

Holmium Laser Lithotripsy in the Management of Ureteric Calculi

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Abstract

Introduction: To evaluate the efficacy and safety of the holmium:YAG laser in retrograde ureteroscopic laser lithotripsy of ureteric calculi. **Methods:** Three hundred and twenty-five patients (256 males and 69 females) with mean age of 45 years underwent 328 retrograde ureteroscopic laser lithotripsy as the primary therapy for ureteric calculi using semirigid mini-ureteroscopes and the holmium:YAG laser (Coherent, Palo Alto, California, USA). Four consultants and three registrars performed the procedures over a period of 31 months. **Results:** The mean largest diameter of the calculi was 8.4 mm. The mean hospital stay was 1.8 days and the mean duration for the operation was 25 minutes. One hundred and twenty-two (37%) procedures were done as day surgery cases. Complete stone-free rates after single primary treatment using only the holmium:YAG laser were 75% and 91% at 4 weeks and 12 weeks of follow-up, respectively. Including 22 (7.6%) renal units which required additional procedures, the overall stone-free rate was 97%. Seventeen cases (5.2%) needed additional extracorporeal shock wave lithotripsy (ESWL) and 5 cases (1.5%) needed an additional repeat ureteroscopy and lithotripsy for complete stone clearance. Significant complications include 1 case of ureteric perforation. **Conclusions:** The holmium:YAG is a safe and effective intracorporeal lithotripter when deployed in a retrograde manner in conjunction with a mini-ureteroscope.

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Introduction

The introduction of extracorporeal shockwave lithotripsy (ESWL) in the 1980s revolutionised treatment of renal and ureteric calculi.¹ Progress in the field of extracorporeal lithotripsy was paralleled by the introduction of smaller caliber ureteroscopes and various intracorporeal lithotripters. In the context of ureteric calculus, the combination of ureteroscopy and intracorporeal lithotripsy have proven to be a viable alternative to ESWL.² The holmium:Yttrium, Aluminum, Garnet (holmium:YAG) laser was developed in the early 1990s and it was rapidly recognised to be an effective lithotripter. It was shown as early as 1993 that the holmium:YAG laser was effective in fragmenting urinary calculi under laboratory conditions.³ Subsequent clinical studies in both children⁴ and adults^{5,6} have shown the holmium:YAG laser to be effective in the treatment of ureteric calculi *in vivo* as well. The holmium:YAG laser has also been demonstrated to fragment stones into smaller size compared with the lithoclast, pulsed dye laser or electrohydraulic lithotripter.⁷ Its wavelength of 2.1 mm is avidly absorbed by water, making

fragmentation independent of stone composition.⁸ For the same reason, holmium:YAG laser has the additional advantage of being able to ablate soft tissues as well. This retrospective analysis of a single centre's experience with the holmium:YAG laser in the treatment of ureteric calculi demonstrates that it is a safe and effective modality.

Patients and Methods

Between the period from November 1997 and June 2000, a total of 325 patients comprising 328 renal units underwent holmium:YAG laser lithotripsy for ureteric calculus as the primary treatment modality in the Department of Urology, Changi General Hospital, Singapore. All the patients had retrograde ureteroscopy and lithotripsy using a single holmium:YAG laser machine (Coherent, Palo Alto, California, USA). All cases were done using a semirigid mini-ureteroscope connected to a video monitor.

There were 256 (78.8%) male and 69 (21.2%) female patients. The mean age of the study population was 45.3 ± 12.7 years, which comprised 63% Chinese, 23% Malays, 9% Indians and 5% others. Two patients had bilateral

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stones and 1 patient had two separate episodes of ureteric calculi, giving a total of 328 distinct renal units treated. Two hundred and seventeen renal units (66%) were operated on by consultants and 111 (34%) were done by registrars. Three patients were lost to follow-up, leaving 325 renal units for final analysis.

The stones were stratified into three levels i.e., upper, middle and lower ureteric stones. For ease of classification, upper ureteric stones were classified as those situated above the pelvic brim, middle stones were those overlying the pelvic bones and lower stones were those below the sacroiliac joint as seen on a plain kidney, ureter and bladder (KUB) X-ray or other radiological examinations. There were 120 (37%) upper ureteric stones, 44 (14%) middle ureteric stones and 161 (49%) lower ureteric stones according to the criteria stated above (Table I). Stone size was quantified as the largest diameter measured on radiography. The smallest stone was 3 mm and the largest was 35 mm with mean of 8.4 ± 4.3 mm. The stones were grouped into separate cohorts of 10-mm intervals for analysis (Table II).

