Laser Applications in Urology

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Abstract

- Summary of laser-tissue interactions in urology.
- Holmium:YAG laser lithotripsy for calculi.
- Laser treatment of benign prostatic enlargement.
- Laser incision of urethral and ureteral strictures.
- Other laser applications in urology for treatment of penile carcinoma, partial nephrectomy, etc.

Keywords

Nephrolithiasis · Renal stone · Ureteral stone
Laser lithotripsy · Holmium laser
Benign prostatic hyperplasia
Laser prostate ablation
Laser prostate enucleation

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Introduction

- Laser energy has become the most commonly used modality for treatment of urinary tract calculi and is increasingly being used for soft tissue applications such as prostate ablation.

Development of medical lasers has had a revolutionary impact on the treatment of urologic disease. The two most common urological conditions treated with laser devices are urolithiasis and benign prostatic hypertrophy (BPH), and the most widely used lasers in urology are currently the holmium:YAG (Ho:YAG) for lithotripsy and BPH and the potassium-titanyl-phosphate (KTP) for BPH. Table 8.1 lists a number of current clinical applications of lasers in urology.

In addition to refinement in laser equipment, advances in fiberoptic and digital endoscopes as well as in optical fiber technology have also

Table 8.1 Clinical uses of lasers in urology

Lithotripsy of renal, ureteral, and bladder calculi
Ablation/enucleation of benign prostate
Incision of ureteral and urethral strictures
Ablation of superficial bladder and ureteral carcinomas
Ablation of penile lesions
Incision of ureteroceles
Ablation of urethral hair post urethroplasty or hypospadias repair
Excision of renal tumors (partial nephrectomy)
Focal ablation of prostate cancer

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provided significant impetus for dissemination of laser techniques into community practice and made minimally invasive outpatient surgery for stones and BPH the rule rather than the exception.

Various mechanisms exist for the interaction of laser energy with a target, be it soft tissue or stone. In urological applications, the photothermal mechanism dominates and is responsible for ablation, incision, and coagulation of tissue. A photothermal mechanism has also been postulated to be of primary importance for Ho:YAG lithotripsy [1]. The photothermal effect of lasers is responsible for the so-called "vaporization" of benign enlarged prostate glands but can also be used to incise through large portions of the prostate in what is termed "enucleation". Laser energy can also vaporize or resect bladder carcinoma, and incise strictures of the urethra and ureter. Tissue "welding" is another application in development which utilizes a photothermal mechanism. Photodynamic therapy (PDT) for treatment of bladder and prostate cancer is an example of a photochemical laser-tissue interaction.

In this chapter we present state of the art information on laser use in urology, focusing on the two most important applications, treatment of calculi and BPH. We will also discuss available data on other uses of lasers in the field of urology and briefly delineate the future directions of research.

Laser Lithotripsy

Introduction

- Due to its efficacy and safety, the Holmium:YAG laser is in widespread clinical use for fragmenting stones throughout the urinary tract.

Development of laser lithotripsy began in the 1960s. The first laser to be used on urinary stones was the ruby laser [2] which worked by heating the stone surface to the point at which the stone melted. Due to its mechanism of action, the ruby laser was impossible to use in vivo and, therefore, never achieved clinical application. The introduction of pulsed dye lasers, namely the coumarin laser, led to the first clinical use of laser energy for lithotripsy in the 1980s [3].

The coumarin laser represented a major advancement in the treatment of urinary stones because the device was able to fragment stones of nearly any composition and small fibers could be used for energy delivery. While very high success rates were reported initially, the coumarin laser had significant disadvantages. It was prohibitively expensive and required unwieldy ocular protection as well as subsequent disposal of the toxic dye.

The Holmium:Yttrium-Aluminum-Garnet (Ho:YAG) laser has multiple advantages and has effectively replaced the pulsed dye laser, becoming the most commonly used device for lithotripsy. Compared to pulsed dye lasers, the Ho:YAG is more compact, less expensive to operate, and more reliable. It fragments stones by both generating shock waves (photomechanical) and by heating the stone surface (photothermal). The latter mechanism is by far the most important for calculus fragmentation [1]. Despite generation of heat and shockwaves, the excellent safety margin of the Ho:YAG is another major advantage. Since its wavelength of 2100 nm is highly absorbed by water, it penetrates tissue to a depth of less than 0.5 mm and can be confidently applied even in the tight confines of the ureter and renal pelvis [4].

Indications and Contraindications

Indications

- Urinary stones less than 2.0 cm in diameter

Contraindications

- Untreated bacteriuria or clinical evidence of urinary tract infection

The Holmium:YAG laser effectively fragments stones located in any part of the urinary tract, regardless of composition. Although any size stone can be treated with laser lithotripsy, the stone burden (size and number of stones) is the major factor determining whether laser lithotripsy is the best choice for a given patient. Stone burden affects treatment efficacy and large stones of the upper tract (kidneys and ureters) may not be amenable to ureteroscopic Ho:YAG laser lithotripsy (URSLL). Ureteral and renal calculi less than 2 cm can be approached with either URSLL [5] or extracorporeal shockwave lithotripsy, although comparisons of the efficacy of these two modalities is beyond the scope of this chapter. The effectiveness of URSLL for large stones is reduced due to limitations of the size of stone fragments that can be extracted through the ureter, as well as impaired visualization caused by stone dust and debris generated during fragmentation of large stones in the renal pelvis. In patients with sizable stone burdens, percutaneous nephrolithotomy using larger diameter rigid ultrasonic and pneumatic devices is a preferable option, although several reports exist of multisession URSLL for stone burdens over 3 cm [5].

