Is the Holmium:YAG Laser the Best Intracorporeal Lithotripter for the Ureter? A 3-Year Retrospective Study

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ABSTRACT

Purpose: To study the efficiency and safety of holmium:YAG laser lithotripsy for ureteral stones.

Patients and Methods: A series of 188 patients with 208 ureteral stones were treated with semirigid ureteroscopy and holmium:YAG laser lithotripsy from January 2003 to December 2005. Of the stones, 116 were lower ureteral, 37 middle ureteral, and 55 upper ureteral.

Results: The success rate was 92.7% at the time of ureteroscopy and 96.7% at 3 months. The failures were secondary to retropulsion of the stones (3.3%). There were no perforations and one stricture. Stenting was done in 90% of patients.

Conclusions: The Holmium:YAG laser is an ideal intracorporeal lithotripter for ureteral calculi, with a high success rate and low morbidity.

INTRODUCTION

The treatment of urinary stones has undergone tremendous and amazing changes in the last two decades. Three modalities of treatment in the form of extracorporeal shockwave lithotripsy (SWL), percutaneous surgery, and ureterorenoscopy have almost replaced open stone surgery.

Intracorporeal lithotripsy is an integral part of both percutaneous surgery and ureterorenoscopy. A number of intracorporeal lithotripters have been used for fragmenting tract stones, from ultrasonic, electrohydraulic, pneumatic, and urinary electrokinetic devices to lasers. Various lasers, starting with the ruby in 1968, the pulsed-dye in 1986, the continuous-wave Nd:YAG, and Q-switched Nd:YAG devices have been used for the fragmentation of urinary stones, but the introduction of the holmium laser has changed the whole scenario, with its fragmentation rate of 100%, its usability with the flexible ureteroscope, and its soft-tissue applications in the treatment of prostate hyperplasia, urethral and ureteral strictures, urothelial (bladder and upper-tract) neoplasms, caliceal diverticula, ureteropelvic junction obstruction, and infundibular stenosis.

Before and after the development of the holmium laser, there were significant improvements in ureteroscopes, particularly the creation of a series of semirigid instruments in 1989. As the experience with the holmium laser grew, the downsizing of ureteroscopes continued, culminating in the development of 4.9F/6.5F-tip instruments with an offset eyepiece. The combination of the smaller ureteroscopes and the holmium laser has created an ideal system for the treatment of ureteral stones and has made this a day-care procedure with no requirement for ureteral dilatation, only minimal anesthesia, and few postoperative complications.

The holmium laser fragments stones primarily by a photothermal mechanism. Pressure waves created by the laser are negligible and result in minimal retropulsion of the stone fragments in comparison with previous laser lithotripters, which fragment stones through shockwaves rather than direct irradiation of the stone surface. The fragments created by the holmium laser are smaller than those resulting from other sources of intracorporeal lithotripsy. A low-wattage holmium laser is sufficient for intracorporeal lithotripsy, and low energy, between 0.6 J and 1.2 J, and a frequency of 5 to 15 Hz, generally is used because use of high energy decreases the safety margin and increases stone retropulsion and fiber damage. It is safe to use the holmium laser in the ureter when the laser is activated 0.5 to 1 mm from the wall.

At present, the holmium:YAG laser is the most effective intracorporeal lithotripter, with a fragmentation rate as high as 100% and a stone-clearance rate ranging from 87% to 100%. Most failures are attributable to stone migration and inability to reach the stone. Although the holmium: YAG laser causes the least stone retropulsion compared with...
the pneumatic lithotripter and the FREDDY laser, stone migration is the main cause of failure. In addition to the higher fragmentation rate, the holmium laser has a better stone clearance rate, 96.0%\textsuperscript{21} and 95.0%\textsuperscript{22} compared with 84.6%\textsuperscript{21} and 69.0%\textsuperscript{22} respectively, with pneumatic lithotripsy, as reported in two studies. Although there are no clinical data comparing the rate of retropulsion with pneumatic and holmium laser lithotripsy, there is evidence that pneumatic lithotripsy causes much more retropulsion than the laser in vitro.\textsuperscript{20}

PATIENTS AND METHODS

We retrospectively reviewed the charts of 188 patients who underwent ureteroscopy and holmium:YAG laser lithotripsy for 208 ureteral stones during the 3 years from January 2002 to December 2005. Patients with renal or bladder stones were excluded, as were patients who underwent intact stone removal or pneumatic lithotripsy. There was no exclusion on the basis of the size or location of the stone or the degree of urinary obstruction. Of the 188 patients, there were 159 males and 29 females having 208 ureteral stones (55 upper, 37 middle, and 116 lower ureter). The age of the patients ranged from 3 years to 86 years (mean 36 years). There were six children, and all were treated in a single session. There were five patients (2.7%) with bilateral stones (13 stones) and 9 (4.7%) with multiple stones on the same side (20 stones). The size of stones ranged from 3 mm to 30 mm with a mean of 10.6 mm.

