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The Holmium Laser in Urology

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ABSTRACT

Objective: **To review the physics related to the holmium laser, its laser-tissue interactions, and its application to the treatment of urological diseases.** ***Summary and Background Data:*** **The holmium:YAG laser is a solid-state, pulsed laser that emits light at 2100 nm. It combines the qualities of the carbon dioxide and neodymium:YAG lasers providing both tissue cutting and coagulation in a single device. Since the holmium wavelength can be transmitted down optical fibers, it is especially suited for endoscopic surgery.** ***Methods:*** **The authors provide a review of the literature as it relates to the holmium laser and its application to urology.** ***Results:*** **The holmium wavelength is strongly absorbed by water. Tissue ablation occurs superficially, providing for precise incision with a thermal injury zone ranging from 0.5 to 1.0 mm. This level of coagulation is sufficient for adequate hemostasis. The most common urologic applications of the holmium laser that have been reported include incision of urethral and ureteral strictures; ablation of superficial transitional cell carcinoma; bladder neck incision and prostate resection; and lithotripsy of urinary calculi.** ***Conclusions:*** **The holmium:YAG laser is a multi-purpose, multi-specialty surgical laser. It has been shown to be safe and effective for multiple soft tissue applications and stone fragmentation. Its utilization in urology is anticipated to increase with time as a result of these features.**

INTRODUCTION

The holmium laser is a relatively new multi-purpose medical laser that has recently become available for use in urology. There has been a considerable amount of interest surrounding this laser as it seems to combine the cutting properties of the carbon dioxide (CO_2) laser and the coagulating properties of the neodymium:YAG (Nd:YAG) laser. These features make it particularly appealing for many surgical applications. Furthermore, becauase the holmium wavelength can be transmitted down silica quartz fibers, the laser is especially suited for endoscopic surgery. In addition to the urologic applications that will be discussed below, the holmium laser has also been reported for use in orthopedics,[1] ophthalmology,[2,3] otolaryngology,[4,5] cardiology,[6,7] oral/maxillofacial surgery,[8] and pulmonary medicine.[9] This article will review the physics related to the holmium laser, its laser-tissue interactions, and its application to the treatment of urological diseases.

HOLMIUM LASER PHYSICS AND LASER-TISSUE INTERACTIONS

The holmium laser is a solid-state laser system that operates at a wavelength of 2100 nm in the pulsed mode. As its name suggests, the laser's active medium is the rare earth element, holmium; and it can be combined either with a yttrium-aluminum-garnet (YAG) crystal as a holmium:YAG (Ho:YAG) laser, or with yttrium-scandium-gallium-garnet (Ho:YSGG).[10] Although the various commercial models vary slightly, the pulse duration of the holmium laser ranges from 250–350 μsec, the pulse energy from 0.2–4.0 J/pulse, the frequency from 5–45 Hz, and the average power from 3.0–80 Watts. The version of holmium laser that one chooses will depend on the applications that one has for the laser. However, the constant in each system is that the same 2100 wavelength is emitted and it is this wavelength that gives the holmium laser its useful clinical properties, distinguishing it from some of the other commonly used lasers in medicine.

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Light at the 2100 nm wavelength is invisible to the human eye and falls in the near-infrared region of the electromagnetic spectrum. The optical absorption coefficient for water at this wavelength is approximately 40 cm^{-1} so that the holmium wavelength is significantly absorbed by water. Since tissue is composed mainly of water, the majority of the holmium energy is absorbed superficially and this results in superficial cutting or ablating. In comparison, the pulsed CO_2 laser operates at a wavelength (10,600 nm) where there is also maximal absorption by water and therefore excellent tissue ablation. However, because the absorption coefficient at this wavelength (800 cm^{-1}) is significantly greater than that for holmium, the depth of tissue penetration is even more superficial and in the range of approximately 0.05 mm.[11] Although this level of penetration will produce a very precise cut with a very narrow zone of thermal damage, the residual thermal energy is not enough to provide for hemostasis in vascularized tissues. As a result, blood vessels larger than 0.5–1.0 mm in diameter will not be adequately controlled during laser surgery. Conversely, tissue studies with the holmium laser have now shown that the zones of thermal injury associated with laser ablation range from 0.5–1.0 mm,[12,13] and this is a level that does produce adequate hemostasis during ablation even for vessels larger than 1.0 mm in diameter. The holmium wavelength has a further advantage over CO_2; it can be transmitted down optical fibers so that its use can be extended to endoscopic applications. This attribute continues to elude the CO_2 laser and will continue to do so until a useful fiber delivery system has been developed.

