Holmium : YAG Laser for Intra Corporeal Lithotripsy

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Introduction

Albert Einstein can be considered the 'father' of laser (light amplification by the stimulated emission of radiation) technology [1]. It was almost seven decades later in 1968 that Mulvaney and Beck [2] developed a ruby laser capable of calculus fragmentation with considerable expenditure of energy, resulting in excessive heat production. The thermal effects on the surrounding tissues precluded its clinical use. Attempts were subsequently made to use continuous wave carbon dioxide and Neodymium : YAG (Nd: YAG) lasers. The inability to transmit carbon dioxide laser via non-toxic fibres suitable for endoscopic applications and thermal effects to adjacent soft tissues associated with the Nd:YAG devices limited their clinical usefulness [3]. Based on the initial experience with these lasers, an understanding of the necessary requirement for successful laser lithotripsy became apparent, including the ability to deliver energy through optical fibres, need to limit distant thermal effects and production of a shock wave of sufficient force to exceed the tensile strength of the stone [4]. The first commercially successful laser lithotrite was the coumarin pulse dye laser but it could not fragment cystine stones. In clinical use the pulsed dye laser has been safe and effective in Nd: YAG and Alexandrite lasers [5, 6]. The holmium: YAG (Ho: YAG) laser is the newest wavelength device available for urological applications. Investigational work for lithotripsy with the Ho: YAG laser dates back to 1990 and clinical use began in 1993. This multi-purpose laser combines the qualities of carbon dioxide and Nd: YAG laser in providing both tissue cutting and coagulation in single device. Since the holmium wavelength can be transmitted down optical fibres, it is especially suited

for intracorporeal/endoscopic lithotripsy.

Holmium laser physics and laser stone interaction

The Ho: YAG laser is a solid state, pulsed laser that emits light at 2100nm. The laser's active medium is the rare earth element holmium and it can be combined either with a yttrium-aluminium-garnet (YAG) crystal as Ho:YAG laser or with yttrium-scandium-gallium-garnet (Ho:YSGG). Although the various commercial models vary slightly, the pulse duration of the holmium laser ranges from 250-350 µsecs, pulse energy from 0.2-4.0 J/pulse, frequency from 5-45Hz and the average power from 30 to 80 watts. The version that one chooses will depend on the intended application. 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 absorbed significantly by water. Since tissues are composed mainly of water, the majority of the holmium energy is absorbed superficially and this results in superficial cutting or ablating only.

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 intra corporeal lithotripsy include the pulse-dye laser and the alexandrite laser, both of which cause stone fragmentation through a plasma-mediated shock wave. This photo acoustic interaction occurs in lasers that operate in the microsecond or nanosecond domain and are capable of generating very high peak powers. Vassar et al [7], have demonstrated that when the pulsed-dye laser is directed on to a calculus, microscopic heating occurs on the stone

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surface causing the liberation of free calcium ions. These ions form a cloud or plasma-bubble that expands and contracts with each subsequent laser pulse. With the collapse of each bubble, a photo acoustic shock wave is generated that has sufficient kinetic energy to cause stone fragmentation of most urinary calculi. In contrast, the exact mechanism for stone fragmentation with the holmium laser is not known. The evidence suggests that it results mainly from a thermal effect with only a secondary shockwave or cavitation effect. Zhong et al [8], have used high speed photography and acoustic pressure measurements to compare stone fragmentation with pulse-dye and holmium laser. As compared to the spherical cavitation, bubble and strong shockwave emission produced by pulse-dye laser, the longer pulse duration of the holmium laser produces an elongated bubble with a much weaker shockwave emission [9]. Therefore, it seems that, 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 thereby effacing a small area of stone. Once stress fractures develop within the stone, the relatively weak shockwave emission may also contribute to the fragmentation process by breaking up the stone along these weakened cleavage planes. 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 [10, 11, 12].

In summary the majority of the holmium laser’s effect during urological applications are due to its thermal effects as a result of its strong absorption by water. This results in excellent superficial tissue ablation and a significant haemostatic effect because of the residual thermal injury associated with the laser energy. A significant advantage of the weak pressure wave as compared to the other lasers is less retropulsion of stone fragments. To minimize retropulsion during holmium: YAG lithotripsy, it is recommended that small diameter fibres and modest energy levels must be used [13].

