How I Do It: Ureteroscopy and high-power holmium laser lithotripsy to treat renal stones

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In North America, ureteroscopy has become the most popular treatment modality for upper urinary tract urinary calculi. Herein we describe our technique for the treatment of renal stones with flexible ureteroscopy and high-power holmium laser lithotripsy. We discuss preoperative planning, intraoperative strategies, and laser settings for a high-frequency dusting technique with the goal to provide optimal patient outcomes.

Key Words: ureteroscopy, laser lithotripsy, dusting, fragmentation, urolithiasis

Introduction

The increasing miniaturization of endoscopic instrumentation, along with advances in pulsed laser technology for lithotripsy, has enabled flexible ureteroscopy to overtake shockwave lithotripsy in North America as the most common treatment modality for kidney stones.[1] Holmium lasers for lithotripsy have evolved from low-power systems that provided a limited range of settings for fragmentation and stone retrieval, to high power, high-frequency, and pulse modulated platforms that can break stones into fine particles for spontaneous passage – a technique called dusting.[2] The advantage of dusting is that it is faster than fragmentation with basketing.[2,3] Furthermore, a prospective multi-center clinical study demonstrated no significant differences in the stone-free rate (SFR) between the two techniques when treating kidney stones.[3]

Compared to low-power holmium lasers, high-power lasers can reduce the operating room (OR) time for ureteroscopy and laser lithotripsy, especially when treating larger stones.[4] At the University of Michigan,

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we have been using a high-power dusting technique to treat renal stones since 2014,[5] and studied optimal laser settings and safety parameters in the laboratory.[6-8] The purpose of this article is to share our principles for the management of patients with renal stones undergoing flexible ureteroscopy using a high-frequency dusting technique with the holmium laser. We outline the different strategies and laser settings available with next-generation holmium lasers, with the goal to improve OR efficiency and patient outcomes.

Method and technique

Preoperative management

A preoperative urine culture is obtained within 30 days of ureteroscopy and is treated if positive. Those with a history of a positive culture, indwelling tube, or stent may be at a higher risk for sepsis and are considered for preoperative antibiotics despite a negative culture. All patients receive intravenous antibiotic prophylaxis prior to induction of anesthesia. Patients are started on a selective alpha1-blocker 7 days before surgery to promote ureteral relaxation and aid ureteroscopic access.[9] Patients are counselled with educational resources from the Michigan Urological Surgery Improvement Collaborative (MUSIC) on what to expect after ureteroscopy, including how to manage stent-related symptoms.[10]

Overall strategy and gameplan

Equipment selection

A review of the preoperative CT for stone density (Hounsfield units, HU), volume, and anatomical factors can help determine strategy. Much like how a coach reviews the gameplan with his team, so must the urologist review the equipment needed with the OR team before each case. Doing this avoids wasting time during the procedure searching for equipment. Only the necessary items are opened which saves on costs. To facilitate this, we utilize a whiteboard system, Figure 1, where we use labeled magnets for equipment items (e.g. wires, baskets) with instructions to have them opened at the beginning of the case or have them available in the room in case they are needed. The latter means these items are physically placed on a

