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Lesson 13 Volume 39

Laser Science and Applications in Urological Diseases*

Learning Objective: At the conclusion of this continuing medical education activity, the participant will be able to recognize the difference between laser modalities, identify the safety implications and risks that come with each wavelength, employ the applications of commonly used wavelengths, describe how laser energy can be beneficial over other surgical energies, and explain why laser safety is important and what precautions should be taken when using lasers in urology practice.

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INTRODUCTION

Remember that periodic table you learned about in school and thought you would only visit again when doing homework with your child? Laser energies use these very elements. These new innovations are exciting and almost futuristic like scenes from the Avengers and Superman. While these surgical energies have the potential to treat patients more efficiently, allow for less invasive surgical interventions and be of significant benefit to patients, they have great capacity for harm. Education on these modalities is challenging. Unlike monopolar or bipolar electrocautery, not every technology is available in every training program. As such, education is generally on an energy by energy basis and may not include all modalities marketed to urologists. Unfortunately, proper training on one modality is not transferable to another as each wavelength laser has its own characteristics. In this Update we introduce the laser energies used in urology with specific consideration given to each of the energy modalities and their applications. We will review some of the risks and benefits of each energy, and delineate differences between them.

LASER PHYSICS

A laser (Light Amplification by Stimulated Emission of Radiation) refers to a specific type of energy. The term was coined in 1957 by its pioneer Gordon Gould. There are many medical lasers in use, each of which has differences in the way it creates and delivers energy to treat tissue relative to their specific atom. However, the physics is the same. Clinicians must understand the similarities and differences between laser energies to know when they are better suited or contraindicated for each disease state. The goal, irrespective of their particular characteristics, is to heat tissue.

An external energy, electrical, optical or chemical, excites an atom (ie holmium, neodymium etc). When the initiating energy excites an atom, its outermost electrons move from their resting state to higher energy levels. Then as the electron spontaneously returns to its resting state, a photon of energy is emitted at a specific wavelength, characteristic of the particular emitting atom. The emitted photon can then strike another atom already at a higher state which leads to emission of its photon, following which the process of stimulated emission ensues and propagates until the external energy is discontinued (fig. 1).

Most medical lasers use electricity to activate energy either directly or by creating a bright light to stimulate an active conducting medium of solid (Nd:YAG), gas (CO_2), liquid (dye) or semiconductor (diode). Emission occurs in the active medium of the laser, which is contained within the laser resonator (the laser "box"). The laser resonator contains 2 parallel mirrors, one of which allows transmission of light (opened via a foot pedal or hand switch), and the other which reflects the atoms and stimulated electrons back into the resonator, causing continued stimulated emission and buildup of energy (fig. 2).

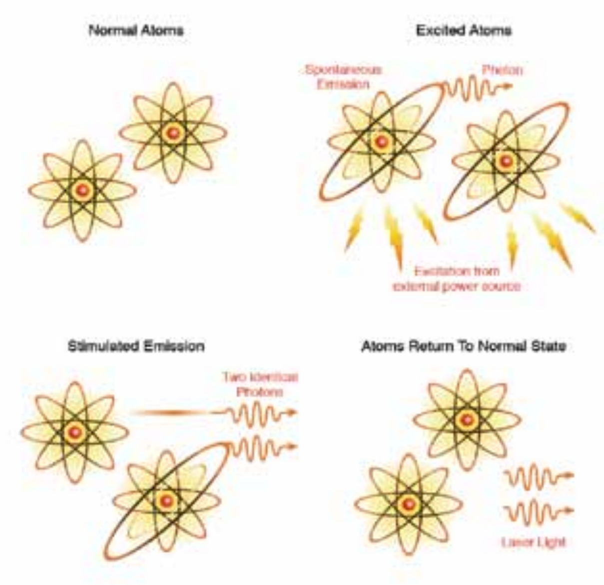

Figure 1. Simulated emission.

Energy is released in a controlled fashion depending on the mechanics of the laser unit. Lasers can operate in multiple different modes, although continuous and pulsed modes are used in urology (fig. 3). This difference in mode can have a tremendous impact on tissue response, which is also dependent on other characteristics such as power, energy and power density, as well as distance from the laser to its target tissue.

- **Energy**: Capacity to do work, expressed in Joules (J)
  - o Joules = Watts (W) × Seconds
- **Frequency**: Cycles per second of delivered energy, expressed in Hertz (Hz)
  - o Hertz = 1/Second
- **Power**: Expressed in watts (W) and reflects how much energy is delivered and how fast
  - o Watts = Joules × Hertz

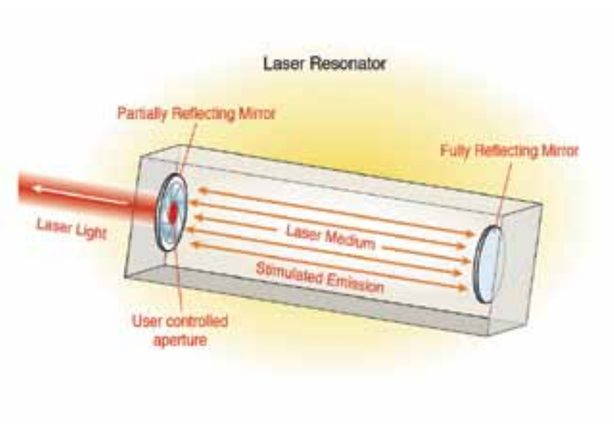

Figure 2. Laser resonator.