Patient selection

Patients with bladder, ureteric and renal calculi are candidates for holmium laser treatment. Most bladder stones can be treated by holmium laser but stone burdens of greater than 5cm are associated with long operative times. Ureteroscopic laser lithotripsy of ureteric calculi can be performed retrogradely in the distal, mid and proximal ureter. Patients with high grade obstruction may require the placement of a ureteral stent prior to laser lithotripsy. Large renal calculi, staghorn and partial staghorn stones are usually treated percutaneously. However calyceal calculi in the lower pole and those that have failed other treatment modalities (e.g.

shockwave lithotripsy) can often be cleared using a retrograde endoscopic approach.

General technique

In a fluid environment, the laser energy must be applied as close as possible to the target site or in what is known as the contact mode. Therefore its use is safe if discharged > 1mm away from the urothelium in a fluid environment. The technique is relatively straightforward and involves placing the fibre on the stone surface and then activating the laser. An errant Ho: YAG laser beam can damage the lens of the eye. Laser protective eyewear effective at the 2100 nm wavelength is mandatory.

Lithotripsy

There are a variety of techniques that may be used, depending on the characteristics of the stone and its location in the collecting system. In general, a “dancing technique” is preferred in which the end of the Ho: YAG fibre is rapidly swept across the surface of stone such that layers of the stone are ablated sequentially. The advantage of this technique is that it minimizes creation of loose fragments that must be chased down. The rapidity of the “dance” depends on the fragility of the stone. The Ho: YAG laser drills into soft stones very quickly, so the fibre must be removed rapidly to avoid drilling holes and instead achieve general stone ablation. For a hard stone, the fibre needs to be repositioned less often since drilling and ablation occur more slowly. For these stones, a “chipping” technique is useful. This technique is appropriate for a stone not intimately surrounded by the walls of the collecting system. The laser fibre is directed to the periphery of the stone and fragments no larger than 1 mm are chipped off. The stone usually rotates a bit with this oblique application of energy, which presents a new surface to the fibre and allows chipping to be performed at a fresh site. Meticulous sculpting of the stone in this fashion allows it to be worked down to a manageable size for a basket or grasper extraction. The 1 mm fragments created by this technique need not be removed. The “coring” technique is similar, except that the pieces are chipped off from inside a central core that is first drilled into the stone with the Ho: YAG laser. Creation of this initial core allows small chips to be created even if the lateral aspects of the stone are in close proximity to urethelium.

In general lasing techniques that completely ablate the stone or create small particles that can be passed spontaneously are preferred rather than techniques that create multiple large fragments. However, for dense calculi or where mobility is limited, fragmentation or “cutting” of the stone by drilling holes into it and then “connecting the dots” with continued ablation may be

more expedient and/or safer than attempts at ablation or chipping. The resulting pieces can then be further fragmented or removed with a grasper or basket. Finally, in the heat of the battle against the stone, one must not forget to remove a final fragment for stone analysis if this is important in the patient's clinical management.

Guidelines for performing laser lithotripsy

- Perform entire procedure under direct vision with the laser fibre in contact with the stone at all times.
- If stone dust obscures vision ("snow storm" effect), halt lithotripsy until irrigant clears field of view.
- Use caution when drilling through the stone to avoid inadvertent injury to the ureter.
- Avoid direct laser energy contact with a guide wire or stone basket as the latter may break.
- Extend laser fibre 2-3 mm beyond endoscope tip to avoid damage to the lens or working channel.

Bladder calculi

Techniques available to treat bladder stones include open cystolithotomy, electrohydraulic lithotripsy, pneumatic lithotripsy and holmium laser lithotripsy. The holmium laser provides a means to clear bladder calculi endoscopically with minimal bleeding and damage to the bladder. A 365 or 550 micron laser fibre is used.