The Nd:YAG laser operates at a wavelength of 1064 nm where the absorption coefficients of water are between 2–10 cm^{-1}; a level that is weakly absorbed and easily scattered by tissue. This results in tissue heating and leads to a wide zone of thermal injury or coagulative necrosis of 4–6 mm in depth. Therefore, this laser is excellent for coagulating tissue but it has no cutting properties. In addition, because the Nd:YAG laser operates in the continuous-wave mode, heat is generated continuously. As a result, it tends to be more difficult to control and predict the depth of thermal necrosis. On the other hand, because the thermal relaxation time for soft tissue has been estimated to be approximately 310 ms,[12] the 250 μsec (0.25 ms) pulse duration of the holmium laser is short enough so that diffusion of thermal energy is minimal. As a result, one is dealing more with a "what-you-see-is-what-you-get" type of tissue effect and this tends to be more appealing to surgeons who are used to this type of tissue-interaction with other surgical modalities.

The specific tissue ablating properties of the holmium laser have been studied in various models and the collective results from these studies are quite uniform.[12–15] As already noted, tissue ablation occurs superficially with thermal injury zones ranging from 0.5–1.0 mm. This is five to ten times smaller than that caused by the Nd:YAG laser and approximately ten to fifteen times greater than that produced by the CO_2 laser.[12] This level of thermal coagulation seems to be sufficient for adequate hemostasis since Johnson et al. found that holmium laser partial nephrectomy in the dog was as efficient as that performed with the Nd:YAG laser.[13] The current clinical experience with holmium laser resection of the prostate also supports this.[16] Tissue ablation can be performed in air or endoscopically within a fluid medium in either a contact or noncontact mode. Van Leeuwen has shown experimentally that even though the holmium wavelength does have a strong affinity for water, noncontact tissue ablation is possible with the holmium laser through a phenomenon that has been called the "Moses effect".[17] In this situation, the pulsed laser energy causes the formation of a water vaporization bubble that expands and elongates with the laser pulse. Since the latter part of the laser pulse is emitted as the bubble is still forming, the laser beam passes through the water vapor within the bubble, which has a lower absorption coefficient, and the majority of the energy is deposited at the "distal" bubble-water boundary.[18]

In addition to its tissue ablating properties, the holmium laser has also been shown to have excellent stone ablating effects. Other lasers used today for intracorporeal lithotripsy include the pulsed-dye laser and the alexandrite laser, both of which affect stone fragmentation through a plasma-mediated shock wave. This photoacoustic interaction occurs in lasers that operate in the microsecond or nanosecond domain and are capable of generating very high peak powers. Nishioka and colleagues have demonstrated that when the pulsed-dye laser is directed onto a calculus, microscopic heating occurs on the stone surface causing the liberation of free calcium ions.[19] These ions form a cloud or plasma-bubble that expands and contracts with each subsequent laser pulse. With each collapse of the bubble, a photoacoustic shockwave is generated that has sufficient kinetic energy to cause stone fragmentation of most urinary calculi. In comparison, the exact mechanism for stone fragmentation with the holmium laser is not known with certainty, but the evidence to date suggests that this results mainly from a thermal effect with only a secondary shockwave or cavitational effect. Zhong and associates have used high-speed photography and acoustic pressure measurements to compare stone fragmentation with the pulsed-dye laser and the holmium laser.[20] Compared to the spherical cavitation bubble and strong shockwave emission produced by the pulsed-dye laser, the longer pulse duration of the holmium laser produced an elongated bubble with a much weaker shockwave emission. This finding has been confirmed by other investigators who have shown that, as the pulse duration of the laser increases, the cavitation bubble produced in the liquid medium becomes more elongated and cylindrical in shape; and this leads to a decreased magnitude in the subsequent pressure wave compared to the spherical bubble produced by short-pulsed lasers.[18] Therefore, it would seem that, because the shockwave associated with the holmium laser is relatively weak, stone fragmentation must be more dependent on a thermal effect that causes "stone vaporization". It is conceivable that with each laser pulse, heating occurs on the stone surface that causes vaporization of water within the stone and on the stone surface thereby effecting a small area of "stone ablation". Once stress fractures develop within the stone, the relatively weak shockwave emission produced by the laser may also contribute to the fragmentation process by breaking up the stone along these weakened cleavage planes. Clinical experience to date supports this type of a theory, since a number of investigators have commented that holmium laser lithotripsy occurs through a "drilling effect," whereby small bits of stone are vaporized, emitting a fine stone dust.[21–23]