Only patients whose stones were treated with holmium:YAG laser as the primary modality were included in this study. Exclusion criteria included those patients in whom more than one intracorporeal fragmentation devices were employed to fragment the ureteric calculi during the primary treatment. Also excluded were patients whose

stones were treated with holmium laser following the failure of previous attempts at ureteroscopic fragmentation.

All procedures were done either under regional or general anaesthesia. Access to the ureter was achieved initially with a guide wire placed through the working channel into the ureteric orifice. This was followed by the semirigid mini-ureteroscope. No patients needed ureteral dilatation prior to the introduction of the ureteroscope. Irrigation was with sterile 0.9% saline under pressure of 50 to 100 mmHg using the Uromed insufflation device. Once the ureteroscope was in place and the stone visualised, the guide wire was removed and the holmium:YAG laser fibre inserted. The initial setting of the holmium:YAG laser was 0.5 J/pulse at 5 Hertz. This was gradually increased to 1.0 J/pulse at 5 Hertz, if the stone was found to be hard. Use of Dormia basket and double-J stent insertion postoperatively was left to the discretion of surgeons.

Laser fibres were reused after sterilisation as many times as possible to save cost. We started off using the 200 μ m laser fibres but these deteriorated rapidly with repeated use. We found that 365 μ m fibres lasted much longer.

The majority of the cases were done without image intensifier and safety guide wires. The initial reason was logistics i.e., the availability of image intensifier. This initial experience showed that it was safe to fragment straightforward ureteric calculi without using an image intensifier. Image intensifier was only used when there was difficulty assessing the stone, need for retrograde pyelogram to further delineate the collecting system and when ureteric stents needed to be placed intraoperatively. For the same reason, no safety guide wires were used when image intensifier was not available because the proper placement of the safety guide wire requires X-ray confirmation. We also think that this selective use of the image intensifier reduces the cumulative radiation exposure to the urologist.

Stone-free status was defined as the complete absence of calculus at 4 or 12 weeks of follow-up. Radio-opaque stones were assessed postoperatively using plain X-rays, while radio-lucent stones were assessed with intravenous urograms, ultrasounds or non-contrast spiral computed tomographic (CT) scans.

Results

The stone-free rates after single primary treatment of 325 renal units were 75% and 91% at 4 weeks and 12 weeks postoperative, respectively (Table I). Consultants achieved a stone-free rate of 92% while the registrars had a stone-free rate of 88% at 12 weeks. This was statistically not significant. The stone-free rates of the upper, middle and lower ureteric calculi were 85%, 93% and 94%, respectively, at 12 weeks of follow-up (Table I). The difference between the upper and lower ureteric calculi is statistically significant

TABLE I: POSITION OF STONE AND STONE-FREE RATES AT 4 AND 12 WEEKS AFTER PROCEDURE

Position of stone	No. of patients (%)	No. of patients stone-free at 4 weeks (%)	No. of patients stone-free at 12 weeks (%)
Upperureteric calculi	120 (37)	84 (70)	102 (85)
Middle ureteric calculi	44 (14)	32 (73)	41 (93)
Lower ureteric calculi	161 (49)	128 (79)	152 (94)
Total	325	244 (75)	295 (91)

TABLE II: RELATION OF STONE SIZE AND STONE-FREE RATES AT 4 AND 12 WEEKS

Size of stone	No. of patients (%)	No. of patients stone-free at 4 weeks (%)	No. of patients stone-free at 12 weeks (%)
1 to 10 mm	261 (80)	209 (80)	240 (92)
11 to 20 mm	59 (18)	33 (56)	52 (88)
21 to 30 mm	4 (1.7)	2 (50)	2 (50)
31 to 40 mm	1 (0.3)	0 (0)	1 (100)
Total	325 (100)	244 (75)	295 (91)

when analysed using the Pearson chi-square test ($P < 0.05$). The stone-free rate of the 1 to 10 mm cohort was 92%, while the stone-free rate of the 11 to 20 mm cohort was 88% at 12 weeks. This difference again is statistically significant when the Pearson chi-square test was applied ($P < 0.05$). There were only 5 calculi with diameter greater than 20 mm and the stone-free rate for this group at 12 weeks was only 60%.