Ureteric calculi

The development of semi-rigid ureteroscopes and the actively deflectable, flexible ureteroscope have revolutionized the treatment of ureteral calculi. Distal, mid and proximal ureteral calculi can be cleared in a single outpatient procedure. For stones in the distal ureter, a small semi-rigid ureteroscope is employed. Standard endoscopic procedures are used to place a guide wire past the stone. Normal saline is used as the endoscopic irrigant. Under direct vision, the scope is advanced to the level of the stone. A 200 or 365 micron fibre is then placed through the working channel of the endoscope. Lithotripsy is begun at low energy settings (0.5 J and 5 Hz). Generally, low power settings are sufficient to fragment majority of calculi, however, hard calculi may require higher energies. Most distal calculi can be fragmented into either extractable fragments or into small sand-like particles, which do not require removal. Proximal and mid-ureteral stones are treated using an actively deflectable flexible ureteroscope. Two guide wires are used, one as a safety wire and the second as a working wire. The endoscope is advanced to the level of the stone in a monorail fashion over the working wire. As with distal calculi, low levels of laser energy are applied to clear a given stone burden.

Renal calculi

Renal calculi can be cleared using the holmium laser

either in a retrograde ureteroscopic approach or through a percutaneous approach. Retrograde ureteroscopic techniques are applied for removal of stones within a calyceal diverticulum, stones in lower pole calyces and large renal calculi. The development of small diameter laser fibres has provided a means of treating lower pole renal calculi. The 200 micron fibre has minimal impact on the flexibility of the ureteroscope. In both the kidney and bladder, slightly higher energy settings can be safely applied as compared to those used in the ureter.

Results

The results of holmium laser lithotripsy for ureteral calculi have been uniformly excellent [11,14-19]. Successful fragmentation of calculi is achieved in more than 85% cases. The final determinant of success is not the laser itself but other factors such as stone location, stone size and difficulty of access because of associated anatomical abnormalities or ureteral narrowing [20]. Recent work of Costello et al [18], has shown 100% success rate. The holmium laser essentially will fragment all calculi regardless of colour and composition including cystine, calcium oxalate monohydrate and brushite [21]. Complications have been few and generally due to ureteroscopy and not the laser. However ureteral perforation is known [11,17, 22].

Holmium laser lithotripsy for renal calculi used either as an adjunct during percutaneous nephrolithotomy or as a primary intracorporeal lithotripsy device during retrograde ureteroscopy has also produced encouraging results with a success rate of 87% [14-17]. During percutaneous surgery Ho: YAG laser is most helpful in clearing small stone volumes when flexible instruments are required to access stones in a calyx, remote from the nephrostomy tract. For larger renal stone burdens using the laser as a sole modality is often time consuming and not as efficient as other devices like pneumatic lithotripter [23]. In situations when retrograde ureteroscopy is used as a primary procedure for renal calculi, the holmium laser is especially helpful since the laser fibres can be used in small calibre ureteroscopes. Now with the 200 µm fibre, almost any stone in any region of the renal collecting system can be accessed in a retrograde fashion. The safety and efficacy of Ho: YAG lithotripsy in children has been proven by several workers [24,25].

The Ho:YAG laser produces very small stone fragments [26,27]. When compared with Lithoclast lithotripsy for ureteral calculi fragmentation Ho: YAG lithotripsy was associated with shorter operation time and postoperative hospitalization periods [28].

In our experience we evaluated 73 endoscopic procedures, utilizing Ho: YAG laser lithotripsy. Twenty-

one renal calculi, 44 ureteric calculi and eight bladder calculi were treated. All but three of the 44 ureteral calculi cases were rendered stone free in our study (93%). The success rate of percutaneous Ho: YAG laser lithotripsy for renal calculi including staged/second sittings was 90%. Seven of the eight bladder calculi were cleared in one sitting. One patient with bladder calculus had a bladder perforation which required laparotomy. There were no other complications.

The Ho: YAG laser combines the qualities of the CO₂ and Nd: YAG lasers by providing tissue cutting and coagulative hemostasis in a single device. The holmium wavelength can be transmitted down optical fibres, so it can be employed in endoscopic surgery and is useful in fragmentation of urinary calculi. It can successfully fragment any stone and truly it can be called the "workhorse of the laser world". The technique is simple and easy to learn. The main limitation of the holmium laser is its overall cost. However when one considers its multi purpose, multi speciality use, this device may in fact become cost effective. It is a solid state laser with minimal maintenance. However its potential for soft tissue damage during use must always be kept in mind. The issue of cyanide production from Ho: YAG lithotripsy of uric acid calculi remains unanswered [24].

Conflicts of Interest

None identified

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