In summary, the majority of the holmium laser's effect during urologic applications is due to its thermal effects as a result of its strong absorption by water. This results in excellent superficial tissue ablation but also a significant hemostatic effect because of the residual thermal injury associated with the laser energy. Even in stone fragmentation, the main interaction appears to be a thermal one since current evidence suggests that the shockwave emission associated with the holmium laser is too weak to overcome the tensile and compression strength of most stones. However, it should be noted that while these photoacoustic properties do not appear to be strong enough to fragment stones, they are powerful enough to cause tissue damage in the form of fissures or fractures.[24] This type of mechanical damage would be undesirable for certain applications, such as laser-assisted coronary angioplasty, where cracks and fissures could increase the risk of thrombogenicity or vessel rupture. Recent work has revealed that in these types of clinical scenarios, a continuous wave holmium laser, which would have no mechanical tissue effects, might be a more appropriate instrument.[25]

UROLOGIC APPLICATIONS OF THE HOLMIUM LASER

Based on the wavelength characteristics of the holmium wavelength and on the actual physics of the laser, one would expect several potential applications for the laser in urology. Over the past five years, a number of applications of the holmium laser have emerged and these generally fall under the broad headings of soft tissue applications and laser lithotripsy.

Soft tissue applications of the holmium laser

As outlined above, this laser possesses both ablative and hemostatic properties and, because the laser light can be passed down optical fibers, these actions can be carried out endoscopically in a fluid environment. Soft tissue applications that have been reported with the holmium laser have involved all portions of the urinary tract and include incision of ureteral or urethral strictures;[26–28] ablation of superficial transitional carcinoma;[26,28–30] bladder neck incision[29,31–33] and prostate resection;[16,34] and superficial ablation of warts involving the external genitalia.[26] There has also been one report where the holmium laser was used for various abdominal applications using a laparoscopic approach.[26] The laser parameters selected for these various applications will differ slightly and these are outlined in Table 1.

Holmium incision of ureteral and urethral strictures. Incision of ureteral or urethral strictures can be performed with either rigid or flexible endoscopes, but when possible, a rigid scope should be used since this tends to afford the most control in applying the laser energy to the tissues. A bare end-firing laser fiber is placed in direct contact with the tissue and a linear incision is made full-thickness through the stricture and into normal tissue on either side. In the case of the urethra, when one is using a cystoscope with a larger working port, the laser fiber can be placed through an open-ended catheter to add further support and control. Similar to incision of strictures using other cutting devices, the site of the incision is based on the anatomic location of the stricture and the associated vasculature at that location. Following incision of strictures in the ureter, a stent is placed and maintained for 4–6 weeks.

Clinical results for ureteral strictures are limited, but they appear to be comparable to the results of endosurgical management with other modalities.[35,36] At our institution, 21 patients with ureteral strictures have been treated with the holmium laser and have a mean follow-up of 10.8 months.[27] Overall, 16/21 (76%) of the patients are clinically well with no evidence of recurrent stricture formation. The five patients in whom treatment failed generally had complex strictures and all recurred within three months.

The holmium laser has also been used during percutaneous endopyelotomy.[26,28,29] In these reports, the laser functioned as well as any other cutting instrument for this purpose, however, extensive and long-term experience with the holmium laser in this scenario is still lacking.