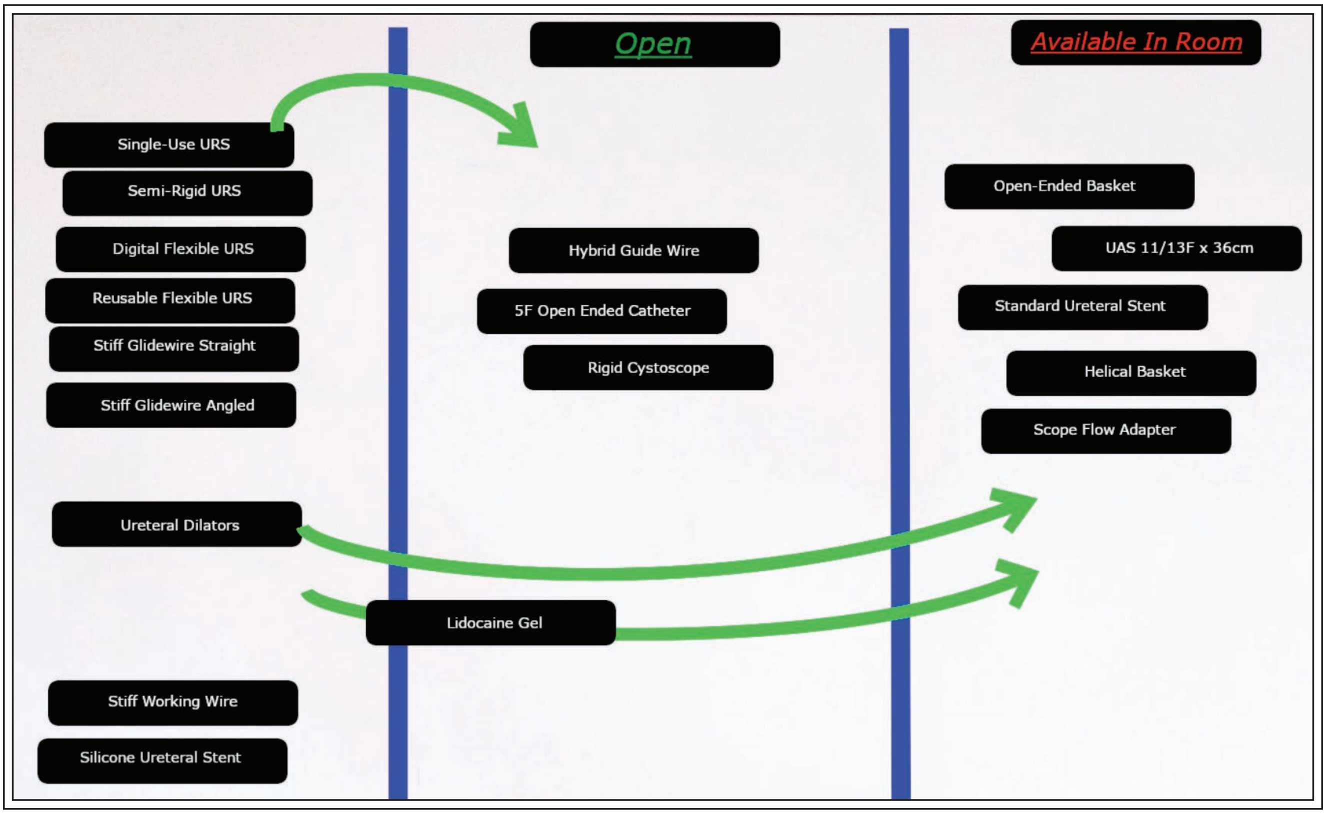

Figure 1. Operating room whiteboard: We use labeled magnets of each equipment item and place it either under the “open” or “in room” category at the start of each case to improve efficiency.

table in the room, to save time hunting for items in the back cupboard while the patient is under anesthesia. By employing this method, we have improved our OR efficiency. Typically, we use a hybrid guidewire (Sensor, Boston Scientific) or stiff hydrophilic angled guidewire (Glidewire, Terumo) with a 6F ureteral access catheter for every case. Small caliber stone baskets (1.5-1.9F) are used for better irrigation, and flexibility, and consist of either the tipless nitinol (Zero-tip, Boston Scientific) or hybrid grasper (Dakota, Boston Scientific) type. Contrast media is opened only if needed and is not routinely used.

Anesthesia

For complicated renal stones we prefer an endotracheal tube for controlled ventilation and tidal volume adjustment. This is important for lower pole stones where renal mobility is increased, or calyceal diverticular stones – where momentary apnea can be provided upon request to permit accurate laser incision. Spinal anesthesia is used in patients with severe respiratory disease, and the patient is counseled to tell the surgeon when they are going to cough, so that laser firing is paused to avoid inadvertent urothelium injury.

Patient positioning

Patients are typically placed in the dorsal lithotomy position, while those with a urinary diversion are positioned supine. An important technical point is the use of Trendelenburg position at the start of pyeloscopy to help with displacement of the stone into an upper or inter-polar calyx, Figure 2, which prevents fragments from coalescing in the lower pole – the Achilles heel

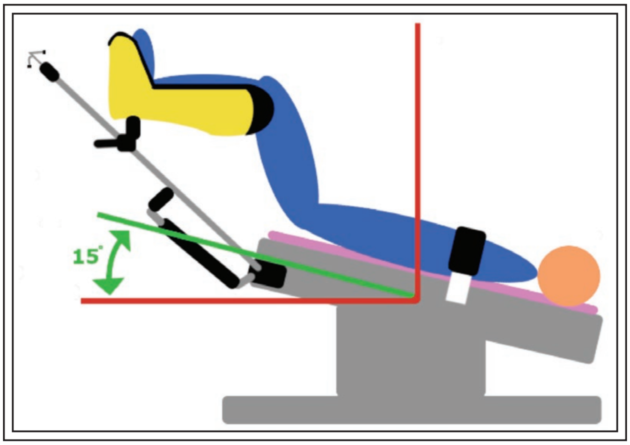

Figure 2. Use of Trendelenburg position to aid with displacement of stones into an upper and interpolar location during ureteroscopy and laser lithotripsy.