Ureteroscopy was performed using one of four semirigid ureteroscopes: 8F/9.8F 43-cm long, 6F/7.5F 43-cm long, 6F/7.5F 31-cm long, and 4.9F/6.5F 43-cm long. Balloon dilatation of ureteral orifice was not required in any patient.

The holmium:YAG laser energy was delivered using a 365-\mu\text{m} fiber. The pulse energy was kept between 0.5 to 1.0 J and the frequency between 10 and 20 pulses/sec. A red diode laser aiming beam of 2.5 mW at 650 nm served for targeting. During the initial phase of laser lithotripsy, a drilling technique was used by moving the laser fiber over the surface of stone, thereby vaporizing the stone and fragmenting it. The bigger fragments so formed were then treated to create smaller fragments that were removed with stone forceps and baskets. Stenting was omitted only in those patients in whom the 4.9F/6.5F ureteroscope was used and there was no injury and no significant stone debris or residual fragments. Post-treatment follow-up was carried out 1 to 3 months after the operation with plain radiography and ultrasonography.

Successful treatment was defined in two ways:

1. Complete clearance, both endoscopic and fluoroscopic, at the time of ureteroscopy;
2. Complete fragmentation but incomplete clearance at the time of ureteroscopy with complete clearance at 3 months.

The patient demographics, location of the stone, operative time, anesthesia, stenting, fragmentation, clearance, failure, and complications were recorded. The results were compared with those in eight reports containing stratified information on the treatment outcomes of Ho:YAG laser ureteral lithotripsy. The total number of patients described in these articles (see Table 1) was 1528 having 1563 stones.

RESULTS

Almost half of the patients (80; 42.5%) were treated as day cases, 98 patients (52.1%) were admitted overnight, and 9 (5%) were hospitalized for 2 days and 1 (0.5%) for 3 days. We have defined day cases as those in which patients were discharged the day of treatment without an overnight stay.

Of the 188 patients, 77 (41%) were operated on under spinal anesthesia, 37 (19.5%) under general anesthesia, 50 (26.5%) under monitored anesthesia care with ketamine or propofol, 9

<table>
<thead>
<tr>
<th>Series</th>
<th>No. pts./stones</th>
<th>Location\textsuperscript{a}</th>
<th>Hospital stay (days)\textsuperscript{b}</th>
<th>Size of ureteroscope (F)</th>
<th>Percent clearance</th>
<th>Retropulsion (%)</th>
<th>Perforation (%)</th>
<th>Stricture (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yip et al (1998)\textsuperscript{19}</td>
<td>69/69</td>
<td>18 U, 17 M, 34 L</td>
<td>Day cases</td>
<td>8.5</td>
<td>91 immediate (one session)</td>
<td>3 U (4)</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Devraj an et al (1998)\textsuperscript{6}</td>
<td>265/300</td>
<td>132 U, 57 M, 111 L</td>
<td>NA</td>
<td>7.5</td>
<td>90 at 6 weeks (one session)</td>
<td>10 U, 1 M (3.75)</td>
<td>11 (4)</td>
<td>10 (3.7)</td>
</tr>
<tr>
<td>Biyani et al (1998)\textsuperscript{5}</td>
<td>48/48</td>
<td>13 U, 10 M, 25 L</td>
<td>1–3</td>
<td>6</td>
<td>98 at 8 weeks + 1 redo (large stone)</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Gould (1998)\textsuperscript{18}</td>
<td>115/115</td>
<td>36 U/M, 79 L</td>
<td>NA</td>
<td>NA</td>
<td>100</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Scarpa et al (1999)\textsuperscript{17}</td>
<td>150/150</td>
<td>32 U, 47 M, 81 L</td>
<td>NA</td>
<td>4.8–14</td>
<td>92.6 at 30 days</td>
<td>10 (6.6)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Cheung et al (2001)\textsuperscript{31}</td>
<td>134/134</td>
<td>NA</td>
<td>Day cases</td>
<td>6.5/7</td>
<td>91.8 at 3 mos</td>
<td>9 U (7)</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Sofer et al (2002)\textsuperscript{32}</td>
<td>542</td>
<td>194 U, 111 M, 237 L</td>
<td>Day cases</td>
<td>6.9–11.5</td>
<td>97 U, 100 M, 98 L</td>
<td>28 (5)</td>
<td>0.2</td>
<td>1.1</td>
</tr>
<tr>
<td>Ilker et al (2005)\textsuperscript{33}</td>
<td>205/205</td>
<td>47 U/M, 158 L</td>
<td>NA</td>
<td>NA</td>
<td>95.2</td>
<td>4 (1.9)</td>
<td>3 (1.5)</td>
<td>2 (1)</td>
</tr>
</tbody>
</table>

\textsuperscript{a}U = upper, M = middle, L = lower ureter.