In many respects, the holmium laser would seem to be an ideal tool for stricture incision. Advantages include the accurate control of the energy delivery and subsequent incision; hemostasis of superficial vessels; a relatively narrow zone of thermal injury that should limit damage to surrounding normal tissue; small caliber fibers that allow excellent irrigation; and the ability to treat strictures in the upper ureter and kidney because the fiber can be used in flexible endoscopes. More data with longer follow-up are still required to determine whether the holmium laser is a better cutting instrument than other current modalities.

Holmium laser ablation of superficial transitional cell carcinoma. Holmium laser ablation of superficial transitional cell carcinoma (TCC) can be performed for both bladder tumors and tumors in the upper tracts. For bladder carcinoma, either rigid or flexible cystoscopes can be utilized depending on the preference of the surgeon. In the upper urinary tract, the choice of scope will depend on the anatomic location of the tumor within the ureter. To perform tumor ablation, most investigators recommend using pulse energies of 0.6–1.2 J at a frequency of 8–12 Hz[28–30,37] (see Table 1). Laser fibers of 365 μm and 550 μm are usually employed but a 200 μm fiber can be very advantageous for ureteral or renal tumors where better deflection with the flexible scope is necessary.

To perform tumor ablation, either a coagulating or a cutting

TABLE 1. RECOMMENDED LASER PARAMETERS FOR VARIOUS UROLOGIC APPLICATIONS OF THE HOLMIUM:YAG LASER

Application	*Pulse energy (J/pulse)*	*Pulse Rate (Hz)*	*Average power (W)*
Incision of stricture	0.6–2.0	8–15	4.8–30
Ablation of TCC	0.6–1.2	8–15	4.8–18
Prostate resection	2.4–2.6	25–30	60–80
Lithotripsy	0.6–1.2	8–15	4.8–18

TCC = transitional cell carcinoma

technique can be employed. To coagulate, the fiber is placed within 1–2 mm of the tumor and then activated. This technique is useful for treating tumors where there is no defined stalk and a "fulguration" type of effect is desired. Cutting is performed by placing the fiber in contact with the tissue during activation and this method is more helpful in incising tumors on a stalk. Although more tissue can be ablated with larger diameter fibers and higher pulse energies and/or pulse rates, there is greater movement of the tissue with these higher settings, thus making ablation more difficult.[37] Some investigators have also noted that as treatment progresses, it is often difficult to recognize the base of the tumor as distinct from surrounding normal tissue.[37] In addition, a peripheral rim of erythema may develop, and this also can mask the resection limits.[30] Consequently, it may be beneficial to outline the perimeter of the area to be ablated before beginning, especially when the area to be lased is a little larger. Furthermore, although any size tumor can be treated with the holmium laser, ablation can be quite slow and tedious for larger tumors, especially for those greater than 1 cm. Johnson has suggested that in these cases, the stalk be treated initially in order to deal with the blood supply to the tumor first as this tends to avoid nuisance bleeding during ablation of the bulk of the tumor.[30] On the whole, holmium laser ablation of TCC is best reserved for small papillary tumors in those patients with a history of recurrent superficial, low-grade cancer. It is best not to use this technique for a first-time tumor or in situations of positive urine cytology or when the cystoscopic appearance suggests high-grade or invasive lesion, since accurate tumor staging is not possible.

Short-term follow-up on patients treated in this fashion suggests that the treatment is as effective as electrosurgical fulguration and resection. Johnson has the largest reported series to date with 15 patients treated for recurrent superficial bladder carcinoma.[30] After three months of follow-up, four patients were free of recurrent disease, eight had out-of-field recurrences, and three were classified as having in-field recurrences, although only one of these patients was unequivocally an in-field recurrence. The remaining two patients had multiple tumors present within the area of the original ablation site; therefore it was difficult to determine accurately the adequacy of the original laser procedure.