of ureteroscopy. For similar reasons, the patient can be "airplaned" towards the contralateral side, which in one study improved the SFR.[11]

Use of ureteral access sheath

Our schema for using a ureteral access sheath (UAS) is determined with the phrase, "Big, Bad, and Ugly." High-frequency dusting can lead to debris and poor vision which in turn requires higher irrigation rates. This is particularly true if lithotripsy time is long, such as when dealing with BIG stones (> 1 cm). In this scenario, a UAS permits higher irrigation rates and mitigates rises in intra-renal pressure. Likewise, higher irrigation rates are needed when using high-power settings (20-40W) for larger stones to prevent heat generation in the collecting system.[7] Similarly, patients with a history of infection or risk of sepsis (BAD) receive a UAS. Finally, stones that have a high HU or are in a hydronephrotic system where the views are suboptimal (UGLY) may benefit from UAS to facilitate a hybrid technique of dusting followed by basketing.

To reduce the risk of ureteral injury, a small caliber UAS (10/12F, 11/13F) is generally used, while larger sizes (12/14F, 13/15F) are used in pre-stented patients. A safety guidewire is used if the plan is to place a ureteral stent. Stents may be omitted for pre-stented patients even if a UAS is utilized. The parallel design UAS (Retrace, Coloplast; Flexor, Cook Medical) is helpful as it needs only a single working guidewire which then becomes the safety guidewire when the inner obturator is removed. This saves on time and costs. Whenever a sheath is in use, we monitor the irrigation outflow through the sheath to ensure adequate intrarenal drainage and temperature monitoring. The surgeon should feel a steady drip of fluid with the non-dominant hand, and the temperature should not be warm to the touch. If no sheath is used, a 12F red rubber catheter is inserted into the urethra, alongside the ureteroscope, to drain the bladder.

Irrigation parameters

To minimize the risk of thermal injury we use room temperature irrigation bags (i.e. no warmed fluid). Our set-up is a 3L bag of normal saline at 1 meter height under gravity irrigation for diagnostic purposes. We switch to pressurized irrigation (compression saline bag with cuff set at 150 mmHg) when using high-power settings and a UAS. With a 200 um laser fiber in a 3.6F working channel, this equates to approximately 38 mL/minute of irrigation if there is no impediment to flow. Adjusting the stopcock attached to the irrigation tubing and ureteroscope, allows us to dial up or down the flow. It's important to be aware of the ratio of the endoscope to sheath diameter (RESD), which may impact intra-renal pressure.[12] This is why we prefer the smallest caliber ureteroscope when using a UAS if possible, as this permits the greatest efflux of irrigation out of the UAS.

Ureteroscope selection

Fiberoptic, digital, or single-use scopes: The type of ureteroscope chosen is dependent on the specific strategy. If planning for a stentless procedure, a reusable fiberoptic scope with a beveled tip is our go-to as it has the smallest diameter and can intubate ureteral orifices with minimal trauma. If using a UAS, lower RESD values will maintain lower intra-renal pressure.[13] Therefore we avoid using larger scopes with a smaller UAS. Currently most digital ureteroscopes are larger than fiberoptic scopes and we use these when using a UAS. Single-use ureteroscopes are used in patients where reusable scopes are more prone to damage, such as lower pole stones, urinary diversion or anatomical abnormalities (horseshoe, fused crossed ectopia, pelvic, or transplant kidney). If the patient is immuno-compromised and at risk of sepsis, we prefer a single-use device because of the low risk of bacterial contamination.

Working channel direction: The stone's laterality is also considered when selecting the ureteroscope, which have different working channel orientations on the tip of the scope. This can be used to your advantage to maximize targeting and being head-on with the stone, especially around corners within the lower pole.[14] Specifically, for right-sided cases, we use scopes where the working-channel is at the 9 o'clock position (e.g. Olympus), while for left-sided cases we use ones where it is at the 3 o'clock position (e.g. Storz or LithoVue).