\textsuperscript{b}NA = not applicable.
cause of its failure to fragment all types of stones, and the Some of the other devices, such as the coumarin-dye laser, been in progress for many years, and abundant literature has been published on the presence of a need for anesthesia. With the realization that electrohydraulic probe, because of its tendency to cause tissue

We used the 6/7.5F or 8F/9.8F ureteroscope in the majority of our patients (161) and the 4.9F/6.5F instrument in 27 patients. It is our practice that we first use the 6F/7.5 F endoscope, and, if necessary and feasible, we change to the 8F/9.8F ureteroscope. The mini-ureteroscope was used mainly for lower-ureteral stones.

The operative time ranged from 10 minutes to 75 minutes with a mean of 32 minutes. Stenting was omitted in only 18 patients (9.5%), in whom the 4.9F/6.5F ureteroscope was used and there was no mucosal injury or significant stone debris or fragments left behind.

Complete clearance was achieved for 92.7% of the stones (193 of 208) at the time of ureteroscopy and 96.7% (201 of 208) by 3 months. Seven stones (3.3%) consisting of six complete stones and one fragment were driven backward from the upper ureter. We did not use the Stone Cone.

None of our patients had a perforation. One patient developed a stricture in the upper ureter. He had undergone ureteroscopy with a 6F/7.5F endoscope and had a narrow ureter, making ureteroscopy was difficult. The stone had been obstructing and impacted in the upper ureter for the previous 3 months and was associated with infection. The patient was later lost to follow-up.

**DISCUSSION**

The management of ureteral calculi has undergone tremendous change in last two decades. Open surgery has become history, but the optimal treatment is still the subject of debate, first between SWL and ureteroscopy and then concerning the most appropriate intracorporeal lithotripter. Many series have compared the results of SWL with ureteroscopy for ureteral stones and concluded that the results of the latter are much superior. The advantages of SWL are its noninvasive nature, ready acceptance by patients, and, with many machines, absence of a need for anesthesia. With the realization that ureteroscopy is an ideal procedure for ureteral stones, a search for an ideal intracorporeal lithotripter has been in progress for many years, and abundant literature has been published on the use of pneumatic lithotripsy as well as the holmium:YAG laser. Some of the other devices, such as the coumarin-dye laser, because of its failure to fragment all types of stones, and the electrohydraulic probe, because of its tendency to cause tissue injury and perforation, have lost favor.

The important aspects to be discussed in relation to holmium:YAG laser lithotripsy for ureteral stones are its success rate, the reasons for failure, complications, its feasibility as day-care procedure, its use with only sedation or lidocaine gel, the role of stenting, its use with small ureteroscopes, and its safe use in children, in all stages of pregnancy, and in patients with bleeding diathesis and, last but not the least, its cost effectiveness. There are conflicting reports on the energy requirement for different types of stones in the literature. Sayer and colleagues reported the lowest energy requirement for a uric acid stone and the highest for a struvite/carbonate apatite stone using a constant energy of 0.5/pulse and a frequency of 5Hz. In contrast, Lumenerman and associates reported 2.74 J/mg (struvite), 5.81 J/mg (brushite), 4.83 J/mg (uric acid), 5.81 J/mg (cystine), and 6.02 J/mg (cystine oxide monohydrate) as the mean energy requirements for complete fragmentation of various types of stones.

We have defined our criteria clearly by presenting two types of success rates: complete clearance at the time of ureteroscopy with no residual fragments and incomplete clearance, with residual fragments left to pass spontaneously. All of these residual fragments indeed passed spontaneously, as fragments created by the holmium:YAG laser are small, and none of our patients required further treatment. Our success rate of 92.7% at the time of ureteroscopy and 96.7% at 3 months is similar to the success rates reported in many other series and shows that the holmium laser has the best success rate in the treatment of ureteral stones.