ABBREVIATIONS: AEs (adverse events), BPH (benign prostatic hyperplasia), DOP (depth of penetration), I-PSS (International Prostate Symptom Score), PVP (photoselective vaporation of the prostate), Qmax (maximum flow rate), SUI (stress urinary incontinence), TFL (thulium fiber laser), ThuLEP (thulium laser enucleation of the prostate), TUR (transurethral resection), TURP (transurethral resection of the prostate)

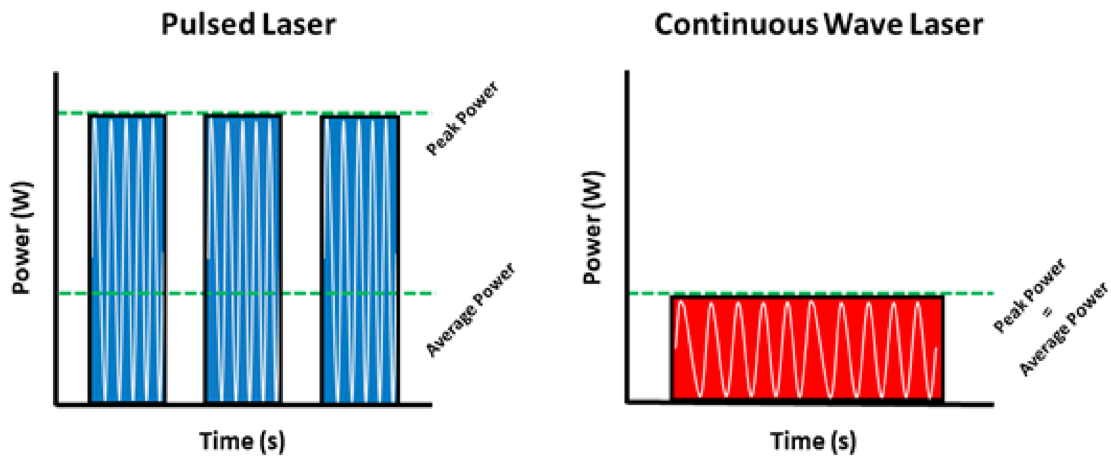

Figure 3. Continuous versus pulsed laser mode.

Laser light is collimated (waves in parallel), monochromatic (same wavelength) and coherent (waves travel in phase). It can reflect backwards, scatter, transmit or be absorbed (fig. 4). Tissue has different absorption coefficients for each wavelength. Important characteristics that affect tissue absorption include hemoglobin content, pigmentation content and chemical composition, which are referred to as the "chromophore." Laser energy travels to its chromophore in the target tissue where it will be absorbed. Absorbed photons raise the temperature and destroy cells. The **depth of penetration** is the distance at which 90% of the energy is deposited, which generally defines how "deep" a particular laser can heat tissue (fig. 5). Don't forget to consider where the other 10% goes. The maximum temperature of the tissue affects the results (table 1). To coagulate tissue, the temperature should range between 60 and 90° Celsius. To vaporize tissue, the temperature must reach 100° Celsius.

Finally, energy is delivered via laser fibers which can be either end-fire (energy releases from the very tip) or side-fire (energy exits at an angle). Fibers come in different sizes and vary by device. When the laser is activated, energy travels along the laser fiber via internal reflection that "bounces" it down the fiber. The surgeon controls precision and tissue effect by directing the laser energy where they wish it to go.[1–5]

Table 1. Photothermal effect at tissue temperatures

Temperature (Celsius) Threshold	Biological Effect
37	Body temperature
45	Hyperthermia
60	Coagulation (near tissue)
100	Vaporization/cutting (in contact with tissue)
150	Carbonization
300	Melting