Laser lithotripsy techniques and settings

In the modern day there are four basic techniques to treat renal stones: fragmenting, dusting (which includes painting, dancing, and chipping), pop-corning, and pop-dusting. First generation low-power holmium lasers were limited to pulse frequencies ≤ 15-20 Hz. As a result, high pulse energies such as 0.8-1.0 J, were typically used to allow a "fragmentation" strategy where the laser is placed in direct contact with the stone, pinning it against the urothelium to sequentially fracture and divide the stone into extractable fragments. To avoid retropulsion, fragmentation is performed with low frequency (6-8 Hz). Next-generation holmium lasers allow for the selection of long pulse (LP) modes of up to 1200 µs.[2] This mode reduces retropulsion, and if available, is our preferred mode for fragmentation.

Dusting with the holmium laser is the use of low pulse energy settings with high frequency to rapidly pulverize stones into fine particles.[2] Because of the low frequency limit on low-power lasers, the use of a dusting technique was not widespread, as it would take too long. High-power (100-120W) holmium lasers, initially capable of 50-80 Hz and pulse energies of 0.2-0.3J, changed the laser lithotripsy landscape and permitted an efficient dusting technique.[5] For renal stones, our preference is to start with dusting. Occasionally, we use a hybrid approach and retrieve fragments at the end if they are not small enough. When performing a dusting technique, there are two phases to consider:

Contact phase: This is the initial phase to debulk the stone. Before we start this, we ensure the stone is an optimal location. Stones in the renal pelvis are pushed into either an upper or inter-polar calyx using a combination of irrigation and "nudging" the stone with the scope, Figure 3, with the patient placed in Trendelenburg position. Once trapped in this spot or in an infundibulum, constant motion of the laser fiber along the surface of the stone with dancing, chipping, and painting maneuvers, Figure 4, using low pulse energies is performed. The laser fiber tip touches the stone surface as much as possible. The frequency is selected according to the available parameters on the system and stone size. Our standard is 50 Hz, which can be increased accordingly.

Constant movement of the laser fiber tip in contact with the stone is done to avoid creating fissures and inadvertent fragmentation into large chunks. The stone is sculpted, and the surgeon-sculptor works

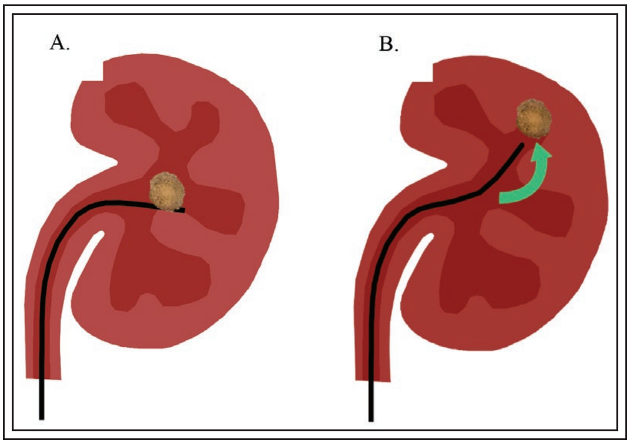

Figure 3. "Nudging" technique for moving a stone from the renal pelvis **(A)** to a more favorable upper or inter-polar location. **(B)** For lithotripsy: this is critical to set up the non-contact lithotripsy phase (pop-dusting).