For treatment of bladder stones, large diameter fibers can be used through cystoscopic instrumentation so there is no particular stone size limit precluding use of the Ho:YAG laser. Essentially any bladder stone can be fragmented with the laser. As with large renal stones, extracting numerous bladder stone fragments, as well as creation of vast amounts of stone dust and debris can render the technique inefficient. Thus, for very large stone burdens in the bladder, an open surgical approach or percutaneous surgery using ultrasonic or pneumatic devices is often more efficient, but clearly more invasive.

Presence of untreated urinary tract infection is the only absolute contraindication to laser lithotripsy as such patients have significant risk of developing life-threatening urosepsis. Holmium laser lithotripsy is feasible in patients who are receiving antiplatelet or anticoagulant therapy, thus making it the modality of choice for removing stones in patients with bleeding diatheses or those who cannot safely stop anticoagulant or antiplatelet drugs [6]. Similarly, laser lithotripsy has been shown to be effective and safe in multiple other patients subpopulations including obese [7] and pregnant [8] patients as well as children [9] and those with horseshoe kidneys [10].

Technique

Fiber selection

- 550 or 1000 μm fibers for use with rigid cystoscope in bladder.
- 365 μm fiber for use with rigid ureteroscope in ureter.
- 200 μm fiber for use with flexible ureteroscope in kidney or ureter.

Energy settings

- Pulse energy, frequency, and duration are chosen based on the desired effect.

Lithotripsy strategies

- Dancing, chipping, fragmenting, and popcorn are various strategies which can be applied depending on the situation.

Choice of laser fiber is dictated by location of the stone and thus the endoscope with which one plans to treat it. Bladder stones are approached via large-bore rigid cystoscopes which can easily accommodate side-firing 550 μm fibers or end-firing 1000 μm fibers. Side-firing fibers are advantageous in cases in which the patient has a large median prostatic lobe that impedes a straight-line approach to the stone. Side-firing fibers are also very useful for prostate vaporization and therefore may be the fiber of choice when both a bladder stone and enlarged prostate are treated during the same procedure. Ureteral and renal stones are addressed via smaller bore ureteroscopes with limited diameter working channels and thus require the use of smaller fibers. The working channel of these scopes must also accommodate flow of irrigant used to distend the ureter and renal pelvis for visualization, and larger fibers tend to impair irrigant flow. Typical fiber diameters used to treat ureteral and renal stones are 200 μm and 365 μm. The smaller of these also allows for maximal scope deflection, which is a requirement for lithotripsy of stones in the lower pole of the kidney. Laser lithotripsy of lower calyceal renal stones can lead to retention of fragments in the kidney postoperatively. Displacing the stone into an upper pole calyx using a stone basket obviates the need for deflecting the scope with a laser fiber in it and also allows for a more direct line for stone fragments to clear the kidney after lithotripsy. Passage of a laser fiber through a maximally deflected ureteroscope is one of the most common causes of scope damage. Recently introduced laser fibers with rounded “ball” tips allow for unencumbered passage of the fiber through a maximally deflected scope, allowing in situ lithotripsy of lower calyceal calculi as well as protecting the integrity of the ureteroscope.

Choosing appropriate laser settings is the most critical step after fiber selection. Available settings vary with the maximum power of the laser. Ho:YAG lasers are commercially available in 20, 30, 60, 100, and 120 W machines. Twenty-watt lasers are the least expensive and also the least versatile in terms of settings. Energy settings of 20 W lasers typically range from 0.5 J to 1.5 J and pulse frequencies range from 5 Hz to 12 Hz, while on a 100 W machine the energy can be set from 0.2 J to 2.5 J and the pulse frequency from 5 Hz to 50 Hz. Application of 20 W lasers is generally limited to stone treatment, whereas lasers of 60 W and higher can be used for both lithotripsy and tissue ablation, again making the latter a more versatile tool. Interestingly, laser manufacturers have recently begun to increase the available energy and frequency settings on 20 W models, with energy range up to 3.5 J and frequency up to 20 Hz.