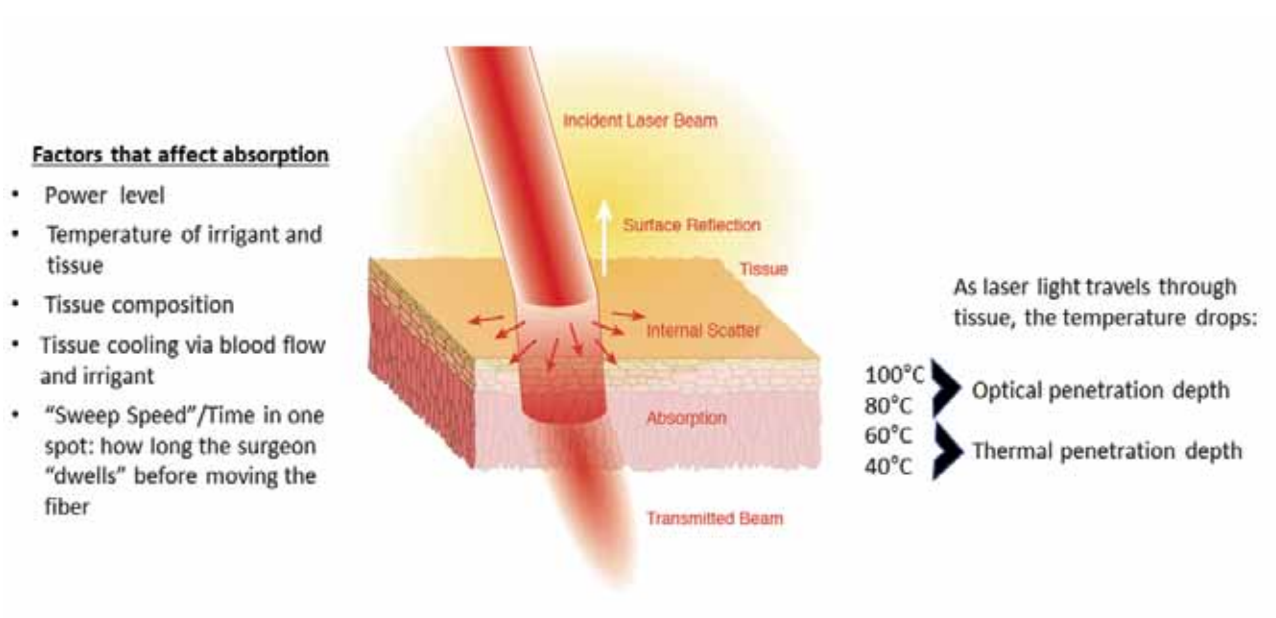

Figure 4. Laser tissue interactions.

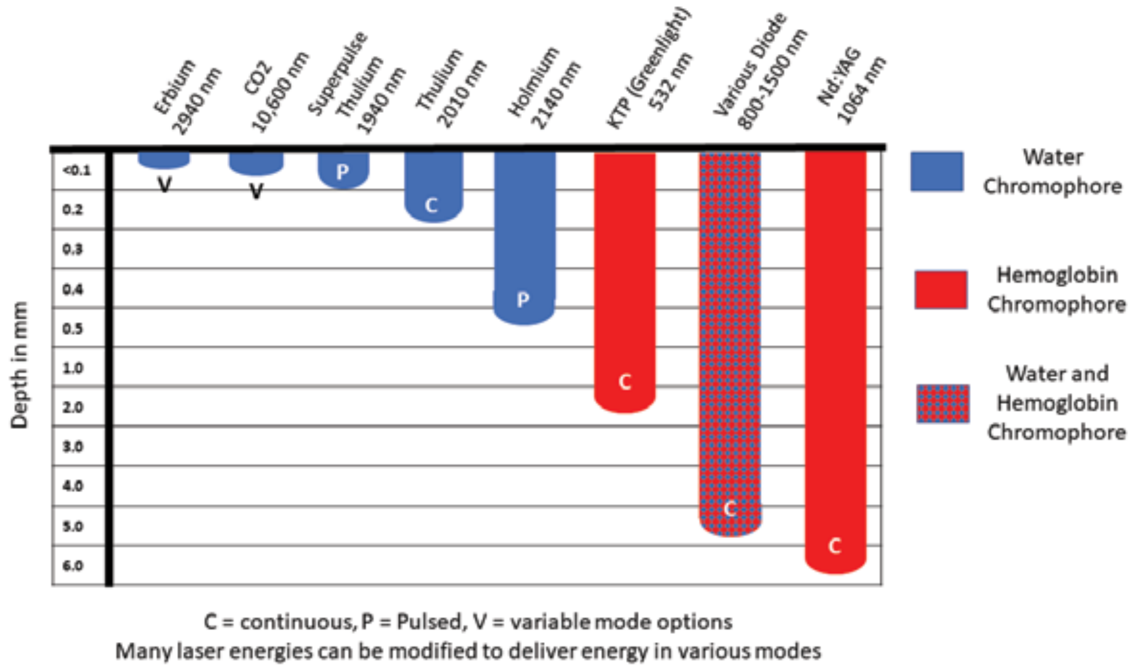

Figure 5. Depth of penetration and chromophores of lasers used in urology.

SAFETY

Most medical lasers are class 4, meaning they can cause eye or skin damage via direct or scattered exposure. Improper use of lasers, lack of safety equipment and device failure can result in adverse events. AEs can affect the surgeon, patient, operating room personnel or endoscopic equipment. Eye injuries, contact skin burns, electrical shock and injuries related to fires have all been reported with the use of medical lasers. Any of these should be reported to either the MAUDE (Manufacturer and User Facility Device Experience) database or the RLI (Rockwell Laser Industries) Laser Accident Database.

Protective, wavelength specific eyewear for all those working with the fiber is recommended. For the patient, the degree of protection is dictated by the nominal ocular hazard distance (table 2). Regular inspection and maintenance of the machine are essential to ensure proper functioning. Lasers contain different internal protective devices that lead to automatic powering down of the laser if it is not working or cooling properly. For those lasers that contain blast shields, replacements should be kept in stock. The laser unit/resonator should be kept in a cool environment and free from moisture. For water based lasers, internal steam/condensation can lead to absorption of energy and blast shield disruption.[6–9]

Table 2. Nominal ocular hazard distance

Laser Type	Power (watts)	Nominal Ocular Hazard Distance (meters)
CO_2	60	175
KTP	180	33.9
Nd:YAG	100	9.8
Holmium	120	1.6
	100	1.9
	50	1.9
	20	1.1
Diode (1470 nm)	100	1.63
Thulium	150	1.08

Beyond this distance eyewear is not essential as the laser energy has decreased in intensity to be lower than the maximum permissible exposure.