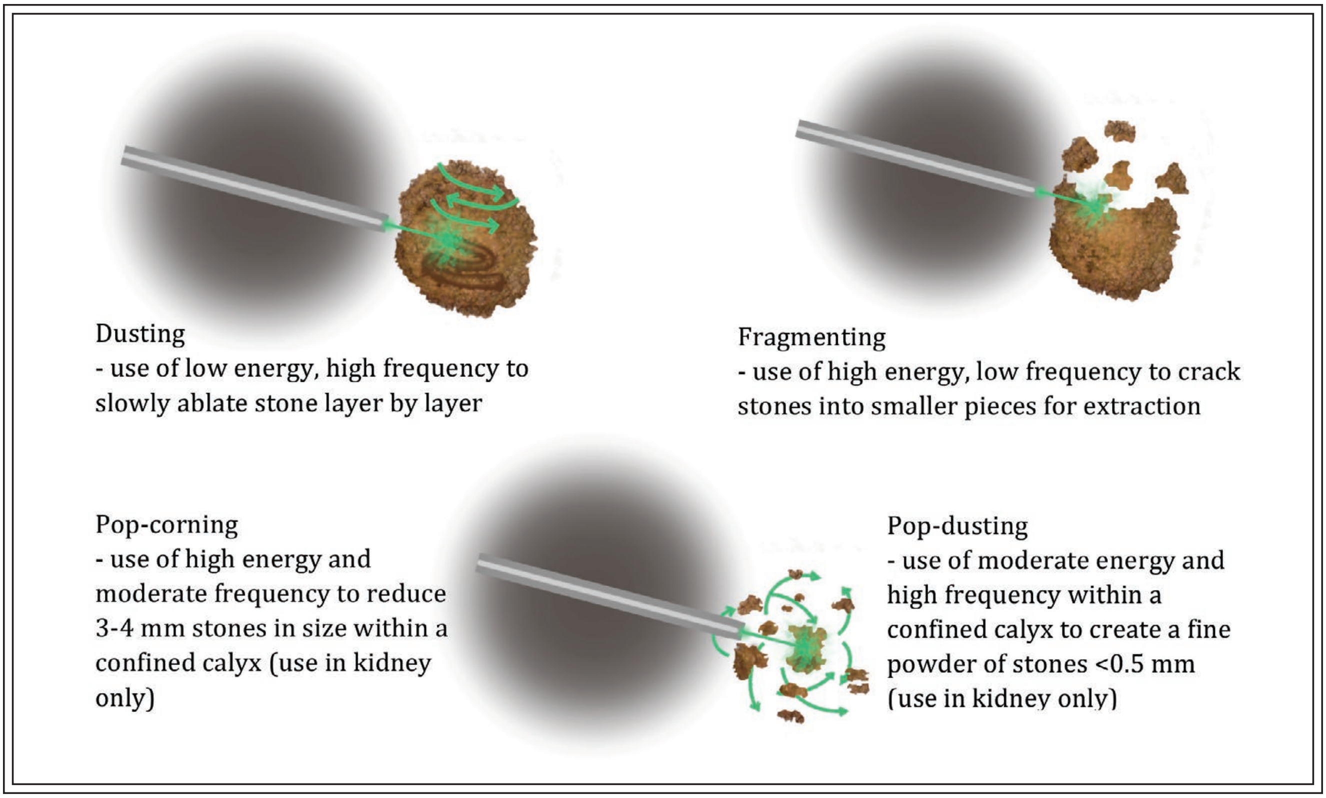

Figure 4. Illustrations of the different dusting and fragmentation techniques for ureteroscopic laser lithotripsy.

on chiseling away the stone focusing on the forward projecting parts of the stone. With dusting there is often significant debris that forms which may obscure the view. If gravity-based, low-flow irrigation is used with high power settings, active lithotripsy may require pausing to avoid excessive heat generation. In these scenarios the frequency may need to be reduced, which in turn decreases the total power (W). Irrigation may also need to be slowed down in cases of a dilated collecting system as the combination of high irrigation and pulse frequency results in retropulsion.

We use high frequency (50-120 Hz) and high-flow irrigation when treating large renal stones to provide rapid pulverization. Increasing the fiber speed when using high-frequency settings increases the rate of ablation.[15] Settings of 0.2J are used for softer stones. Harder stones are "chipped" away using settings of 0.3-0.4J. The stone is painted or attacked along its leading edge to shave it in a systematic manner. Many modern lasers have a dual pedal footswitch for the surgeon to alternate between two settings without needing to place the system on standby, thus improving the efficiency. The dust particle size must be small to avoid large residual fragments, and careful selection of the energy and technique is paramount.

Non-contact phase: Despite one's best attempts to debulk the stone as a single entity during the contact phase, it is inevitable the stone will crumble into smaller, medium-sized fragments. At this stage, non-contact laser lithotripsy is performed with the laser fiber tip kept a few millimeters away from the stones, and a different sequence of settings are used. Initially described by Dr. Demetrius Bagley, and called the "popcorn technique" due to the chaotic and noisy movement of fragments, the pulse energy is increased (e.g. 1J) and frequency reduced (e.g. 15-20 Hz). This results in a whirlpool-like effect that causes the fragments to move around, come in direct contact with the laser tip, and undergo fragmentation. The technique allows the surgeon to not spend time repositioning the laser on the stone between pulses. Unlike the contact phase, with popcorning the surgeon keeps movement of the laser fiber to a minimum, and the laser is fired intermittently.

