



Ureteroscopy with thulium fiber laser lithotripsy results in shorter operating times and large cost savings

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Received: 13 January 2022 / Accepted: 3 May 2022 / Published online: 21 June 2022
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Abstract

Purpose Prolonged ureteroscopy (URS) is associated with complications including ureteral perforation, stricture, and urosepsis. As laser lithotripsy is one of the most common urologic procedures, small cost savings per case can have a large financial impact. This retrospective study was designed to determine if Thulium fiber laser (TFL) lithotripsy decreases operative time and costs compared to standard Holmium:YAG (Ho:YAG) lithotripsy without pulse modulation.

Methods A retrospective review of URS with laser lithotripsy was conducted for 152 cases performed from August 2020 to January 2021. Variables including cumulative stone size, location, chemical composition, prior ureteral stenting, and ureteral access sheath use were recorded for each case. A cost benefit analysis was performed to show projected cost savings due to potentially decreased operative times.

Results Compared to Ho:YAG, use of TFL resulted in an average decrease of 12.9 min per case ($p = .021$, 95% CI [2.03–23.85]). In subgroup analysis of cases with cumulative stone diameter less than 15 mm, the difference was 14.0 min ($p = .007$, CI [3.95–23.95]). For cases less than 10 mm, the mean difference was 17.3 min in favor of TFL ($p = .002$, 95% CI [6.89–27.62]). This ~ 13 min reduction in operative time resulted in saving \$440/case in direct operating room costs giving our institution a range of \$294,000 to \$381,900 savings per year.

Conclusions TFL has a significantly shorter operative time and decreased cost when compared to the standard Ho:YAG for equivalent kidney stone and patient characteristics. Longer term follow up is needed to see if recurrence rates are affected.

Keywords Ureteroscopy · Lithotripsy · Nephrolithiasis · Stones

Introduction

Nephrolithiasis is a common condition with 16% of men and 8% of women developing at least one stone by the age of 70 [1]. Over the past 30 years in the United States both the prevalence and incidence of kidney stones has been increasing reaching 10.1% and 0.9% in 2015, respectively [2–5]. Due to current trends in lifestyle and diet, rates of nephrolithiasis are expected to continue to rise worldwide [2]. In the US

alone, the costs related to nephrolithiasis are estimated to exceed \$5 billion each year [6].

Flexible ureteroscopy (URS) with laser lithotripsy is a common surgical intervention used for small to moderately sized stones (<2.0 cm) [7]. Other conventional surgical interventions for nephrolithiasis include percutaneous nephrolithotomy (PCNL) and extracorporeal shockwave lithotripsy (SWL). When compared, URS with laser lithotripsy offers lower risk of complications than PCNL and decreased residual stone burden than SWL; however, URS with laser lithotripsy is associated with a longer operative time than SWL [8]. Prolonged ureteroscopic operative times have been shown to increase the risk of postoperative and intraoperative complications of URS [9–13]. Examples of such complications include pain, ureteral perforation, ureteral stricture and hydronephrosis, urinary tract infection, and sepsis [14–17].

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One of the latest advancements in URS with laser lithotripsy is the thulium fiber laser (TFL) which uses a long silica fiber doped with elemental thulium to generate the energy beam. The current gold standard in laser lithotripsy is the Holmium:Yttrium–Aluminum–Garnet laser (Ho:YAG), used without pulse modification. When directly compared to Ho:YAG, TFL allows the energy to propagate more efficiently, in a more concentrated beam, and at a wavelength that has a higher absorption coefficient for water [18, 19]. Due to these intrinsic laser properties, in vitro and ex vivo studies of TFL have shown less time and energy are required to ablate kidney stones, though data from clinical trials are lacking [19].

URS with laser lithotripsy now represents one of the most commonly performed procedures by urologists in North America [20, 21]. Our institution obtained the first commercially available TFL in the United States in October 2020 and anecdotally our urologists noted decreased stone treatment times. In this study, we conducted a retrospective review of URS laser lithotripsy procedures before and after the acquisition of the TFL to determine if there was a difference in operative times between Ho:YAG and TFL lithotripsy.