The main advantage of the holmium laser for treating superficial bladder tumors is that when used in combination with a flexible cystoscope, the procedure can be performed with local anesthesia or no anesthesia at all in an outpatient setting. In addition, because tissue penetration is <0.5 mm, there is a low risk of perforation and obturator spasm is non-existent. For ureteral tumors, the superficial depth of penetration is also a large advantage since it allows precise ablation with low risk of injury to neighboring structures. Moreover, the hemostatic properties of the laser allow these procedures to be carried out in a relatively bloodless field.

Holmium laser prostatectomy. The application of the holmium laser to the prostate gland has undergone an interesting evolution in technique over the past 3–4 years. The first descriptions of holmium laser prostatectomy occurred in 1995 when a combined laser technique was reported by Gilling and colleagues in New Zealand[38] and Denstedt and associates in Canada.[34] In both institutions, there was a desire to improve upon the visual ablation of the prostate (VLAP) that was being performed with the Nd:YAG laser. Although the VLAP technique was minimally invasive, it was fraught with problems. Patients required urethral catheterization for up to three weeks while waiting for the coagulated prostate tissue to slough; there were significant irritative voiding symptoms following catheter removal that often lasted six weeks or more; and symptomatic improvement for the patient was often delayed because of these factors. It was felt that if the holmium laser's cutting and ablative properties could be applied to the prostate, it would allow immediate removal of obstructing tissue with less morbidity and good symptomatic relief.[32]

The combination endoscopic laser ablation of the prostate was done by initially performing a standard four-quadrant Nd:YAG coagulation prostatectomy, followed by holmium laser ablation in which a side-firing fiber was used to vaporize a channel in the lateral and median lobes. Denstedt performed holmium ablation first, followed by Nd:YAG coagulation in order to limit the amount of surface charring that could occur with the Nd:YAG treatment. It was believed that this carbonization might limit the amount of laser energy penetration into deeper tissue because of its scatter effect on the Nd:YAG laser energy.

Gilling and colleagues treated 110 patients using this combined laser technique and Denstedt et al. treated 16 patients. For both groups there was a decrease in the AUA symptom score of approximately 50%–60% and an increase in the peak urinary flow rate (Qmax) of approximately 20%–40%; and although these results were comparable to those reported with VLAP, there still were some concerns with this technique. First, except for small prostate glands, this technique was extremely slow and tedious. In addition, the recatheterization rate was 20%–25% and 10% of patients required analgesics for irritative voiding symptoms so that this seemed to negate the potential benefit of using the holmium laser to create an immediate channel. Gilling et al. believed that these adverse effects were due to swelling and edema caused by the Nd:YAG coagulation.[38]

In order to eliminate these problems, the holmium laser was then used alone with a side-firing fiber to circumferentially vaporize a channel with the Nd:YAG laser being used only for hemostasis.[32] It soon became apparent to the New Zealand group that the Nd:YAG laser was essentially redundant and not necessary since, by withdrawing the fiber a few millimeters from the tissue, the holmium beam was defocussed and was able to coagulate in a non-contact mode effectively. More than 30 patients were treated in this fashion and, although the recatheterization rates dropped to 10% and the irritative voiding symptoms also decreased, tissue removal was still inefficient and laborious compared to the gold standard transurethral resection of the prostate (TURP). This has led to the most recent evolutionary step, whereby large pieces of prostate are resected using an end-firing laser fiber as a precise cutting instrument.

The technique has been well described by Gilling et al.[16] and has been called holmium resection of the prostate gland (HoLRP). Briefly, high laser settings of 60–80 watts are used and the procedure is performed with a modified 26F continuous flow resectoscope that is fashioned with a circular fiber guide in the tip of the scope (see Fig. 1). Further stabilization of the fiber is achieved by placing the fiber through a 6F open-ended ureteral catheter. Resection of each lobe is begun by first incising the lateral and medial resection margins to define the depth and amount of tissue to be removed (Fig. 2). The lobes are then