The only reason for failure in our series was migration of a few stones, all upper-ureteral stones, beyond the reach of the laser. If we exclude upper-ureteral stones, the success rate was 100%. In the eight published case series (see Table 1), the failures were attributed to retropulsion; large stone mass, and failure to access the stone. The majority of failures in these series were likewise attributable to migration. Large stone mass and failure to access the stone was seen in only a few cases. The basic reason for retropulsion in our series was not the holmium laser but rather the pressurized irrigation (6 of 7 migrations); the same cause was reported by Taari et al. Cheung and coworkers suggested controlled intermittent manual irrigation to prevent proximal migration of stone fragments. Yip et al. who had a 4% incidence of retropulsion, again all from the upper ureter, avoided the use of pressurized irrigation and reduced the power settings to clear the fragments. Six of our stones migrated before the laser was actually used. In only one patient did a fragment move upward into the kidney as a result of laser lithotripsy. Perhaps the use of the Stone Cone could have prevented this migration; however, the six stones that migrated intact were impacted and moved before we passed a guidewire. Because all these patients were in the Trendelenburg position and the side bearing the stone was elevated laterally by 30°, the gravitational force prevented them from slipping into inferior calices. The migrating stones moved into either a superior calix or the renal pelvis, where they underwent SWL (three patients) or intracorporeal lithotripsy and SWL (four patients). The incidence of retropulsion in various series has been reported as 0 to 7%.

To our minds, retropulsion from the upper ureter occurs for three main reasons: gravitational force, depending on the anatomy of the upper ureter and pelvicaliceal system; pressurized irrigation; and intracorporeal lithotripsy. The first two factors remain the same with any type of intracorporeal lithotripsy. The holmium:YAG laser causes the least retropulsion, and factors such as decreasing the pulse energy and optical fiber diameter and increasing the pulse width reduce migration further.

We had no perforations in our series, and the same has been reported by Gould and Scarpa and colleagues. In one of the largest series, 542 ureteral stones, described by Sofer et al,
there was only one perforation. Similarly, the incidence of stricture is low, and we had just one case, in which the ureter was narrow before treatment.

We performed day care ureteroscopy and laser lithotripsy in 42.5% of our cases. There are three series in the literature describing exclusively day-care holmium laser lithotripsy for ureteral stones in a total of 745 cases, clearly demonstrating the feasibility of doing this procedure on an outpatient basis. We only partially agree with those earlier authors, as 41% of our patients were operated on under spinal anesthesia because of patient preference. In the remainder of our 16.5% patients who were hospitalized, there were various reasons, which included admission 1 day prior to the operation, prolonged anesthesia, and patient preference. However, a trend toward day-care ureteroscopy and holmium laser lithotripsy has picked up.

A similar trend is being noticed to perform this procedure under monitored anesthesia care or sedation with 2% lidocaine gel or 2% lidocaine gel alone (26.5%, 5%, and 8%, respectively, in our series), particularly with the availability of smaller-diameter ureteroscopes.

Whether to stent after this procedure is a matter of great debate. We stented 90% of our patients, omitting stents only in those patients in whom the ultrathin ureteroscope (4.9F/6.5F) was used and there was no injury or residual fragment. Denstedt and colleagues37 and Cheung and associates38 concluded that routine stenting after ureteroscopic intracorporeal lithotripsy with the holmium laser is not required as long as the procedure is uncomplicated. These were both randomized controlled trials comparing unstented and stented ureteroscopic lithotripsy. Neither study was powerful, as there were only 58 patients in each series, 29 stented and 29 unstented. The total number of unstented patients thus was only 58. Denstedt and coworkers used 6.9F semirigid and 7.5F flexible ureteroscopes, whereas Cheung et al used a 6.5F/7F semirigid ureteroscope. We had 18 patients we did not stent, but in these cases, we used a small ureteroscope. Further large studies are required to define clearly the indications for stenting.

We had only six children in our series, and they were all treated safely in one session. However, larger series have shown holmium:YAG laser lithotripsy to be safe in children. This type of laser lithotripsy also is safe in all stages of pregnancy because of patient preference. In the remainder of our 16.5% patients who were hospitalized, there were various reasons, which included admission 1 day prior to the operation, prolonged anesthesia, and patient preference. However, a trend toward day-care ureteroscopy and holmium laser lithotripsy has picked up.

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The major disadvantage of the holmium:YAG laser is its high purchase price and maintenance costs, which keeps urologists away from this instrument, at least in developing countries. However, prices are declining, and availability will become greater in the days to come. Although there are no studies comparing repeat ureteroscopy after holmium laser and pneumatic lithotripsy, the incidence of redo after holmium laser lithotripsy is low, which reduces the economic burden.

CONCLUSIONS

The holmium:YAG laser is the best intracorporeal lithotripter for the treatment of ureteral stones. The success rate reported in various meta-analyses and our own series is >90% with low morbidity. The procedure is being adopted for day cases and is safe in patients with bleeding diathesis, at all stages of pregnancy, and in children. We suggest stenting as an acceptable measure in the majority of patients except those in whom small ureteroscopes are used, no dilatation is done, no injury is caused to the ureter, and no fragments are left behind.

REFERENCES


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ABBREVIATIONS USED

SWL = extracorporeal shockwave lithotripsy; YAG = yttrium–aluminum–garnet.