Materials and methods

IRB approval was obtained for retrospective review of patients who underwent ureteroscopy and laser lithotripsy at a tertiary stone center from August 2020 to January 2021 and 152 patients were identified. All cases performed between August 2020 and October 28th, 2020 utilized Holmium:YAG laser lithotripsy. All cases from October 28th 2020 to January 2021 utilized TFL. Cases were performed by 11 different surgeons (2 fellowship trained endourologists) and 4 residents. Cases that involved bilateral and combined procedures ($n=18$), aberrant anatomy (i.e. duplication of collecting systems, transplant and pelvic kidneys) ($n=3$), those without recorded kidney stone composition, or those without a pre-op KUB or CT ($n=6$), were excluded from analysis. Cases that were aborted due to tight ureters preventing passage of the ureteroscope, or discovery of perforation or contrast extravasation prior to inserting ureteroscope ($n=4$) were also excluded. Study data were collected and managed using REDCap electronic data capture tools hosted at Tufts Clinical and Translational Institute [22, 23].

The resultant 102 cases were analyzed in 2 groups, those that underwent ureteroscopic lithotripsy by Lumenis Ho:YAG without pulse modification (80 or 100w) and those treated with the Soltive TFL. Operative time was defined as the time between insertion and retraction of the endourological instruments. Variables including stone size, location,

chemical composition, prior ureteral stenting, and ureteral access sheath use were recorded for each patient within an anonymized database. In cases with 2 or more stones, the cumulative stone diameter was measured from pre-op CT imaging and reported as the summation of the largest diameter from all treated stones when measured in coronal, transverse, and sagittal planes. Guidance on preference for dusting or fragmentation was left to the surgeon's discretion.

Statistical analysis performed in R (R Core Team, 2021) [24]. Continuous variables were summarized by mean and standard deviation or median and interquartile range (IQR) based on parametric and nonparametric distribution. Categorical variables were summarized as a percentage. For hypothesis testing, chi-square and Fisher's exact test were used for categorical variables. Student's t-test and Kruskal–Wallis test were used for continuous variables.

A cost benefit analysis was performed for Ho:YAG lithotripsy compared to TFL. The list price of the capital investment for the Olympus SOLTIVE™ SuperPulsed (TFL) Laser was obtained. The institutional cost of individual Lumenis Ho:YAG fibers and Olympus TFL were compared. Direct and indirect operating room costs for ureteroscopic laser lithotripsy procedures were calculated by our financial department based on an average of all laser procedures performed in 2020. Indirect costs were assumed to be the same between Ho:YAG and TFL lithotripsy. Expected annual cost savings were calculated using the formula:

$$\begin{aligned} & \text{Average Time Saved} \left(\frac{\text{min}}{\text{case}} \right) \\ & \times \text{Direct OR Cost} \left(\frac{\$}{\text{min}} \right) \times \frac{\text{Cases}}{\text{year}} \\ & = \text{Annual cost saving} \end{aligned}$$

Results

A total of 102 cases were analyzed with 51 in each group (Ho:YAG vs TVL). Patient sex, BMI, stent prior to lithotripsy, cumulative stone diameter, intra-renal vs intra-ureteral stone location, chemical composition, number of impacted stones, and cases performed by an endourological fellowship trained surgeon did not differ significantly between groups (Table 1). Additionally, resident participated in > 60% of all cases and there was no difference in number of procedures involving residents, procedures with junior residents (post-graduate year 2/3), or procedures with senior (post-graduate year 4/5) residents when comparing groups. For ureteral stones specifically, there were more distal-ureteral stones in the Ho:YAG group ($n=21$) than TFL ($n=10$), $p=0.031$ and more mid-ureteral stones in the TFL ($n=8$) than Ho:YAG ($n=1$, $p=0.036$).

Table 1 Comparison of baseline factors between Holmium:YAG and TFL treatment groups