Choice of pulse energy and pulse frequency is dictated by the goals of treatment and stone hardness. If the overall power of the laser remains constant, settings with higher pulse energy and low frequency are significantly more efficient as shown by increased ablation volume. Thus, pulse energy is the crucial determinant of the ablation volume, while pulse frequency and total power are less important [11]. However, high pulse energy can lead to stone migration, known as retropulsion. “Dusting” a stone into fine particles which can pass spontaneously after the procedure is best accomplished with low pulse energy (e.g. 0.3 to 0.5 J) and high pulse frequency (e.g. 20 to 30 Hz), settings which yield the smallest particles and very little stone retropulsion. Fragmenting stones into pieces small enough to remove with a stone basket is achieved with higher energy and lower frequency (e.g. energy of 0.8 to 1.0 J and frequency of 8 Hz). The degree to which these two mechanisms can be applied depends to some extent on the stone composition. Soft stones, such as calcium oxalate dihydrate and uric acid, are easier to dust into fine particulate matter, whereas very hard stones such as calcium oxalate monohydrate are quite resistant to dusting and tend to break into coarse fragments. The energy required to dust harder stones cannot be effectively delivered due to resultant retropulsion of the fragment. Also, as stone pieces become smaller, a given pulse energy causes relatively more stone migration.

Pulse duration is another parameter which has recently been added as a controllable parameter in newer Ho:YAG machines. Short pulse mode has been the default parameter and some manufacturers have added the ability to choose a long pulse mode up to 1500 μs per pulse. Traxer and coworkers have shown using artificial stones that shorter pulse duration results in significantly more ablation than longer pulse durations regardless of which energy-frequency-power settings are chosen [11]. However, shorter pulse duration, as with higher pulse energy, also increases retropulsion. Long pulse mode may result in slightly less damage to the fiber’s cladding and tip [11].

Preparation of a reusable laser fiber frequently includes tip cleavage with various tools and stripping of the terminal portion of the polymer coating. A recent study examined the effects of stripping the laser fiber versus leaving the laser fiber coated, and compared the difference between cleaving the fiber with specialized ceramic scissors and using simple metal scissors [12]. Results showed that fiber stripping leads to reduced ablation efficiency. Furthermore, no differences were found between metal and specialized ceramic scissors, as long as the fiber tip remained coated. These surprising findings may have significant influence on clinical practice and obviate the necessity of purchasing fiber strippers and specialized scissors.

Several techniques of laser application for stones with different mechanical characteristics have been described [13]. For soft stones, a “dancing” technique is recommended. The laser fiber is brushed back and forth across the stone surface resulting in a uniform ablation into small fragments. For harder stones a “chipping” technique is suggested. With this method the laser fiber is directed at the periphery of the stone with an intention of breaking off small (<1 mm) fragments. This is continued until the stone is small enough to be extracted with a basket. Chipped fragments are usually able to pass spontaneously. “Fragmenting” technique includes continuous firing at the center of the stone mass. This results in stone weakening along the natural cleavage planes. In some cases several holes should be bored and then connected. This method is recommended for very hard stones. Finally, the “popcorn” technique is used when multiple stones of average size are accumulated in one of the calices and chasing individual stones is inefficient. Instead, the fiber is positioned near the stone collection and the laser is fired at relatively high frequency resulting in a whirlpool-like phenomenon. Stone fragmentation is achieved by both direct laser ablation and collisions between stone fragments [13]. Table 8.2 summarizes the various approaches and gives examples of settings which can be used.

Adverse Events

- Injury to urothelial tissue and tissue perforation.
- Stone migration
- Endoscope damage

The Holmium laser has a very wide safety margin and serious complications related to laser energy are uncommon, especially in the renal collecting system. Thermal injury is more likely to occur in the ureter, especially with larger stones that are impacted within the ureteral wall, thus necessitating firing of the laser at the periphery of the stone. The most common adverse event is injury of the urothelial tissue, usually in the area adjacent to the treated stone. Since the depth of tissue penetration of the Holmium laser is less than 0.5 mm, most injuries are managed conservatively, but in relatively rare cases, a ureteral stricture may develop.

Stone retropulsion is another potential complication which can lead to incomplete stone removal. Retropulsion is due to the photomechanical effect of the laser pulse producing shockwaves which push the stone retrograde, away from the operator. Retropulsion is directly proportional to pulse energy. To prevent retropulsion and retrograde migration of ureteral stone fragments the urologist should use lower energy and higher frequency settings.

The Ho:YAG laser can cause significant damage to flexible ureteroscopes. The fiber itself can perforate the working channel of the scope if the fiber is passed through the scope when the latter is in a deflected state. Laser emission within the scope or too close to the tip of the scope will destroy the optics. Laser-related endoscope damage is a leading cause of the frequent need for, and high cost of, repair of flexible ureteroscopes.

Future Directions

- Development of smaller fibers that are more flexible and do not impede ureteroscope deflection.

Table 8.2 Lithotripsy techniques—Holmium laser

Technique	Energy-frequency combination	Example settings
Dancing	Low energy—high frequency	0.4 J × 30–40 Hz (12–16 W)
Chipping	Moderate energy—low frequency	0.8 J × 6–10 Hx (4.8–8 W)
Fragmenting	High energy—low frequency	1–1.5 J × 6–10 Hz (6–15 W)
Popcorn	High energy—high frequency	1 J × 20 Hz (20 W)

- Introduction of more efficient solid-state lasers and fibers (e.g. Erbium and Thulium lasers).
- Use of laser lithotripsy for stones larger than 2 cm.

