[31, 66, 67] there is some evidence also to the contrary.[68] As a consequence, one should accommodate fiber size selection and laser settings to the needs of a specific case.

Fiber tip preparation may also affect lithotripsy performance. Most manufacturers provide the fiber with a stripped tip. Stripped fibers were considered to achieve greater stone ablation and were sold along with specific stripping (laser fiber stripper) and cleaving (ceramic scissors, scribe pens) devices.[69] Because of fiber degradation during the lithotripsy procedure, the aforementioned preparation was regularly needed or recommended by some surgeons. Some investigators proposed preparing and renewing the fiber tip as soon as 15 minutes of lithotripsy had passed, or 10,000 J of laser emission were given.[67] However, such strict protocols have not proven superior to the continuous use of the fiber until its degradation.[70] There is a strong evidence that certain cleaving methods result to similar short-term fiber degradation.[70, 71] Current studies strongly support that covered fibers perform better then stripped fibers as stripping may not only damage the fiber tip and its cladding, but may also increase the chance of silica and its cladding to break off during lithotripsy.[69, 71] In addition, covered fibers are less harmful to scopes than stripped fibers as they can be easily advanced through the working channel at every angle of scope deflection.[72]

Fibers can be for single or multiple use. A multiple use fiber shows no difference in ablation capability compared with a single-use fiber, provided that the shaft and the connector of the reusable fiber are intact.[39] Although contradictory data exist,[73] it seems that multiple-use fibers are more cost-effective, especially after their third use.[74] There are new developments in laser fibers, such as the miniaturized fiber integrated with a basket[75] and the fiberoptic muzzle brake tip,[76] both applied with thulium lasers. Although these technologies claim to reduce stone retropulsion, further research is needed before they are recommended for everyday use. Furthermore, laser suction devices have been developed allowing the concomitant use of regular (LithAssist device; Cook Medical, Bloomington, IN)[76] or high power (Laser suction hand piece; LSHP, Lumenis, San Jose, CA)[11, 77] laser fibers to treat large stones during percutaneous nephrolithotomy. The potential of their use still remains to be evaluated.

Conclusion

After years of research on laser technology, advances have been made on lithotripters, laser fibers, techniques used, and modifiable parameters. Ho: YAG laser has stood the test of time and is used by most endourologists. A new lithotripter, the TFL, was successfully used at the preclinical and clinical levels and seemed to result in better ablation and retropulsion rates. In addition, newer operational techniques and modifiable laser parameters aid urologists to achieve high SFR in shorter operative times and with fewer complications, which can be also achieved if certain principles are followed during surgery.

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