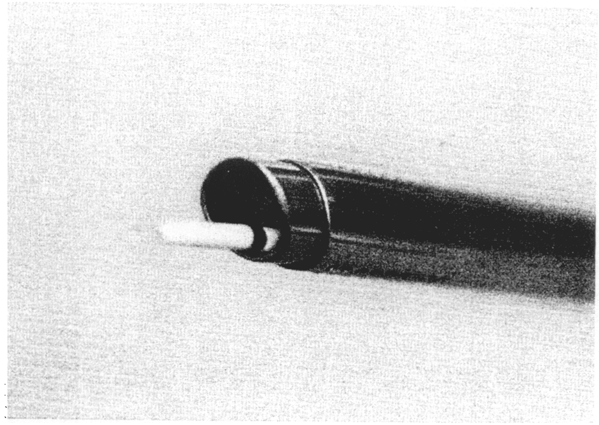

FIG. 1. Modified continuous flow resectoscope sheath used for holmium laser resection of the prostate. A circular fiber guide has been inserted; this and an open-ended ureteral catheter help to stabilize the laser fiber.

individually undermined and released in a retrograde fashion until only a bridge of tissue remains at the bladder neck. To facilitate the removal of the resected tissue through the urethra, the lobes are cut with the laser into several smaller portions prior to their release into the bladder. These resected pieces of tissue are then removed from the bladder using a combination of Toomey syringe irrigation and manual removal with a modified resectoscope loop (see Fig. 3).

The New Zealand group has the largest experience with this technique worldwide, having treated more than 480 patients and the results, to date, have been very encouraging.[39] There has been a mean increase in the Qmax at six months of almost 200% and a mean decrease in the AUA symptom score of approximately 80%. Furthermore, the recatheterization rate overall was less than 5% and although dysuria and frequency were still present in the majority of patients, these symptoms were significantly less than those seen with VLAP or the other holmium laser techniques. Fear that the narrow thermal injury zone produced by holmium laser ablation would not provide adequate hemostasis in the very vascular prostate also appears to be unfounded, since only 1.5% of patients required rehospitalization as a result of gross hematuria. No patient needed a blood transfusion and four patients underwent HoLRP without bleeding complication while on therapeutic levels of warfarin. The coagulative properties of the laser also appear to seal off venous channels adequately and prevent absorption of irrigation fluid since there were no cases of significant hyponatremia or TUR syndrome. Finally, although their follow-up time is still relatively short, there have been no cases of bladder neck contracture and only one case of urethral stricture.

This operation is now being employed by several centers around the world[40–42] and results from these trials are confirming the initial excellent results reported from New Zealand. In addition, for those patients with smaller prostate glands, there are also reports of holmium laser bladder neck incision with some of these being done as day cases.[32,33]

Therefore, the main advantages of the HoLRP procedure are that the holmium wavelength allows one to create a large "TURP-like" cavity by immediately removing obstructing tissue; it can be performed in a relatively bloodless field with excellent hemostasis; the operation can be done rapidly for all prostate sizes up to 80–100 gm; and although it has been estimated that approximately 75% of the prostate is vaporized during the resection,[16] there is still tissue available for histology, a property that is lacking with many of the other minimally invasive methods for treating symptomatic benign prostatic hyperplasia (BPH). The rate-limiting step of this operation at present is the time it takes to manually remove the pieces of tissue from the bladder. However, a tissue morcellator has already been used successfully by the New Zealand group[43] and once this becomes universally available, it should significantly enhance the technique of holmium prostate resection.