USES AND INDICATIONS

Prostate. Multiple laser energies have been used to treat BPH. Prostate enucleation, ablation/vaporization and even percutaneous transperineal techniques are currently used. Holmium, thulium, potassium titanyl phosphate (KTP/GreenLight™) and various diodes have their respective followings. While there are similarities between the surgical approaches using these laser wavelengths, different tissue interactions make it necessary for variations. Surgeons familiar with one wavelength and approach cannot necessarily use the same approach with another laser without putting the patient at risk for injury. All laser energies use saline, thereby negating the risk for TUR syndrome.

Holmium Laser Enucleation of the Prostate: The first wavelength used and longest running, holmium has proven to be a safe and reliable energy source for enucleation. Of all the current enucleation techniques HoLEP has been the most rigorously studied in many randomized trials on TURP and open prostatectomy. Multiple approaches are used but all rely on identification of the surgical capsule and retrograde enucleation along this plane. The holmium laser operates at 2100 nm

Table 3. Most commonly used lasers for urological disease

	Carbon Dioxide	Diode	Erbium	KTP/ GreenLight	Holmium	Thulium	Nd:YAG
Bladder cancer					X	X	
Prostate ablation		X		X	X	X	
Prostate enucleation		X		X	X	X	
Radiation cystitis				X			
Skin lesions, including warts	X	X			X		
Stone disease					X	X	
Transperineal prostate ablation		X					
Upper tract cancer					X	X	X
Urethral stricture				X	X	X	
Ureteral stricture					X		
Vagina (genitourinary reconstruction, SUI, urinary tract infection)	X		X				

and is pulsed. As such there is not only a thermal effect, but also mechanical separation as cavitation bubbles get into the plane between the surgical capsule and adenoma separating them. The original approach uses initial incisions at 5 and 7 o'clock positions. Then the middle lobe is enucleated from just proximal to the verumontanum up to the bladder neck. The lateral lobes are similarly enucleated along the capsule, one side at a time. A 12 o'clock incision is often made to separate the right and left lateral lobes. Other surgeons have used a single bladder neck incision in either the 5 o'clock or 7 o'clock position, with incorporation of the middle lobe with one of the lateral lobes and the other lateral lobe removed afterwards. When no middle lobe is present, a single 6 o'clock incision can be made. Lastly, some surgeons will enucleate a lateral lobe and continue across the anterior connection (12 o'clock position) over to the other side, taking both lateral lobes en bloc.

Many different laser settings can be used. Most surgeons use 2 J and 50 Hz but rates as low as 30 Hz have been used. Some surgeons will reduce the joules near the verumontanum to decrease a theoretical risk for sphincter injury but this is not universal practice. Most HoLEP practitioners use a combination of blunt dissection with the beak of the scope and application of laser energy.[10–14]

Thulium Laser Enucleation of the Prostate: ThuLEP is performed with a conventional thulium:YAG laser. This laser has a solid-state design using YAG crystals as the active conducting medium. It emits energy at 2010 nm in a continuous wave fashion, so there is less mechanical bubble effect than with holmium but higher generation of continuous heat. As such, separation of the adenoma off the capsule is via vaporization along the plane. These characteristics mean better hemostasis compared to holmium. Like HoLEP, ThuLEP users describe a combination of laser energy and blunt dissection to complete anatomic enucleation along the surgical capsule.[15–18]

GreenLight Laser Enucleation of the Prostate: KTP/GreenLight lasers have been used for vaporization and have an extensive following among urological surgeons. Green enucleation of the prostate emerged in 2010 and its use has been increasing. Functioning as a continuous laser but with absorption by hemoglobin as opposed to water (holmium and thulium), a combined "vapoenucleation" approach is described.

Multiple units are marketed, including 120 and 180 watt systems. The 2090 and MoXY™ side fire fibers have been used for enucleation. The technique is generally to make a vaporizing incision proximal to the verumontanum to identify the surgical capsule and then, similar to other methods of enucleation, the beak of the scope is used to mechanically peel the adenoma anteriorly working clockwise/counterclockwise along the capsule. The laser beam is turned upwards/inwards towards the adenoma, concentrating the energy into the adenoma and away from the capsule. Quick applications of energy can be applied to capsular bleeders.[19–22]

Diode Laser Enucleation of the Prostate: Several diode laser wavelengths have been used for enucleation including 980 nm, 1318 nm and 1470 nm. These are continuous or near-continuous wave. They have absorption affinities for water and hemoglobin, thus combine the properties of the lasers previously mentioned. The DOP of diode lasers is high compared to most lasers in urology (4 to 5 mm), and so attention to technique is essential. Diode enucleation techniques are similar to HoLEP, using a 600 micron end fire fiber.[23–25]

Photoselective Vaporization of the Prostate: PVP is an ablative method of treating BPH, usually with KTP/GreenLight lasers, working from the mucosal surface towards the surgical capsule. Various power KTP lasers have been demonstrated to be safe and efficacious with similar Qmax and I-PSS improvements, comparable complication and reintervention rates, shorter catheterization time and hospital stay, and minimal risk of bleeding compared to other techniques for BPH. Care must be taken near the capsule as the energy can pass through the capsule until it "finds" hemoglobin. PVP, like most ablative approaches, is generally seen as a debulking procedure. Hemostasis is excellent and there is decreased tissue slough compared to TURP.[26–28]