	Holmium:YAG <i>n</i> = 51	Thulium Fiber Laser <i>n</i> = 51	<i>p</i> =
Patient characteristics (%), [IQR]			
Patient sex			
Female	20 (39.2)	26 (51.0)	0.32
Male	31 (60.8)	25 (49.0)	
BMI	29.5 [24.6–33.7]	28.1 [25.8–32.3]	0.503
Stone characteristics (%), [IQR]			
Cumulative stone diameter (mm)	10.0 [8.0–12.0]	10.6 [6.7–13.0]	0.992
Stone size (mm)	9.0 [6.8–10.0]	7.0 [6.0–10.3]	0.113
Major stone composition (%)			
CaOx monohydrate	33 (64.7)	27 (52.9)	0.337
CaOX dihydrate	6 (11.8)	13 (25.5)	
CaPhos	8 (15.7)	8 (15.7)	
Uric acid	3 (5.9)	2 (3.9)	
Operative characteristics (%)			
Stone location			
Intra-renal	27 (52.9)	28 (54.9)	1.000
Intra-ureteral	35 (76.1)	29 (59.2)	0.124
Distal	21 (41.2)	10 (19.6)	0.031
Mid	1 (2.0)	8 (15.7)	0.036
Proximal	15 (29.4)	12 (23.5)	0.654
Pre-stented	19 (37.3)	12 (23.5)	0.196
Impacted stones	8 (15.7)	6 (11.8)	0.774
Ureteral access sheath used	37 (72.5)	32 (62.7)	0.397
Number of locations treated			
One location	38 (74.5)	44 (86.3)	0.261
Two Locations	11 (21.6)	5 (9.8)	
Three locations	2 (3.9)	2 (3.9)	
Endourology fellowship trained surgeon			
Yes	20 (39.2)	18 (35.3)	0.682
No	31 (60.8)	33 (64.7)	
Resident involvement and experience			
No resident	18 (35.3)	19 (37.3)	0.847
Junior resident	25 (49.0)	26 (51.0)	
Senior resident	8 (15.7)	6 (11.8)	

Compared to Ho:YAG, use of TFL resulted in an average decrease of 12.9 min per case (95% CI [2.0–23.9], $p = 0.021$). In subgroup analysis of cases with cumulative stone diameter less than 15 mm, the difference was

14 min (95% CI [4.0–24.0] $p = 0.007$). For cases less than 10 mm, the difference was 17.3 min in favor of TFL (95% CI [6.9–27.6], $p = 0.002$) (Table 2). Stone-free rates (SFR) for comparison were not reliably measured, likely due to low

Table 2 Comparison of mean operative time between Holmium:YAG and thulium fiber laser stratified by size and comparison of Emergency Department (ED) visits within 30 days

	Holmium:YAG <i>n</i> = 51	Thulium fiber laser <i>n</i> = 51	<i>p</i> =
Mean Op Time (min ± SD)			
Overall (<i>n</i> = 102)	62.8 ± 26.3	49.8 ± 29.1	0.021
Cumulative diameter < 15 mm	55.9 ± 24.6 (<i>n</i> = 41)	41.9 ± 20.5 (<i>n</i> = 40)	0.007
Cumulative diameter < 10 mm	53.8 ± 20.1 (<i>n</i> = 30)	36.5 ± 17.9	0.002
Return to ED < 30 days (%)	3 (6)	3 (6)	1.00

adherence to post-op imaging during a COVID-19 peak in our state.

The initial capital investment for 2 SOLTIVE Super-Pulsed laser systems based on list price was \$350,000 and used for cost benefit analysis. Individual TFL and Ho:YAG fibers costs at our institution were \$319.50 vs \$450.00, respectively. Direct operating room costs for the facility were calculated at \$33.82/min. This costs includes a blended average of the individual laser fiber costs for Ho:YAG and TFL that is heavily weighted to Ho:YAG as TFL was used for only 2 of the 12 fiscal months in 2020.

Average operation time with TFL was ~ 13 min less than with Ho:YAG, saving \$440/case. Including laser fiber cost savings, not fully accounted for from direct cost/min alone, raises estimated maximum savings to as high as \$570/case. Over a 5-year average, our institution performed 670 cases of laser lithotripsy per year. Annual cost savings for TFL when compared to traditional Ho:YAG at our institution can be estimated at \$294,800 per year with a range of up to \$381,900 per year when accounting for difference in laser fiber costs.

Discussion

Ureteroscopy with laser lithotripsy is a mainstay of treatment for small to moderately sized kidney stones. In our study, use of TFL was found to decrease operative time by approximately 20% with no difference seen based on stone composition, stone location, ureteral access sheath use, pre-stenting, obesity, and laterality. Importantly, there was no significant difference in number of cases performed between Ho:YAG and TFL groups when endourologic fellowship training, presence of a resident, or resident experience was examined. Overall, 11 different attending surgeons performed laser lithotripsy in each of the groups and residents were involved in > 60% of cases. With this many different treating providers it is exceedingly unlikely that the technique or skill of a subset of surgeons would be able to influence the decrease in treatment times observed and it is therefore attributed to the TFL technology.

Our results support findings of preclinical experiments that have shown TFL to be faster and more effective. A systematic review by Kronenberg and Traxer in 2019 showed that TFL was more efficient than Ho:YAG by delivering less energy to achieve photothermal ablation of stones [19]. A review of TFL by a Toronto based group, Gao et al. also supported our results and found shorter operative time associated with thulium fiber laser based on findings consisting mostly of trials originating in the Russian Federation [25].