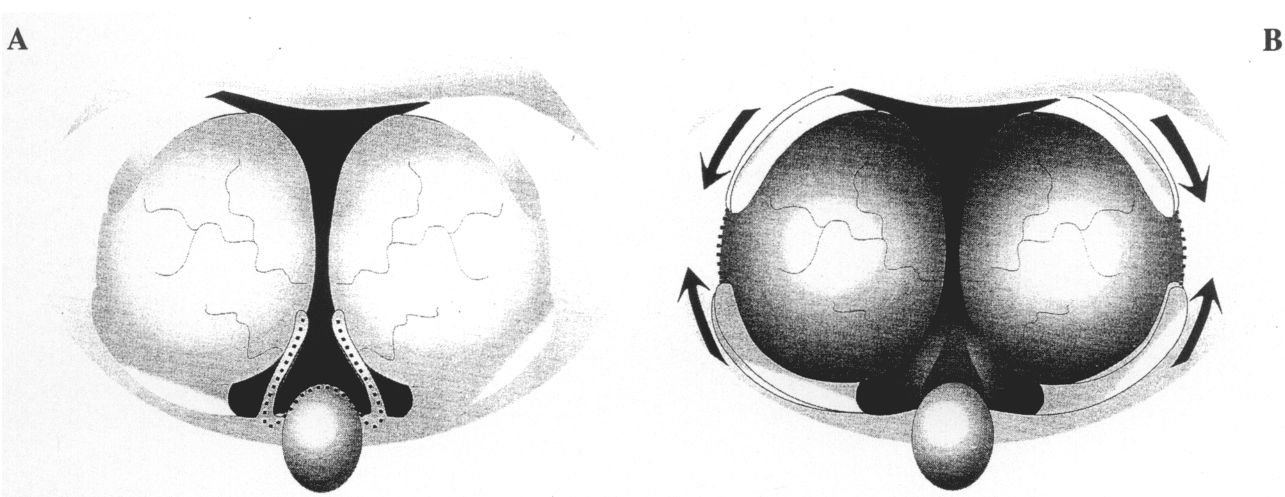

FIG. 2. Holmium resection of the prostate. A. Resection of the middle lobe. Following incisions of the bladder neck a transverse incision is made just proximal to the verumontanum and the middle lobe is undermined and finally detached into the bladder. B. Resection of the lateral lobes. Incisions are made at 11 o'clock and 1 o'clock along the entire length of the prostate; each lobe is then released in a retrograde fashion up to the bladder neck. Large lobes are cut into smaller portions before releasing into the bladder.

Holmium laser lithotripsy

The first published reports of holmium laser lithotripsy appeared in 1995[44,45] and since that time, there have been several other published papers reporting the results of using the holmium laser for fragmenting urinary calculi.[21–23,46–48] These series have all demonstrated that the holmium laser has excellent stone fragmenting properties and, as a result, it is now a well-established modality for performing intracorporeal lithotripsy.

The technique of holmium laser lithotripsy is relatively straightforward and involves placing the fiber on the stone surface and then activating the laser. Compared to some of the soft-tissue applications of the laser, the overall power used for stone fragmentation is considerably less (see Table 1). In general, pulse energies of 0.8–1.2 J and pulse rates of 6–10 Hz are more than adequate to achieve effective fragmentation. As noted earlier, stone fragmentation occurs in a "drilling" fashion so that the laser fiber bores down into the stone while emitting a fine spray of stone dust. To perform lithotripsy, one can create multiple holes within the stone surface or alternatively work away by creating a larger superficial cavity. In either situation, as the main calculus breaks apart, the lithotripsy process is continued on the smaller fragments until these are either small enough to pass spontaneously or able to be safely retrieved with baskets or grasping forceps.

Obviously, because the holmium wavelength can cut and coagulate tissue, it is very important that certain guidelines be followed. The entire procedure must be done under direct vision with the fiber in contact with the stone at all times. In situations where stone dust begins to obstruct the operator's vision, lithotripsy should be halted until the irrigation has an opportunity to clear the field. One must also be cautious about drilling through the stone to the backside where tissue damage can occur blindly. Finally, because the holmium wavelength is capable of cutting through metal, it is important not to direct the laser energy directly at the safety guidewire or stone baskets. Moreover, the laser fiber should always be extended at least 5 mm beyond the tip of the endoscope to avoid damage to the lens system of the scope. Failure to adhere to these principles can lead to unwanted effects in the surrounding tissue or endourologic equipment.