The best settings and conditions for non-contact laser lithotripsy has been assessed in the bench model by treating stone phantoms in glass bulbs to simulate a calyx, and by varying the pulse energy, frequency, size of bulb, and fiber tip to stone distance.[6] Higher pulse frequencies (> 40 Hz) and power settings (40W), performed in a smaller cavity, and keeping the fiber positioned as close as possible to the stone surface, significantly improved sub-millimeter fragmentation; the best setting was 0.5J x 80 Hz. At the University of Michigan, we coined the term "pop-dusting," to differentiate it from Dr. Bagley's "popcorning" setting of 1J x 15-20 Hz. This high-frequency, high-power setting rapidly pulverizes the stones into dust. Given the high power used for this technique, we fire the laser in 5-10 second bursts to limit heat generation. The goal is to get fragments < 0.5-1 mm for optimal spontaneous passage. The laser fiber tip (~0.2-0.3 mm) serves as a good guide of fragment size. Regardless of the setting used, if the calyx is too dilated for effective pop-dusting, it may be more appropriate to retrieve the fragments.

<u>Lower pole stones</u>: We no longer relocate lower pole stones to an upper pole location with a basket. Because of high-power lasers we now perform in-situ lower pole laser lithotripsy unless the stone cannot be targeted because of an acute lower pole angle. At the end of in-situ lithotripsy and pop-dusting, the fragments in the calyx are flushed out with a saline injection, and if large fragments persist, they are extracted with a basket.

<u>Pulse modulation</u>: Pulse modulation is a method of manipulating the waveform of the pulse to provide distinct advantages for lithotripsy. The most popular system is MOSES Technology (Boston Scientific) which provides a split-pulse mechanism for optical energy delivery with creation of a vapor channel through which a second laser pulse travels. The benefits are increased fragmentation and reduced stone retropulsion.[8] Another split-pulse system is Virtual Basket (Quanta Lasers).

With MOSES Technology, for frequencies between 5-80 Hz there are two modes one can select, Moses Contact (MC) and Moses Distance (MD), with different split-pulse dynamics. When the optical pulse profiles were assessed at 1 J, MC mode delivered 25% of the total optical energy in the initial pulse, and 75% in the second pulse. In contrast, MD mode divided the optical energy evenly with ~50% delivered for each split pulse.[8] In the bench, use of MD mode resulted in 28% and 39% greater ablation compared to other pulse modes at 0 and 1 mm distance from the stone, respectively.[8] We have found this mode excellent for dusting technique where the constant fiber movements during ureteroscopy can result in the surgeon working at distance. MD has also been shown to improve popcorning fragmentation outcomes.[16] As a general rule, we use MD mode for both contact and non-contact phases. MOSES 2.0 is the next version of this system which can provide pulse frequencies up to 120 Hz.

High-power laser lithotripsy and heat generation

In vivo studies have shown that the collecting system fluid temperature can reach 60 °C after 10s of laser activation at 40W power settings, if no or low flow irrigation rates are used.[7] Thermal injury with possible stricture, could be produced by high-power settings without appropriate mitigation strategies. In this regard, we never use more than 10W when treating stones in the ureter. However, unsafe thermal boundaries do not occur if high flow irrigation rates (such as 38 mL/min) are used when using high-power settings, especially if they are limited to short laser bursts. This is why we use such parameters when treating large renal stones with a UAS (we do not exceed 40W). As a result, we have never encountered a stricture or stenotic infundibula as a sequalae of treatment. Chung et al, used even higher power settings for flexible ureteroscopy (100W pop-dusting) and assessed the safety of this in 82 patients with follow

TABLE 1. **Stenting, strings, and staged procedures: criteria for when to place a ureteral stent vs. no stent, after ureteroscopy and laser lithotripsy**

No stent	**Stent**	
Pre-stented and stone ≤ 1.5 cm	Complex anatomy or solitary kidney	
Not pre-stented and stone ≤ 1 cm	Not pre-stented and UAS was used	
	String	**No string**
	• Stone ≤ 1 cm	• Stone > 1 cm
	• Remove in 5-7 days	• Complex anatomy
		• Ureteral impaction
		• Remove in 7-14 days

If the stent dwell time is > 7 days, we prefer using a silicone stent.
For staged procedures for large volume stones, we schedule the second procedure 2 weeks later.

up CT and diuretic renography, and found no evidence of hematomas or strictures/obstruction.[17] They used a UAS and pressurized irrigation in all cases. As a general rule, in the kidney 20W settings are safe with medium flow rates (14 mL/min), while 40W settings require higher flow rates.