Current and future efforts to advance laser lithotripsy focus on refining existing Holmium laser technology, extending the application of laser lithotripsy to larger stone burdens, and developing alternative lasers such as erbium:YAG and thulium. As mentioned previously, Holmium laser fibers with rounded, coated tips have recently been introduced in a 242 μm size which allow for passage of the fiber through a fully deflected flexible ureteroscope, thus facilitating in-situ lithotripsy of lower pole calculi. Further miniaturization of existing laser fibers may also improve accessibility to stones in the lower pole by allowing for improved deflection of scopes. Features which make the Holmium laser more user friendly are also being introduced, such as foot-pedal control of energy and frequency settings and feature-rich touch-screen interfaces, as well as the ability to save the preferred settings of a user, and "preset" settings for various techniques such as dusting or fragmenting. Increasing power (up to 120 W, 6 J, 80 Hz in one model) and combination with in-line suction allow for much more efficient use of lasers during percutaneous nephrolithotomy, a procedure in which laser use has been limited to deployment through flexible scopes to access smaller stones in peripheral calyces which could not be reached with more efficient rigid instrumentation. Continued refinements such as these will continue to improve efficiency of Ho:YAG lithotripsy and widen its potential application.

Two devices have been explored as potential alternatives to the Holmium laser but have not yet achieved clinical application for stone management. The erbium:YAG laser [14] has a wavelength of 2940 nm, which is better absorbed by water than that of the holmium laser's wavelength of 2120 nm. While this yields a much more efficient rate of stone fragmentation in vitro, currently available fibers are not suitable for erbium:YAG transmission in vivo. The thulium laser can be used for calculus fragmentation and in contrast can be used with standard fibers [15]. In vitro studies show more rapid stone fragmentation resulting in shorter laser and operation times for the experimental thulium laser compared to conventional holmium laser, suggesting potential clinical utility for this new technology [15].

Further innovation in endoscope design will also continue to promote the widespread use of laser lithotripsy. Development of smaller and more flexible ureteroscopes, introduction of digital optics, as well as increasing surgical experience has resulted in a gradual increase in the size of renal and ureteral stones which can be safely and efficiently managed ureteroscopically with laser lithotripsy. Although current guidelines suggest ureteroscopy for stones up to 2 cm, there is a growing body of literature describing successful treatment of even larger stones [5]. In properly selected patients this approach can result in stone-free rates up to 90% and allows one to avoid the potential increased morbidity of percutaneous surgery. Longer operative times and frequent need for repeat procedures are the main disadvantages of this management option.

Benign Prostatic Hyperplasia

Introduction

- Holmium:YAG and Potassium Titanyl Phosphate (KTP) Greenlight™ are the most commonly used lasers for treatment of BPH.
- Higher power Holmium:YAG (120 W) and Greenlight™ XPS (180 W) lasers are available for rapid treatment of BPH.

Benign prostatic hyperplasia is one of the most common conditions prevalent in aging men. While effective pharmacotherapy exists, surgical management is an excellent option for advanced cases or those refractory to medical treatment. Transurethral resection of the prostate (TURP) has been considered the gold standard procedure in such cases and has withstood the test of time, but over the past two decades Ho:YAG and KTP laser therapy for BPH have become accepted and effective alternatives.

These newer laser systems had to overcome the initially disappointing results of the first laser used for the treatment of BPH, the neodymium-doped yttrium aluminium garnet (Nd:YAG) laser. Procedures termed “visual ablation” and “interstitial coagulation” were accomplished with this device, but postoperatively patients often developed long-term dysuria and urinary retention, and the technique quickly fell out of favor [16]. Contemporary laser procedures differ significantly from these early techniques. Terminology used to describe different laser surgeries of the prostate is presented in Table 8.3. A considerable amount of experience has been accumulated with the Ho:YAG laser and Greenlight™. Two other devices—Thulium:YAG and diode lasers have shown some encouraging results, although more data is required to support their clinical use.

The two most commonly used systems for laser treatment of BPH, the GreenLight™ and the Holmium: YAG, use photothermal energy to heat intracellular fluid above the boiling point, thus vaporizing cells and either ablating or cutting through the prostate. The 532 nm wavelength of the GreenLight™ is absorbed by hemoglobin, resulting in efficient ablation of well-vascularized tissue. Penetration depth is approximately 0.8 mm, and within this zone, tissue is vaporized with a peripheral region of thermal coagulation of approximately 1–2 mm. It is important to understand that the term GreenLight™ includes several generations of devices, which differ in terms of efficiency, although safety and outcomes are thought to be comparable. The first generation of GreenLight™ KTP laser procedure [17] was termed Photoselective Vaporization of the Prostate (PVP) due to the interaction between the laser and hemoglobin within the tissue. As tissue is vaporized, a cavity is created in the prostate resulting in a wider lumen for urine flow. The original KTP laser system was introduced in 2002 and had power up to 80 W. The 120 W HPS laser system introduced in 2006 had higher maximum power output and focus of the laser beam, resulting in more rapid tissue vaporization. The most recent 180 W XPS laser system has a modified thicker inner core fiber, which in combination with increased power provides even higher ablative energy per time unit. Furthermore, fiber degradation leading to a loss in power output is no longer observed [18].