Holmium Laser Ablation of the Prostate: Different lasers, due to their distinct characteristics, achieve ablation uniquely. Dwell time must be considered to ablate safely and effectively. Holmium is a pulsed laser and consequently needs a slow sweep speed and longer dwell time compared to continuous lasers to allow the tissue to reach the required temperature (100° Celsius) for vaporization. As such, holmium takes longer to treat prostates and is most successful with prostates smaller than 40 gm. Compared to GreenLight PVP in glands <60 gm, no significant differences in outcomes or complication rate during a 3-year follow-up period were noted.[29–31]

Thulium Vaporization of the Prostate: Thulium laser has been used for prostate vaporization with a good safety profile, demonstrating excellent hemostasis as well as short hospitalization and catheterization times. Several studies have shown no significant difference in Qmax, post-void residual, quality of life and I-PSS compared to TURP.[28, 29] Thulium is a continuous laser and thus reaches optimal temperature sooner and keeps it there so the fiber can move more swiftly with a shorter dwell time. It is important to keep in mind that the constant application of energy can drive up the temperature of the irrigant with continuous lasers like thulium. It is vital the surgeon know these key laser properties in order to prevent thermal injury to the bladder mucosa.

Diode Laser Vaporization (980 nm): The diode laser has been used for ablation but literature is sparse. Tissue ablation is efficient with excellent hemostasis due to rapid increase of tissue temperature (and also irrigant). Compared to TURP, complications such as bleeding, capsule perforation and TUR syndrome were not present in patients treated with diode laser vaporization but there was no significant difference in success rates.[32] Compared to PVP, diode vaporization demonstrated similar improvement of I-PSS, quality of life, Qmax and post-void residual but had a significantly higher reoperation rate.[33]

Transperineal Laser Ablation of the Prostate: A new application of laser energy via a percutaneous transperineal approach has been described. Thus far, this approach has only been described with the diode 1064 nm wavelength laser and is still in the early stages of study.[34]

Urolithiasis. The most common urological use of lasers is to treat calculi. Laser fibers are passed through the working channel of urological endoscopes (flexible or rigid) that are introduced into the collecting system. Lasers can interact with stones to create dust and/or fragments. Dusting involves breaking the stone to miniscule pieces that will pass easily on their own after surgery. Fragmenting involves breaking stones to a fewer number of larger pieces that can be extracted with an endoscopic basket. Historically, laser lithotripsy has been performed with a holmium laser. Recently, a newly developed superpulse thulium fiber laser has been investigated with promising results for the treatment of urolithiasis.[35]

The various sizes of holmium fibers used to treat stones are 200 µm (better flexion into lower pole renal calyces), 365 µm (less flexion in upper pole, excellent in ureter and better with rigid scopes than smaller fiber), 550 µm (can be used with rigid scopes in the ureter, bladder or urethra) and 1000 µm (typically only used for bladder stones). Urologists can adjust the frequency and energy to achieve the desired effect. Since holmium laser energy is absorbed by water and has a short DOP (~0.4 mm), it is less likely to damage urothelial mucosa unless it is extremely close. This characteristic also requires the laser fiber to touch the target stone for maximally efficient lithotripsy.

The holmium laser takes advantage of the Moses effect to efficiently break up stones. A vapor bubble is created that then collapses, creating turbulence in the irrigant. This turbulence breaks stone bonds, creating fragments and/or dust. Newer studies have experimented with Moses technology that emits 2 closely spaced pulses in time, the first of which creates a vapor tunnel and the second travels through this tunnel to the stone. This sequence allows for increased stone fragmentation touching the stone and within 1 mm of the stone, while decreasing the propulsion of the stone away from the fiber.[36] In general, stone dusting is performed at higher frequency (50 to 80 Hz) and lower energy (0.2 to 0.4 J), whereas stone fragmentation occurs at lower frequency (4 to 10 Hz) and higher energy (1 to 2 J) more like a lithotripter.

Overall, stone-free rates are similar when comparing dusting and fragmenting but there are advantages and disadvantages to each. Fragmenting a stone in the kidney or ureter will require basket stone extraction and typically a ureteral access sheath. Fragmentation also involves slightly increased operative time and higher risk of ureteral stone retropulsion from the higher energy, causing the surgeon to "chase" the stone. The risk of damage to urothelial mucosa is theoretically higher when using fragmentation settings as well due to the higher energy setting. That said, fragmentation is better able to break up harder stones (such as calcium oxalate monohydrate and brushite) that do not respond as well to dusting.

Dusting settings do not necessarily require an access sheath and may be somewhat more efficient but this is user dependent. Dusting can be better for small ureteral stones to avoid retropulsion of the stone or damage to the mucosa in a narrow area. However, dusting does not easily allow for stone analysis, which may be important depending on the patient. Softer stones, such as struvite and uric acid stones, are more susceptible to dusting. Generally, once the stone is small, it is likely to fragment and basket extraction of the outer shell may still be necessary. The choice of dusting versus fragmenting often comes down to surgeon preference and experience. It is easy to change laser settings intra-operatively, and so adjusting them in real time based on stone location and fragmentation response is smart practice. Regardless of the settings chosen, the user should be cognizant of the potential for thermal and/or mechanical injury with high power use (via high energy and/or frequency), particularly when only using limited irrigation. High power settings are best used in short pulses and with generous irrigation.[37–41]