Exit strategy

Saline flush: At the end of pop-dusting, fragments in the calyx are irrigated out by gentle injection of saline with a syringe. This is important for dependent calices. Unless contraindicated, patients are administered IV furosemide (10 mg) for diuresis to further help with clearance of dust fragments.

Stenting: The ureter is assessed on withdrawal of the scope (+/- UAS) to assess for injury. If there is no ureteral trauma, we perform stent omission in select scenarios, Table 1.

Postoperative medication: Unless contraindicated, patients are administered IV ketorolac for pain control at the end of the procedure. If a stent without a string is employed, lidocaine jelly is injected into the urethra for pain relief.

Tracking your laser lithotripsy efficiency

By recording and keeping a track of the laser parameter data, over time the surgeon can understand her/his efficiency and improvement. For all cases, we track multiple metrics which are defined in Table 2. By measuring the stone volume on the preoperative CT (using the ellipsoid formula and three dimensions: $0.167 \times \pi \times L \times W \times H$), the "speed" of treating a particular stone, measured in mm^3/s can be calculated.[18] Recording this data helps with scheduling, technique efficiency, and comparing laser platforms.

Postoperative medication

Patients are discharged on the MUSIC pain-control optimization pathway protocol: NSAIDs (oral ketorolac 10 mg q6h for 5 days) and acetaminophen 650 mg q6h.[19] Patients continue the alpha-blocker for 21 days for symptom relief and fragment passage. If a stent is placed, an anticholinergic is provided for the duration of stenting. Phenazopyridine 100-200 mg is also provided as needed for 3 days. Opioids are rarely needed. In patients with a positive urine culture, antibiotics are continued for an additional 3-7 days. In patients who have a uric acid stone, an 8-12 week course of potassium citrate is provided for dissolution of fragments.

Imaging follow up

For patients with small stones, we obtain a renal ultrasound at 6-8 weeks postoperative to assess for residual fragments and rule out hydronephrosis. Patients with radio-opaque stones also get an abdominal x-ray. CT scans are obtained in patients with large or complex stones. For patients who have residual fragments in the lower pole, we recommend percussion inversion therapy (St Michael's Toronto protocol) for 4-6 weeks.[20]

Discussion

Our initial series of flexible ureteroscopy with high-frequency, high-power laser lithotripsy for renal stones demonstrated a complete SFR of 62%.[5] More recently, outcomes for single renal stones treated with MOSES Technology were assessed and the complete SFR was 79.3%.[18] Using pulse modulation, the ablation speed for a renal stone was calculated at ~1 mm^3/s.[18] Figure 5 summarizes our lithotripsy techniques and laser settings.

TABLE 2. **Laser parameters recorded for each ureteroscopy case to track and determine efficiency**

Lithotripsy ("laser-on") time	Time from first laser activation to end of last laser activation, including pedal on and off time (all pauses).
Lasing time	Summative time of when the pedal is depressed with laser activity, provided by the laser system.
Energy used (J)	Total energy used during the case provided by the computer in Joules.
Laser activity ratio or operator duty cycle (%)	Calculated by dividing the lasing time with the lithotripsy time and reported as a %.
Fragmentation speed (mm^3/s)	Amount of stone that can be fragmented per unit time: stone volume (mm^3) is divided by its corresponding lasing time (sec) to provide the fragmentation speed.
Energy used per unit stone volume (J/mm^3)	The total energy (J) used is divided by the corresponding stone volume (mm^3)