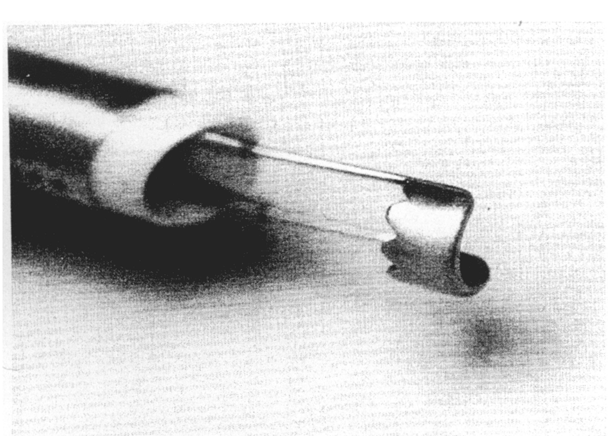

FIG. 3. Modified resectoscope loop used to retrieve fragments of tissue from the bladder.

The clinical results of holmium laser lithotripsy for ureteral stones have been uniformly excellent.[21–23,45,46] Successful fragmentation of calculi is achieved on average in greater than 90% of cases and the final determinant of success is not the laser itself, but other factors such as stone location, stone size, and situations of difficult access because of associated anatomic abnormalities or ureteral narrowing. The holmium laser essentially will fragment all calculi regardless of composition, including cystine, calcium oxalate monohydrate, and brushite. Complications have been few and are most often the result of the ureteroscopy and not the laser. At our institution, we have treated over 225 patients with the holmium laser and currently, seven patients have developed strictures in follow-up. However, for all cases, there has either been a past history of iatrogenic injury that occurred during previous attempts at stone fragmentation, a long duration of stone impaction with ureteral narrowing and fibrosis noted at the time of ureteroscopy, or a combined history of a large, impacted stone in a ureter that was previously irradiated during treatment for pelvic malignancy. We do not believe that the laser contributed to stricture formation in any of these cases. Nonetheless, the potential for this type of injury exists and careful attention to technique must be maintained to avoid ureteral complications.

Holmium laser lithotripsy for renal calculi used either as an adjunct during percutaneous nephrolithotripsy or as a primary intracorporeal lithotripsy device during retrograde ureteroscopy has also been reported.[22,23,45] During percutaneous surgery, the holmium laser is most helpful in clearing small volumes of stone when flexible instruments are required to access stones in a calyx remote from the nephrostomy tract. For larger stone burdens, using the laser as a sole modality is often too time-consuming and not as efficient as other devices such as the ultrasonic lithotriptor or the Swiss Lithoclast. (Electro Medical Systems, Meersburg, Germany). However, as retrograde ureteroscopy is being expanded into the proximal ureter and kidney, some investigators are reporting using ureteroscopy as a primary procedure for patients with renal calculi.[23,49,50] It is in these situations that the holmium laser is especially helpful since the laser fibers can be used in small-caliber ureteroscopes; and now, with the 200 μm fiber, almost any stone in any region of the renal collecting system can be accessed in a retrograde fashion and then fragmented with the laser. Grasso currently has the largest reported experience treating intra-renal calculi in a retrograde manner with the holmium laser.[23] Out of 26 patients, 88.5% had their stones fragmented and cleared with a single procedure. Three patients with partial staghorns required a second-look endoscopy, but all were eventually rendered stone-free. Finally, bladder calculi also have been treated with the holmium laser.[23,48] Once again, investigators have noted that the laser is able to fragment all calculi and that it can be used safely for this application. The procedure can be time-consuming with larger calculi, however, Teichman[48] and colleagues have noted that by using a 70° side-firing fiber, the lithotripsy process can be sped up, thereby making the operation more efficient.

CONCLUSIONS

The holmium:YAG laser is a solid-state laser that emits light at 2100 nm and combines the qualities of the CO_2 and Nd:YAG lasers, providing tissue cutting and coagulative hemostasis in a single device. Furthermore, the holmium wavelength can be transmitted down optical fibers so that it can be applied in endoscopic surgery. As a result of these properties, the holmium laser has found several applications within urology including incision of ureteral and urethral strictures, ablation of superficial TCC, prostate resection, and fragmentation of all varieties of urinary calculi. The main limitation of the holmium laser is its overall cost, with initial start-up costs ranging from \$80,000–\$140,000. For many, this price may seem prohibitive; however, when one considers the potential uses for this laser in urology and its expanding list of applications within other specialties, this device may in fact become more cost-effective than many other surgical instruments and tools we now employ.

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