Table 8.3 Terminology of laser prostate surgery [16]

Visual laser ablation	Early and largely abandoned laser technique to ablate prostate tissue by heating the tissue with a laser beam
Interstitial laser coagulation	Early and largely abandoned laser technique where laser probes were introduced into prostatic tissue to induce coagulation necrosis
Enucleation	Surgical removal of the entire adenomatous tissue of the prostate
Vaporization	Surgical removal of prostate tissue by heating above the boiling point of water
Morcellation technique	Surgical technique that uses a device to crush and remove enucleated prostate tissue
Vaporesection	Surgical removal of prostate chips by incisions with a laser that also vaporizes prostate tissue
Vapoenucleation	Surgical removal of the entire adenomatous tissue of the prostate with a laser that also vaporizes prostate tissue to some extent

Greenlight™ laser has been compared to TURP in multiple randomized studies, most of which used the 80 W and 120 W devices. Postoperative catheterization time and hospitalization time were shorter with Greenlight™, whereas operative time was shorter with TURP [19]. These findings are similar to those for other laser-based procedures. The risk of postoperative blood transfusion and clot retention was significantly lower in patients undergoing the Greenlight™ procedure. This is expected, as the physical properties of lasers operating at 532 nm include the ability to ablate the tissue at the center of the beam area and coagulate the tissue at the outer area of the beam. This makes Greenlight™ ablation ideal for patients who are at increased risk of hemorrhagic complications, such as those on anticoagulant or antiplatelet therapy. The safety of this technique in these patient populations has been shown in several case series [20, 21]. The incidence of other complications, such as postoperative retention, urinary tract infection, gross hematuria, urethral stricture, and bladder neck stricture, were also found to be comparable between the Greenlight™ system and TURP.

There have been several procedures developed for BPH treatment using the Holmium laser. The first was termed HoLAP (holmium laser ablation of the prostate) and was performed with lower power devices. As such, it was limited to use on small prostates. Holmium laser resection of the prostate (HoLRP) was later introduced, in which prostate tissue was incised into pieces that required subsequent removal from the bladder. However, it was not significantly advantageous compared to HoLAP in terms of speed and also was not very effective for large prostates. With higher power Holmium lasers, some practitioners have found these techniques to be more practical, but their use is still not widespread.

High wattage systems have also fostered the HoLEP (holmium laser enucleation of the prostate) technique [22]. HoLEP involves creating incisions in the prostatic lobes, carrying these incisions down to the avascular plane between the prostatic capsule and the adenoma, using the beak of the resectoscope to mechanically dissect the tissue off the capsule, and connecting the areas of incision until the lobes are freed and pushed into the bladder. This procedure is very effective for removing the median lobe as well as both lateral lobes. In addition to having a steep learning curve, it requires a high power laser as well as a tissue morcellator to cut the enucleated prostate into pieces that can be evacuated through a resectoscope sheath. Unlike HoLRP, this technique can be used on the largest of glands and in the hands of those familiar with the technique is a viable substitute to an open prostatectomy. Multiple randomized studies comparing HoLEP and TURP have consistently demonstrated that catheterization time, length of hospital stay, blood loss, and requirement for blood transfusion are more favorable for HoLEP. Nevertheless operative time is longer and postoperative dysuria is seen more frequently than with TURP [16]. The functional outcomes of HoLEP, including symptom improvement, maximum urine flow, and post-void residual volumes are at least comparable to those of TURP. Similar results have been shown in studies comparing HoLEP to open prostatectomy in patients with large prostate volumes [23]. Like the Greenlight™ laser system, the holmium laser can be safely applied to patients on anticoagulant treatment or those with bleeding diatheses [24].

HoLEP is thought to be more challenging to learn than Greenlight™. For example in a recent multicenter study of the HoLEP learning curve, three of nine participating centers abandoned the procedure due to complications. Of the remaining centers only one was able to meet the preset criteria for successful mastery of the procedure (ability to perform four consecutive successful HoLEPs out of 20 cases) [25]. All participants were surgeons experienced in TURP.

Indications and Contraindications

Indications

*Moderate to severe lower urinary tract symptoms due to BPH resistant to medical therapy.

- Complications of BPH such as urinary retention or bladder stones.

Contraindications

- Untreated bacteriuria.

Practice guidelines from the American Urological Association endorse surgical therapy for men with moderate to severe lower urinary tract symptoms due to BPH resistant to medical therapy, as well as for patients who develop sequela of this condition, such as urinary retention or bladder stones. The choice of procedure depends on multiple factors, including equipment availability and training, with electrosurgical resection (i.e. TURP and its variants) and laser surgery being the most commonly used options. The Greenlight™ and holmium lasers each have unique characteristics which make them more suited in certain cases.