There were more distal ureteral stones treated in the Ho:YAG group than the TFL group. While this was statistically significant, overall we would predict this result to

skew the mean operative time in favor of Ho:YAG as distal ureteral stones are often faster to treat due to easier access and believe this further supports the result of shorter operative times for TFL.

Prolonged duration of ureteroscopy with lithotripsy of the kidney and ureter has been clearly demonstrated to affect both outcomes and cost of patient care [9–13]. It is postulated that complications arise due to surgical trauma as well as injury of the genitourinary mucosa caused by sustained high intrarenal pressure from the irrigation used during the procedure [11]. Specific complications identified from prolonged operative times are fever, bleeding, ureteral perforation, ureteral stenosis, sepsis, and septic shock [10, 11, 13]. A systematic review by Lane et al. in 2020 showed that a longer operative time for ureteroscopy and stone treatment has been associated with increased complication rates [9]. A 2013 retrospective study performed by Sugihara *et al.* included 12,374 patients who underwent URS with laser lithotripsy. They found an increase in complication rate occurring with each additional 30-min increase in operative time compared to a reference group of cases < 59 min [11]. This timeframe was further supported in 2019 by a study done by Ozgor et al. which found that operative times > 60 min had higher rates of infection [10]. These trials suggest the reduction from the 62.8 min mean operative time seen with Ho:YAG to the 49.8 min mean operative time of TFL seen in our study would result in decreased risk of complications; however, demonstrating this would require additional research.

In the US, the economic burden of nephrolithiasis is estimated to be upward of \$5 billion dollars [6]. Even marginal improvements in the treatment of stone disease can have a significant impact given the degree of disease prevalence. In this instance, increasing efficiency and reducing operative time will have financial impacts on the institution as a whole. We have found that by switching to TFL we are able to save \$440–\$570 per case and estimate an annual financial savings of \$294,000–\$381,900 for our institution. It is worth noting that the upper end of this estimate includes the savings from individual laser fibers, which are highly likely to vary between institutions. We estimate that we will recoup our hospital's initial investment in ~ 5 fiscal quarters.

Limitations to our study include its retrospective nature, as a randomized control trial may more definitively demonstrate time savings as being attributable to laser technology. Additionally, total operative time was used instead of “laser time” (time from the start of laser use until the completion of stone fragmentation) as this is not reliably recorded and case time was felt to be the most important clinical outcome. Other limitations include our inability to measure SFR in a reliable fashion in the two groups retroperitoneal ultrasound in the post-operative period due to low compliance with

follow up imaging (39%). Low compliance may have been due to the influence of the COVID-19 pandemic and our institution's recommendation to avoid non-essential office visits and imaging, as our study overlapped with a peak in COVID-19 cases in our state. Finally, there is a current lack of research to corroborate our results, which is likely attributed to the recent debut of the thulium technology.

It should again be made clear that this work compares TFL to traditional Ho:YAG without pulse modification and the results should not be used to suggest that newer Ho:YAG lasers including pulse modification (i.e. Lumenis MOSES™ Pulse 120H) would not lead to similar improvement in operative times. While the results may not be generalizable to all practices, this work provides real world evidence for improved operative times in URS stone treatment with TFL.

Conclusions

TFL has a significantly shorter operating room time and decreased institutional cost when compared to the standard Ho:YAG for URS with laser lithotripsy for equivalent kidney stone and patient characteristics. Randomized controlled trials are required to assess if TFL has a different SFR and complication rate compared to Ho:YAG.

Acknowledgements No financial disclosures or institutional/corporations affiliations were reported by authors. All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

Author contributions All persons who meet authorship criteria are listed as authors, and all authors certify that they have participated sufficiently in the work to take public responsibility for the content, including participation in the concept, design, analysis, writing, or revision of the manuscript.

Funding The authors received no financial support for the research, authorship, and/or publication of this article.

Declarations

Conflict of interest The authors report no proprietary or commercial interest in any product mentioned or concept discussed in this article. All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript. All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

Ethics approval Ethical approval was waived by the MaineHealth's Institutional Review Board in view of the retrospective nature of the study and all the procedures being performed were part of the routine care.

Consent to participate Informed consent was obtained from all individual participants included in the study.

Consent to publish Patients signed informed consent regarding publishing their data and photographs.

Research involving human participants and/or animals No human cells were used in this study. No animals were used in this study.

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