Only 5 cases (1.5%) had preoperative double-J stent insertion. This meant that 320 (98.5%) cases were done without the benefit of previous double-J stenting. Forty-three (13%) cases had double-J stents inserted post-operatively, including 15 (4.6%) cases following superficial injury to the ureteric mucosa (blanching). In addition, high stone load, associated stricture and pre-ESWL for ipsilateral renal stone were the major reasons for postoperative double-J stenting.

There were 22 (6%) renal units which required additional procedures to achieve stone-free status. Proximal stone migration occurred in 16 (4.6%) cases. Fifteen of these were stones in the upper ureter. All were treated with ESWL. These were included in the 15 (4.5%) cases which required 1 additional ESWL session and 2 (0.6%) cases which had 2 ESWL sessions. Five (1.5%) cases required an additional repeat ureteroscopy and lithotripsy. This gives an overall re-treatment rate of 6.7%. Twenty of these cases which required additional procedures were stone-free at 12 weeks. Including these, the overall stone-free rate at 12 weeks was 97%.

The mean hospitalisation was 1.83 ± 0.81 days and the mean operating time was 25 ± 19 min. A total of 122 cases (37.2%) were done on a day surgery basis. One patient had a delayed perforation of the ureter secondary to holmium:YAG laser injury. Injury to the ureteric mucosa was noted at the time of operation. No double-J stent was inserted and the patient was discharged well on the first postoperative day. Ureteric perforation was diagnosed on CT scan. She was treated successfully with conservative measures of percutaneous nephrostomy and ante-grade stenting. Interestingly, 17 (5%) cases were noted to have mucosal blanching intraoperatively secondary to holmium:YAG laser injury and 16 of these had double-J stents inserted. The sole exception was the patient who had perforation. In addition, 11 (3.4%) patients were readmitted for urinary tract infection and/or haematuria. All needed only conservative treatment for resolution. There were no cases of ureteric stricture at a mean follow-up of 3 months.

Discussion

There have been tremendous advances made in the treatment of ureteric calculus in the preceding two decades. Since the introduction of ESWL and the smaller diameter

semirigid ureteroscopes, the debate has been about the choice between ESWL and ureteroscopy coupled with the various intracorporeal lithotripters. These intracorporeal lithotripters can be divided broadly into the ballistic lithotripters such as the Swiss pneumatic lithoclast and the electrokinetic lithotripter (EKL), ultrasonic lithotripter, electrohydraulic lithotripter (EHL) and the laser lithotripters.

Present day controversies centred around the choice between these non-invasive and minimally invasive therapies, the stone-free rates of these systems when employed as a single modality, their effectiveness based on the size and location of the ureteric calculi and the cost of operating each modality. The cost is defrayed if a system is versatile and can be used in more than one type of procedure. Open surgery is now a rarity rather than the norm, although it still has a role to play in selected clinical situations.⁹

Extracorporeal shockwave lithotripsy is attractive because it is non-invasive, may not need general anaesthesia and has a low morbidity rate. The efficacy of ESWL in the treatment of upper ureteric calculi is well accepted.² In this region, the possibility of proximal stone migration and the difficulty of ureteroscopic access make ESWL the modality of choice where it is available, even though ureteroscopy is still a viable alternative. It is in the middle and lower ureter where the indications become less well-defined. ESWL in the middle and lower ureter tends to have a higher re-treatment rate and lower stone-free rate when compared with ureteroscopy. Hendrikx et al,¹⁰ in a randomised study comparing ESWL and ureteroscopy, demonstrated a stone-free rate of only 51% in spite of a re-treatment rate of 45% using ESWL, compared to a stone-free rate of 91% with only a re-treatment rate of 9% in the ureteroscopy group. Eden et al¹¹ achieved a single treatment stone-free rate of 74.8% for solitary distal ureteric stone and 50% for multiple stones using the Storz Modulith SL 20 extracorporeal lithotripter, compared with stone-free rates of 89.7% and 88.9%, respectively, using ureteroscopy and the Swiss lithoclast. Bierkens et al¹² concluded that ESWL provided a non-invasive, simple and safe option in the treatment of mid and lower ureteric calculi measuring less than 50 mm.

The ultrasonic lithotripter remains a powerful fragmentation tool in the percutaneous treatment of renal calculus. However, it is rarely used in the treatment of ureteric calculi due to its need for large caliber ureteroscopes and poor vision associated with this mode of stone fragmentation.

The electrohydraulic lithotripter is about to suffer a similar fate. The disadvantage of using electrohydraulic lithotripter is its non-directional energy dispersion leading to possible ureteric haemorrhage, which hampers vision and predisposes to ureteric perforation.