The TFL, compared to the conventional thulium laser described previously, has a fiber laser construction. Energy is electronically modulated with multiple diode lasers, and a thin, long silica fiber chemically doped with thulium ions acts as the active medium for generation of the laser beam. The emitted laser energy is pulsed at a wavelength of 1940 nm. Compared to the holmium laser, TFL has several properties that make it attractive for stone treatment in the future. It has a water absorption coefficient that is 4 times higher than holmium, allowing for higher ablation efficiency at equivalent pulse energies. This quality also makes it safer with a shorter DOP (~0.2 mm). TFL can operate at much higher frequencies (up to 2000 Hz) than holmium (up to 120 Hz). In addition, laser fibers as thin as 150 µm can be used which allow for increased irrigant flow through the scope, better scope deflection and eventually creation of more narrow scopes. TFL has been shown in studies thus far to create smaller stone fragments and more efficiently break up stones with decreased retropulsion.[35, 42, 43]

Urothelial carcinoma. Laser technology has been used to treat urothelial carcinoma of the bladder and upper urinary tract. Laser energy can be effective in ablation or removal of malignant tumor tissue, while minimizing damage to the surrounding epithelium and parenchyma. Papillary urothelial cancers are very water rich and vascular, making them well suited for laser therapy. That said, there are pros and cons to each laser based on their unique characteristics.[44, 45]

Bladder Cancer: Lasers were first used in urological oncology for tumor ablation/vaporization or en bloc resection of bladder tumors using neodymium:YAG lasers intially. Absorbed by hemoglobin with a high DOP, Nd:YAG lasers permit deeper, more effective tumor ablation and hemostasis. However, with this comes a higher risk of bladder perforation and bowel injury. The laser power used typically ranged from 30 to 50 W, as the risk of perforation increased at power greater than 50 W. Despite its hopeful efficacy, the Nd:YAG laser fell out of favor for bladder cancer given the risks.[44, 46, 47]

With the emergence of different wavelength lasers, enthusiasm for laser energy for bladder cancer returned. In general, lasers are used when there isn't a need for a pathological specimen or in anticoagulated patients. Laser energy is best applied to the surface of the tumor, working towards the bladder wall and vaporizing along the way. En bloc resection can be done by experienced surgeons as well but is performed less often.[44, 45, 48]

Holmium minimizes risk of perforation due to its shallow penetration and lower thermal effect. It requires direct contact with its target, creating precise and focused tumor ablation. Published series have suggested 0.6 to 1.0 J at 10 to 15 Hz with a 200 or 365 micron fiber, although many users apply higher rates up to 30 Hz and use larger fibers. Indeed, small fibers can be difficult to use through a cystoscope. Side-fire 550 micron fibers can be effective and easier to use. End bloc resection is typically performed with 0.8 to 1.2 J at 10 to 20 Hz with a 550 micron end-fire fiber. Again, higher rates are often used by experienced surgeons.[48, 49]

The continuous thulium laser has a more shallow DOP than holmium, can raise tissue temperatures quickly and will rapidly vaporize tissue. Studies have described en bloc resection at various levels of power (5 to 50 W) with a 550 micron fiber but ablation is certainly appropriate.[44, 47]

Laser treatment has been demonstrated to reduce pain scores, decrease the degree of hematuria and decrease the incidence of perforation. As such, laser therapy is particularly amenable to outpatient settings even with the patient under local anesthesia. As laser energy has more superficial penetration than either bipolar or monopolar energy, delayed tissue sloughing is reduced.[45, 47, 48]

Upper Tract Urothelial Carcinoma: Less common than bladder cancer, upper tract urothelial carcinoma accounts for 5% to 10% of all urothelial carcinomas for which the gold standard treatment is radical nephroureterectomy. However, in select patients with low grade disease, a solitary kidney or chronic kidney disease when renal sparing surgery is necessary laser therapy is desirable.[50, 51] Endoscopic laser tumor ablation has been achieved with holmium and Nd:YAG lasers without affecting oncologic outcomes. More recently, thulium has entered the arena with newly published studies.[44, 51]

The depth penetration and pulsed mode of holmium allow for focused ablation under direct visualization with a lower risk of perforation, which is especially useful in the ureter and kidney. However, these characteristics can be less than ideal for tumors that cannot be accessed to allow for direct contact, decreased visibility from bleeding or a bulky tumor which may lead to incomplete tumor ablation. While this is less of an issue with ureteral tumors, tumors in a renal calyx may be more difficult to treat.

The deeper penetration and continuous delivery of energy of Nd:YAG lead to higher generation of heat. The benefit is that as long as the heat makes it to the tumor, treatment will ensue, negating the need for direct contact. Application of continuous energy is particularly efficacious for controlling bleeding from the kidney. That said, deeper penetration and higher temperatures make Nd:YAG energy unsuitable for ureteral disease as the risk for ureteral perforation is significant.[44]

Thulium penetration is shallow and, like holmium, the fiber must be very near to or in contact with the tumor. As it delivers continuous energy, care should be taken in the ureter to avoid overheating the irrigant since this could injure the surrounding urothelium. That said, thulium provides excellent hemostasis. With holmium, ablation is typically started at 1 J and 10 Hz through a 200 or 365 micron laser fiber, with increases in frequency as needed. Thulium power is 30 to 50 W.[44, 52]

Stricture disease. First line treatment of short ureteral, ureteropelvic junction and urethral strictures involves minimally invasive, endoscopic techniques. Lasers are commonly used to treat stricture disease, often in combination with balloon dilation.