The Greenlight™ vaporizes the prostate through photothermal ablation of vascular tissue, which results in vaporization of prostate tissue. The rate of tissue removal is therefore to some extent limited, and for very large glands the operative times can be prolonged. The procedure seems to yield reductions in prostate size and PSA levels of 30–44% [26], so it may be best suited to smaller to medium size glands. Nevertheless, larger glands can be treated effectively if the surgeon invests enough time in the procedure. This concern may be less relevant for the most recent generation of XPS laser system, with its significantly higher power level. Holmium laser ablation is also limited by prostate size, thus also restricting its utility to small and medium size glands. For men with large prostates, the holmium laser is more suitably applied for enucleation rather than ablation. HoLEP also requires a significant time investment and therefore does not provide a time advantage over Greenlight™. The only significant surgical contraindication to these procedures is untreated bacteriuria.

Technique

- Equipment includes laser, cystoscope with irrigation system, and side-firing fiber.
- Greenlight™ is used to vaporize obstructing prostatic tissue.
- In HoLEP the laser is used to enucleate the prostatic adenoma.
- HoLEP is technically more complex than HoLAP or Greenlight™ ablation, but yields anatomically similar results to simple prostatectomy.
- Both Ho:YAG and Greenlight™ provide excellent hemostasis.

The technique of laser ablation, whether it is done with a Greenlight™ or a holmium laser, is essentially the same. The procedures are facilitated by using a continuous flow laser cystoscope, which has a stabilizing channel to guide the fiber through the scope. The KTP fiber is a side-firing fiber while, for Holmium applications, either side-firing or end-firing fibers can be used. The former is usually preferable. The fiber is maintained so that it nearly touches the surface of the tissue and is rotated from side to side in a sweeping arc traversing about 45–90°. The scope itself is moved back and forth in small increments to target unablated tissue, in effect "spray painting" the surface. Effective vaporization is confirmed by visualizing air bubbles escaping from the tissue. The median lobe is ablated first, just as in a standard TURP, taking care to identify and preserve the ureteral orifices. Vaporization then continues past the bladder neck, and is extended towards the verumontanum, which is the distal extent of treatment. Next, the lateral lobes are addressed, continuing the incremental spray painting motion from the bladder neck to verumontanum. The goal is to reach the transverse fibers of the prostate capsule, indicating complete ablation of adenoma tissue. Hemostasis is achieved by defocusing the laser fiber, or moving it away from the surface of the tissue, thus enhancing coagulation.

Holmium laser resection and holmium laser enucleation of the prostate are somewhat more complex procedures. If a prominent median lobe is present, this structure is generally enucleated or resected first. Using the laser a groove from the bladder neck to the verumontanum is created on either side of the median lobe, and deepened to the level of the surgical capsule. The median lobe is then undermined just proximal to the verumontanum and the plane between the adenoma and capsule is developed in a retrograde fashion. The lateral lobes are then dissected at a plane between the surgical capsule and the prostate adenoma. The laser is used to incise the attachments of these two structures, and the beak of the resectoscope pushes the adenoma upward, facilitating its separation from the capsule. Next, a groove is created at the extreme anterior aspect of the prostate and joined to the previous plane of dissection. The lobe is then freed from the capsule and pushed into the bladder, morcellated, and evacuated. The same steps are repeated for the contralateral lobe. If a morcellator is not available, the prostate is not completely freed from its final attachments, and the laser is used to incise the prostate into pieces small enough to be evacuated. The final attachments can then be separated from the capsule after this step.

Adverse Events

- Bleeding
- Perforation of the prostate
- Bladder neck contracture
- Urinary incontinence

Laser prostate surgery typically results in relatively little bleeding. Hemorrhage is more likely in men with large and very vascular prostates. However, even in such cases transfusion is rarely required. Perforation of the prostate may happen when the depth of the ablation or resection is poorly controlled. Bladder neck contracture is rare, particularly with HoLEP, and if it does occur it can usually be corrected with a transurethral incision procedure. Urinary incontinence may result from damage to the urethral sphincter but is unlikely if appropriate margins of ablation are carefully maintained.

Future Directions

- Development and validation of higher power Holmium: YAG and Greenlight™ lasers.
- Novel laser sources (e.g., Thulium:YAG and Diode Laser).
- Comparative studies of different laser techniques

Currently there exist only limited data regarding the outcomes of treatment with the latest Greenlight™ 180 W XPS laser system. The key feature of this new device is the high speed of vaporization which should translate into superior tissue ablation. Indeed, in a comparative study of 120 W HPS and 180 W XPS laser vaporization of the prostate performed by one surgeon, the operating time and lasing time were significantly shorter in the XPS group [27]. Given the rather generous mean prostate volume of 79.1 cm^3 in this series, these findings suggest that the new Greenlight™ device can be used efficiently for prostates of any size. However, further studies are required to confirm this.

The Thulium:YAG laser, operating in a continuous mode at wavelengths ranging from 1940 to 2013 nm, is a relative newcomer to the arena, introduced as a would-be alternative to the holmium laser for soft tissue applications. The thulium laser utilizes a front-firing fiber and provides excellent tissue cutting and hemostasis. Unlike Holmium:YAG, the Thulium:YAG laser fiber does not pulsate, which may slightly increase its ease of use. The optical penetration of 0.2 mm results in powerful vaporization. After treatment, the prostatic bed has a slightly charred appearance, as opposed to the fluffy white appearance that remains after Ho:YAG therapy. Due to the powerful vaporization effect, procedures utilizing Thulium:YAG are best labeled vaporesection and vapoenucleation (Table 8.3), although for the latter procedure the term ThuLEP is commonly used. Currently, Thulium:YAG is mainly used for vapoenucleation and according to a large cohort study provides high efficacy and perioperative safety [28].