The intracorporeal ballistic lithotripters, especially the Swiss lithoclast, have been shown to be both effective and economical in the treatment of ureteric calculi by many authors.¹³⁻¹⁵ The Swiss lithoclast is simple and cost-effective to maintain.¹³ The problem of proximal stone migration may have been overcome with the introduction of the lithovac suction device.¹⁴ Yinghao et al¹⁵ reported a fragmentation rate of 70% after single treatment of ureteric calculi with the Swiss lithoclast with a morbidity rate of 6%, including 4 ureteric perforations. The disadvantage is that the Swiss lithoclast is solely a stone-fragmentation device with no soft tissue application.

The initial use of continuous beam lasers such as the carbon dioxide and neodymium:YAG lasers failed because of associated thermal injury to tissues. Continuous beam lasers cause heat vaporisation of the calculi at temperatures of 2000°C to 3000°C and this results in thermal injury to collateral tissues.¹⁶ Lasers can also fragment stones by inducing shockwaves. This requires much less energy, generates less heat and it fragments stones as a result of the shearing forces created by the shockwaves. Photoacoustic shockwave creation is the result of direct translation of laser energy into a cavitation bubble which collapses thus generating the shockwave. Photothermal shockwave is the result of rapid vaporisation of water at the stone-water interface, which gives a rapidly expanding plasma, providing the shearing force for stone fragmentation. Which effect predominates depends on the pulse width and wavelength of the laser. Pulsed dye laser was the first widely used laser lithotripter. It has a wavelength of 504 nm, which is absorbed by the colour pigment on the stone surface. Cystine stones are pigment-free and therefore poorly fragmented by pulse dye laser. Soft tissues also do not absorb energy at this wavelength and this makes the pulse dye laser a relatively safe lithotripter. In a retrospective series of 239 patients, Foo et al¹⁷ demonstrated a complete fragmentation rate of 85% with 3 cases of ureteric perforations. This is consistent with an *ex vivo* study done by Santa-Cruz et al,¹⁸ which showed that the candela pulse-dye laser together with the lithoclast had high safety indices.

Holmium:YAG laser has a wavelength of 2.1 µm and pulse width of 320 µsec. This wavelength is well absorbed by water and it has been shown that the shockwave it generates is predominantly due to a photothermal effect.¹⁸ This property of the holmium:YAG laser also renders it an effective lithotripter for all stones as it does not depend on the presence of stone pigments and for similar reason it can potentially damage the ureter.

Our results show that the holmium:YAG laser is an effective and safe intracorporeal lithotripter when used on ureteric calculi. We only had 1 case of ureteric perforation.

The significance of this perforation lies in the fact that it presented in a delayed manner. Distal ureteral oedema with its associated functional obstruction and raised pressure in the collecting system in the absence of a stent could have provided the final insult which resulted in a transmural perforation of an already damaged ureter. It is therefore recommended that all cases of ureteric blanching be stented.

That 320 (98.5%) renal units were done without preoperative double-J stenting and that all patients did not need ureteral dilatation testify to the progress in miniaturisation of semirigid ureteroscope and techniques in accessing the ureter.

The statistically significant difference between the stone-free rates of the upper and lower ureter is not surprising. This is not unique to this modality but a function of anatomy and the mechanics of retrograde ureteroscopy. Similarly, the difference in the stone-free rates of calculi of increasing size is a common theme in all intracorporeal lithotripsies.

Our centre's experience with the use of the semirigid ureteroscope and intracorporeal lithotripter preceded the acquisition of an ESWL machine and publication of the American Urological Association (AUA) guidelines by several years. Therefore, the senior urologists in our department have accumulated substantial experience in fragmenting upper ureteric calculi employing the semirigid ureteroscope and intracorporeal lithotripter.^{19,20} They are equally comfortable in offering the choice of ESWL or URS/lithotripsy for upper ureteric calculi. The stone-free rate of upper ureteric stones after a single primary treatment of 84% at 4 weeks in isolation is comparable to, if not better than, the stone-free rate obtained with ESWL when it is employed as the primary mode of treatment. The attribute of the holmium:YAG laser in causing minimal forward propulsion of the calculus under treatment may be a contributing factor. This together with the virtues of versatility and mobility may confer a distinct advantage to the holmium:YAG laser as a lithotripter of upper ureteric calculus compared to ESWL. A randomised prospective trial will help to answer this question.

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