Retrograde laser endoureterotomy has been a popular minimally invasive tool for treating benign ureteral strictures.[53–55] While success rates for laser endoureterotomy for benign stricture disease have been as high as 90%, this is largely variable and likely secondary to the different presentations of benign stricture disease.[56–59] Better success has been shown with strictures less than 2 cm.[56] Other factors that may reduce successful outcomes include presence of impacted stones, ischemia, preoperative ipsilateral impaired renal function and mid ureteral site. Holmium is most commonly used and is likely the best laser modality for use in the ureter. Its pulsed nature and affinity in water allow for control and avoidance of high temperature rises that can lead to ureteral injury. Several studies have shown similar success rates and low complication rates compared to other non-laser based minimally invasive methods.[56, 60–66]

Similar to ureteral strictures, ureteropelvic junction strictures are most commonly treated with holmium laser endopyelotomy with success rates of 70% to 89%.[61, 67] Greater success was found after considering risk factors for recurrence such as extrinsic secondary cause, higher degree of hydronephrosis, stenotic segment >2 cm and impaired renal function.

Urethral strictures have been treated with several different laser types. While holmium is most common, thulium and KTP/GreenLight lasers have been applied to urethral strictures, although long-term evidence is sparse. Compared to a hot knife, holmium and thulium have much more superficial penetration rates, resulting in less conduction of heat to non-involved tissue and risk for further ischemia. Highest success rates are seen for primary anterior urethral strictures <2 cm long. In a randomized clinical trial comparing holmium to cold knife incision with no transfer of heat, holmium had a shorter operative time with less recurrence at 6 to 12 months. Holmium was also studied for urethral stricture disease in pediatric patients with 1 prospective cohort study showing results similar to those of cold knife urethrotomy and outcomes more favorable for strictures <1 cm.[62–66]

Radiation cystitis. Radiation cystitis, a challenging disease to treat, has occasionally been managed with lasers for their ability to address refractory bleeding. KTP, with its high affinity for hemoglobin, is used most often. Photoselective vaporization can treat submucosal vasculature while preserving the overlying mucosa. Settings can be adjusted between vaporization and coagulation parameters to maximize therapy while minimizing injury to the bladder neck and/or ureters. Ureteral stents should be considered. Diode and holmium have also been used to treat radiation cystitis but the literature is sparse.[68, 69]

Stress urinary incontinence. Laser treatment of stress urinary incontinence (SUI) is a more recent use of laser energy. While it is not included in the 2017 AUA stress urinary incontinence guidelines, use of this approach is increasing and warrants mention. Similar to facial resurfacing, a pulsed fractional laser is used to superficially ablate a portion of the vaginal mucosa to create a lattice. This in turn initiates a biological response that promotes neovascularization, collagen deposition and elastin generation. The laser thickens and tightens the anterior vaginal wall, providing support for the bladder with tissue effects similar to estrogen therapy. Initially used for genitourinary syndrome of menopause, improvements in SUI and urinary tract infections have also been reported. For SUI, improvements have primarily been demonstrated using erbium lasers (wavelength 2940 nm) which have a superficial penetration depth of less than 20 microns. Several studies of erbium lasers for female SUI showed improvement in incontinence for up to 12 months as well as improvement in symptoms, quality of life and sexual function. AEs were mild and rare. Overall, the SUI cure rate ranged from 21% to 39%, which is lower than the cure rate seen with injectable bulking agents. Although there are few studies investigating CO_2 laser treatment for SUI, some observational studies have shown an 82% success rate in improving SUI symptoms with effects lasting up to 36 months.[70–75]

Genitourinary syndrome of menopause. Treatment of genitourinary syndrome of menopause, particularly vulvovaginal atrophy, has been performed with CO_2 lasers, although evidence of long-term effects is limited.[75-79] In 1 study dyspareunia, dryness, burning, itching, dysuria, frequency, urgency, urge incontinence and stress incontinence improved 1 month after treatment.[78] In a randomized controlled trial comparing CO_2 laser treatment with topical estrogen therapy and a combination of both, the laser and combination groups had improvement in symptoms such as dyspareunia, burning and dryness.[79] The combination group also experienced improvement in the Vaginal Health Index and Female Sexual Function Index scores. However, the laser group demonstrated worsening of pain after treatment. Also reported was a decreased incidence of postmenopausal urinary tract infection in women treated with laser therapy. In general, this reduction in incidence is considered similar to what is encountered with estrogen therapy. In women who cannot, or chose not to, use estrogen, laser therapy can be beneficial.

Genital warts. Ideal lasers for skin lesions such as genital warts are those that have superficial penetration rates and will not lead to fibrosis and scarring. Fractional (CO_2), pulsed-dye, holmium and diode lasers have been demonstrated to be safe options with clearance rates ranging from 48% to 100%, few AEs and a low risk of scarring. Some studies have shown efficacy with augmenting penetration by removing the hyperkeratotic layer of warts with a keratolytic agent or by physical paring with a scalpel. While multiple laser modalities have been applied, location of the lesion, lesion size, and risk for bleeding and scarring should direct which laser to use, with diode/continuous lasers used for highly vascular lesions (deeper penetration) and pulsed CO_2 fractional lasers used for the most superficial, recognizing that recurrence rates are higher with more superficial penetration. In comparison with other treatment modalities (cryotherapy, surgery, podophyllin), laser treatment of genital warts has been shown to have the lowest recurrence rate.[80–83]