The Thulium:YAG has been compared to mono- and bipolar TURP in several small randomized studies with limited follow-up. Similar to other laser prostate surgery techniques, ThuLEP was associated with shorter catheterization time and hospital stay compared to TURP while functional outcomes were comparable [16]. At this time Thulium:YAG vaporesection of the prostate seems promising, but high-quality evidence is scarce and proper trials with long-term follow-up are lacking.

Modifications in diode lasers have also resulted in renewed application to BPH. Diodes are semiconductors which are able to produce monochromatic light. Light is passed through a crystal, which leads to the final wavelength. Diode laser systems are available in different wavelengths (ranging from 940 to 1470 nm) and fiber designs (side-fire and end-fire). Due to its physical properties the diode laser has significant penetration depth with deep tissue coagulation up to 6.1 mm [29]. This rim of necrotic tissue postoperatively results in sloughing and severe dysuria along with bladder neck stricture formation, as was seen with Nd:YAG visual laser ablation procedures decades ago. Attempts have been made to reduce penetration depth of diode lasers by modulating frequency, pulsation, maximum power, or fiber design. Currently there are several diode laser systems available.

In small comparative trials the outcomes of diode laser vaporization of the prostate and diode laser enucleation of the prostate were similar to those of TURP and other laser procedures, although a trend towards a higher incidence of dysuria, passing of sloughed tissue, and reoperation owing to bladder neck stricture and obstructive necrotic tissue was evident [30]. A novel end-firing fiber with a 30-degree angulation, overlain with quartz for concentrating energy at its tip, and which works only in contact mode, was compared to a side-firing fiber in a small randomized study of prostate ablation [31]. Functional outcomes were similar in both arms, but complications were more common in the side-firing group. Thus, the quartz head fiber may improve performance of diode laser vaporization and requires further study.

Comparative studies of outcomes of different laser prostatectomy techniques remain wanting, as most trials have used TURP as a control. The few available investigations have not demonstrated major differences between the commonly used laser devices. For example, a recent study compared HoLEP with GreenLight™ vaporization of the prostate (HPS 120 W) in 80 patients with large prostates (>60 cm^3) [32]. Operative time and duration of catheterization were similar in both groups, but several conversions to HoLEP or TURP were observed in the Greenlight™ group due to bleeding. With 1-year follow-up, symptomatic improvement was comparable between the groups, while changes in postvoid residual (PVR) and maximum flow rate (Q_{max}) favored HoLEP. In another study, HoLAP was compared to the Greenlight™ (80 W) in 109 patients with prostate volumes less than 60 cm^3 [33]. The operative time was shorter in the Greenlight™ group, while catheterization time and hospital stay were comparable. Significant improvements in symptoms, PVR, and Q_{max} were seen in both groups. The retreatment rate was slightly higher in the Greenlight™ group (25% vs. 19.2%). This area clearly requires further investigation.

Urethral and Ureteral Strictures

Introduction

- Urethral and ureteral strictures usually result from trauma and iatrogenic injury.
- Cold knife or electrosurgical incision and balloon dilation provide inconsistent results.
- Open surgical repair is the gold standard, but is associated with greater morbidity for ureteral strictures.
- Holmium and Thulium lasers have been used for treating strictures with some success.

Strictures of the ureter and urethra may result from injury (iatrogenic and traumatic), stones, infection, and radiation therapy. Open surgical reconstruction involving removal of the diseased segment and re-anastomosis of healthy tissues remains the most definitive type of treatment. The significant morbidity associated with open repair, particularly of ureteral strictures, provided impetus for development of minimally invasive procedures such as balloon dilation and incision using cold knife, electrocautery, and holmium laser. These techniques have met with variable success, and as more urologists receive training in urethral reconstruction, it is expected that reparative urethroplasty, which has excellent success rates, will doom incision procedures for urethral strictures. Similarly, the widespread dissemination of robotic assisted laparoscopy has provided urologists with a less invasive, but highly effective alternative to open ureteral reconstruction, possibly making endoscopic ureteral stricture incision a thing of the past.

Indications

Indications

- Short (less than 2 cm) ureteral or urethral strictures.

Contraindications

- Ureteral or urethral strictures longer than 2 cm.

Stricture length is the most important parameter predicting treatment outcome of minimally invasive incisional treatment. Thus, patients with short strictures are the best candidates for endoscopic laser urethrotomy or ureterotomy. When the narrowing is longer than 2 cm, laser therapy is rarely effective and such patients should undergo open or laparoscopic reconstruction.

Technique

Ureteral Strictures

- Full thickness incisions with Holmium laser settings of 1–1.2 J and 10–15 Hz.
- Postoperative ureteral stenting for 4–6 weeks.