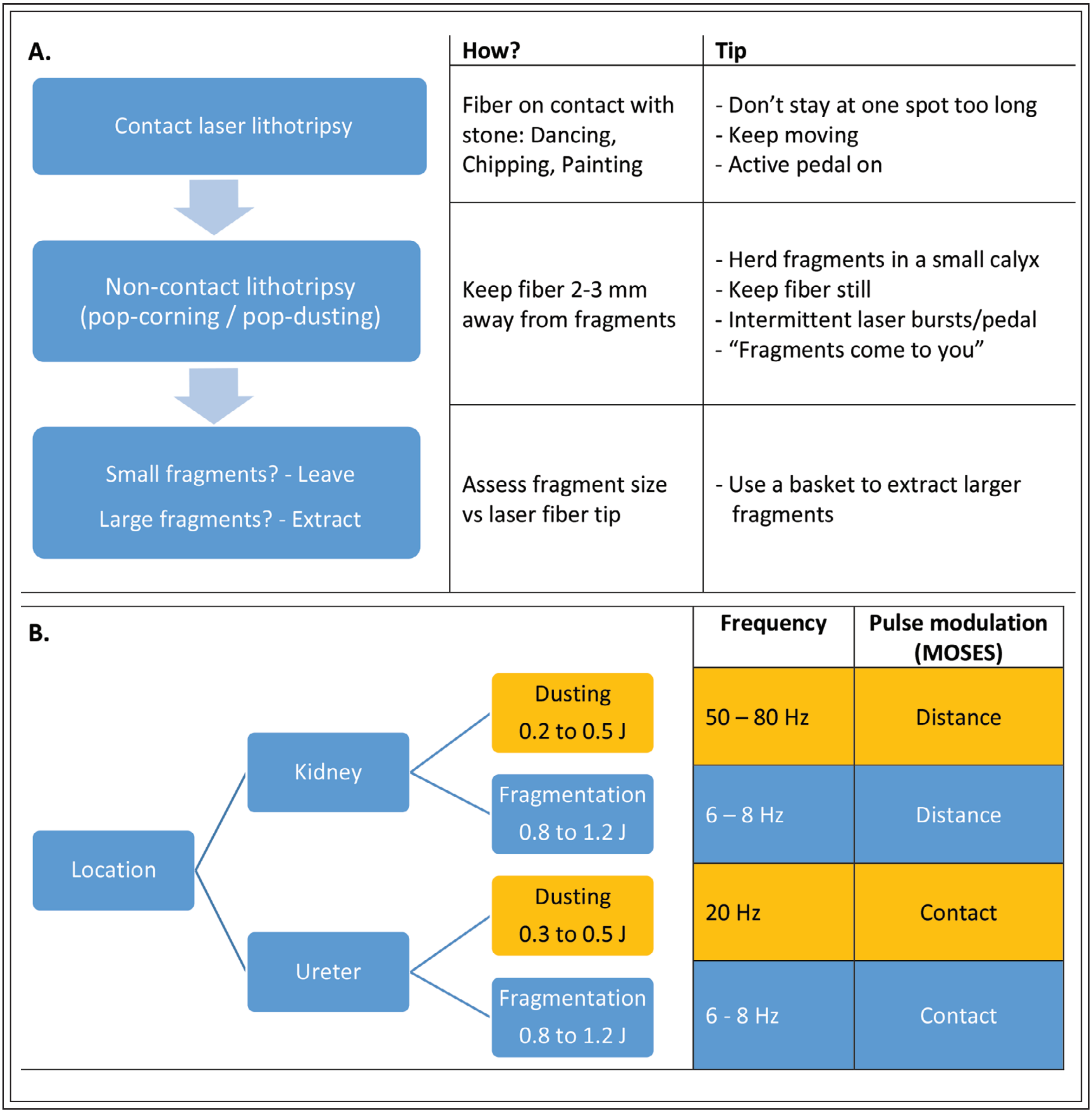

Figure 5. Summary of ureteroscopic laser lithotripsy treatment techniques **(A)** and settings **(B)** when using a high-power holmium laser.

The Thulium fiber laser (TFL) has now emerged as a promising platform for lithotripsy and soft tissue applications. The appeal of the TFL is the ability to use lower pulse energies (e.g. 0.05 J) and higher frequencies (e.g. 2500 Hz). However, when equivalent energy settings are used between TFL and holmium, stone fragmentation characteristics are different. The low peak power of TFL makes it an excellent dusting laser with small fragment size production and low retropulsion. However, the low peak power limits the ability to fragment and crack stones, or to perform pop-dusting in dilated calyces. This can be a limitation when treating an impacted ureteral stone. We have found that high-power settings with the TFL causes a lot of stone charring and carbonization.

Conclusions

An understanding of the principles of laser technology and their safe use during ureteroscopy is essential for the modern endourologist. Laser lithotripsy outcomes must progress beyond the efficacy measure of SFR to incorporate safety such as the risk of stricture from the use of excessive power and heat generation that is not appropriately mitigated with sufficient irrigation, and the impact of techniques on the patient experience via patient-reported outcomes. Future developments in active suction, feedback modulated irrigation systems, intra-renal pressure and temperature monitoring, and artificial intelligence/computer vision integration with laser lithotripsy should help overcome these challenges. Ureteral stents, once considered a mandatory part of ureteroscopic surgery, have increasingly been shown to be one of the most troubling aspects of the procedure for patients. Dare we dream of a future where baskets are rarely used, and stents will be a relic of the past?

Disclosures

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