COMPLICATIONS

Injuries can result from equipment failure, technique errors, and an inadequate understanding of the properties of the particular laser being used and its thermal effects. An extensive review of all reported research and clinically related complications dating back since 1964 was performed.[84] Of the 433 AEs reported 46% were due to generator failure or tip breakage. For example, small bore laser fibers fired within flexible ureteroscopes at severe deflection angles can break and damage the scope. The neodymium laser, which is rarely used clinically in the modern era, accounted for 48% of the AEs. There were 164 eye injuries to the laser operator ranging from corneal abrasion to blindness due to inadequate or improper eye protection associated with neodymium, KTP and diode but not holmium lasers. This finding may be due to the fact that holmium laser energy is absorbed by water whereas the others are absorbed by hemoglobin. Finally, 8.3% of the AEs represented harm to the patient including 7 mortalities directly related to laser use due to air emboli generated from the neodymium laser (from 1987 to 1990) in 4 cases and ureteral perforation by the holmium laser causing intractable retroperitoneal bleeding (from 2003 to 2005) in 3. Other intraoperative injuries were bladder perforation, skin burns and significant mucosal bleeding.

Proper education and knowledge of the differences among the various laser energies are essential in order to reduce the risk of complications. Movement of laser fibers (slow versus fast) varies depending on the laser wavelength and chromophore, meaning that techniques are different when applying different energies. Improper use can lead to under/overtreatment of tissue and potentially lead to injury (long dwell times for certain lasers can cause deep tissue damage/injury). In addition, with prolonged laser use the surgeon should be cognizant of overheating of the irrigant fluid that can lead to thermal injury of the urothelial mucosa. Commonly reported long-term complications associated with lasers are listed in the Appendix.

CONCLUSION

Laser energies have been of significant benefit to patients and surgeons. In this Update we presented the majority of laser use in urology, highlighting some of the differences about which the surgeon must be aware to use the technology safely and correctly. Over time we are likely to see new energies with new applications coming to market or application of existing energies to new disease processes. Urologists are not only encouraged to educate themselves about these new technologies and applications, but to seek out training and propagate that knowledge. This Update exemplifies that there is more to laser use than many realize, and we hope it will serve as a catalyst to learn more when being introduced to laser technology and applying it.

DID YOU KNOW?

- Continuous lasers heat tissue and irrigant very rapidly and, therefore, continuous flow is essential to prevent thermal injury to the bladder.
- To dust stones, holmium laser energy should be reduced to the lowest effective level (0.2 to 0.4 J), while the rate should be adjusted as high as possible (50 to 80 Hz).
- Continuous lasers such as YAG and thulium can be especially beneficial for endoscopic ablation of upper tract calyceal tumors that are difficult to reach. Due to its constant delivery of energy and prolonged generation of heat, the laser does not need to be in direct contact with the tumor as long as the heat makes it to the tumor, a property that differs from pulsed lasers.
- In postmenopausal women vaginal laser therapy has been shown to produce tissue changes similar to topical estrogen therapy, and leads to similar reduction in the incidence of urinary tract infection. Laser therapy can be beneficial in women who cannot, or choose not to, use estrogen.

Appendix. Long-term complications associated with lasers

- Prostate reduction surgery:
  - ¤ Incomplete tissue removal which may require re-treatment
  - ¤ Irritative symptoms, sometimes severe, from thermal effect (more common with continuous lasers and deeper penetration)
  - ¤ Erectile dysfunction
  - ¤ Stress and/or urge incontinence
  - ¤ Bladder neck contracture (likely due to excessive coagulation instead of vaporization and prolonged heat delivery to the bladder neck)
  - ¤ Damage to the ureteral orifices
  - ¤ Severe thermal injury to the bladder from elevated temperature of irrigant (it is important to use irrigation at room temperature and avoid fluid warmer when performing laser prostate surgery, particularly with continuous laser energies)
- Upper tract urothelial carcinoma/stones:
  - ¤ Aggressive lasering within the ureter can result in ureteral damage leading to perforation, scarring, fibrosis and stricture formation
  - ¤ Pulsed modes and cool irrigation fluid reduce collateral thermal damage
- Bladder therapy:
  - ¤ Bladder perforation with extensive lasering (laser energy is best when applied to the surface of the bladder in short bursts)
  - ¤ Room temperature irrigant advised if using a high energy continuously (if short bursts are applied, a fluid warmer can be considered)
  - ¤ Distal ureteral injury
  - ¤ Bowel injury from prolonged dwell time with hemoglobin based lasers

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Study Questions Volume 39 Lesson 13

1. The most common adverse event from class 4 medical lasers is
   a. scope damage
   b. air emboli
   c. ureteral injury
   d. eye injury to the operator

2. A key feature of Moses technology that can facilitate lithotripsy is
   a. lower energy emission at the same settings
   b. avoidance of Moses effect
   c. no transfer of energy via the vapor bubble
   d. decreased retropulsion

3. Coagulation of tissue and vaporization respectively begin at the following temperatures in degrees Celsius
   a. 0 and 100
   b. 0 and 300
   c. 60 and 100
   d. 60 and 300

4. The following laser has hemoglobin alone as its chromophore
   a. KTP
   b. holmium
   c. diode
   d. thulium

5. Thermal injury to the bladder when a laser is used in either the bladder or prostate can be prevented or mitigated by
   a. a fluid warmer to avoid temperature fluctuations
   b. resection times less than 1 hour
   c. continuous flow irrigation
   d. sterile water medium

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