Urethral strictures

- Incisions at 6 and 12 o'clock.
- Postoperative urethral catheterization

Laser ureterotomy is usually accomplished with a ureteroscope, but may also be performed via a percutaneous antegrade approach depending on stricture location. A safety wire guide is used to traverse the stricture. Location of the incision in the ureteral wall depends on stricture location. A computed tomography scan will provide excellent guidance on avoiding incision towards periureteral structures immediately adjacent to the site of the stricture. For example, incision should be on the posterolateral wall in patients with proximal ureteral strictures, and on the anteromedial wall for distal strictures. If the narrowing is in proximity to the iliac vessels, incision should made on the anterior wall. A full thickness incision, extending into periureteral fat and ranging several millimeters into normal appearing ureter on both the proximal and distal margins, is mandatory. Multiple passes of the laser are often necessary to achieve adequate depth. In the ureter it is very challenging to make a focal longitudinal incision, especially using a flexible ureteroscope, and great care must be taken not to thermally injure a wide sector of the ureteral circumference. Typical laser settings include energy of 1–1.2 J and rate of 10–15 Hz. A balloon catheter may be inflated across the stricture before or after the laser incision to facilitate tissue separation. Injection of radiographic contrast media through the scope should reveal extravasation at the site of incision. A ureteral stent is then positioned and remains in situ for 4–6 weeks. Success rates of up to 80% have been reported in carefully selected patients with short strictures [34].

Urethral stricture incision is performed via cystoscopy. A safety wire guide is positioned traversing the stricture into the bladder, and then the stricture is incised at the 12 o'clock position. A 6 o'clock counter-incision may be necessary if a single urethrotomy seems inadequate. Laser settings are similar to those previously described for the ureter. No studies determining optimal duration of post-procedural urethral catheterization exist. Most urologists leave a catheter for several days, which is likely inadequate given that healing occurs by scarring and in-growth of tissue from the cut edges. A meta-analysis of laser versus cold knife urethrotomy demonstrated an average success rate of 75% for the former compared to 69% for the latter [35]. There were no differences in serious complications, suggesting that use of lasers for urethrotomy is well tolerated.

Laser incision of strictures is a very safe procedure. The most significant intraoperative complication is bleeding, which can typically be managed with Foley catheter tamponade of the urethra. Avoidance of vascular structures such as the corpora cavernosa is necessary and not difficult to accomplish. During laser endoureterotomy bleeding can occur if a periureteral vessel is entered. If the vessel is small, bleeding will be self-limited. Large vessels can be avoided with appropriate choice of incision site on the ureteral wall as previously described.

Other Applications of Lasers in Urology

Less common applications of lasers in urology include laser ablation of non-muscle invasive bladder tumors using holmium or KTP lasers [36], laser ablation of penile lesions including penile cancer with Nd:YAG and CO_2 devices [37], laser incision of ureteroceles [38], laser ablation of urethral hair in patients with prior urethroplasty or hypospadias repair [39], focal laser ablation for prostate cancer [40], and laser partial nephrectomy [41].

Laser partial nephrectomy holds some very interesting potential given the dramatic increase in small, asymptomatic renal masses detected with ever widespread use of axial imaging over the past two to three decades. Most such neoplasms are amenable to treatment with nephron-sparing surgery, in which only the diseased tissue and a small rim of normal kidney parenchyma are resected, either via an open or minimally invasive (laparoscopic or robotic assisted) approach. Due to the abundant vascularity of renal parenchyma, hemostasis is a major concern associated with partial nephrectomy. Traditionally, renal blood flow is interrupted during resection of the mass. This requires dissection of the renal hilum with clamping of the arterial and sometimes venous supply of the kidney and, more importantly, results in ischemia which may negatively affect kidney function. The excellent cutting and coagulation properties of many lasers suggest their potential use in partial nephrectomy to provide bloodless tumor excision while avoiding ischemia. Almost all existing laser systems have been assessed for both open and minimally invasive nephron-sparing surgery, however most of the trials were performed in small single-institution cohorts [41]. The most promising results have been seen with the thulium laser. Several groups have successfully reported successful laparoscopic partial nephrectomy without clamping of the renal vessels using this device [42, 43]. This technique clearly merits further investigation.

Conclusions

It is truly difficult to imagine contemporary urology without laser devices. The combination of both the power and precision of laser energy has promoted multiple applications in the field, especially laser lithotripsy for urinary stones and laser surgery for BPH, as well as incision, ablation, and excision of other structures and lesions. New, less expensive but more powerful, versatile and compact systems continue to be developed, creating novel opportunities for minimally invasive treatments and improving on existing applications. A typical example of this is the evolution of laser prostate surgery which accompanied the development of holmium, KTP, and thulium laser platforms, as well as the increasing power of subsequent generations of these lasers. In the future, even smaller and more efficient laser technologies, such as fiber lasers, may become available and replace current solid state devices. Applications of high-power lasers may further disseminate to other procedures requiring strong hemostatic efficacy such as laser laparoscopic partial nephrectomy, which is still in its infancy. Further innovation will no doubt promote increasing use of lasers even more dramatically for both benign and malignant genitourinary conditions.

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