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Pulse-modulated Holmium:YAG Laser vs the Thulium Fiber Laser for Renal and Ureteral Stones: A Single-center Prospective Randomized Clinical Trial

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Study Need and Importance: Numerous preclinical data on the thulium fiber laser (TFL) have shown great promise for potential improvement over the gold standard of Ho:YAG (holmium:yttrium-aluminum-garnet) lithotripsy. Prior randomized trials suggest an improvement in operative time using the TFL compared to Ho:YAG; however, none used the latest high-powered pulse-modulated Ho:YAG technology with similar fiber diameters for comparison.

What We Found: A total of 108 patients were included in this randomized trial for routine outpatient ureteroscopy of nonstaghorn stones <2 cm. The pulse-modulated Ho:YAG with Moses 2.0 technology (Lumenis/Boston Scientific) and the SOLTIVE Premium SuperPulsed Laser System (Olympus) groups were well balanced with similar stone characteristics. Similar 200 μm-core laser fibers and similar starting laser parameters for fragmentation (0.8 J and 8 Hz) and for high-powered dusting (0.3 J and 80 Hz) were employed for both lasers. We found no significant difference in ureteroscope time between the pulse-modulated Ho:YAG (mean 21 minutes) and TFL lasers (mean 19.9 minutes, see Figure). Subset analysis comparing ureteroscope times subdivided by stone size, greater than or less than the median Hounsfield units of 1,023, and stone location also showed no significant differences. No differences were detected in stone-free rates or complications.

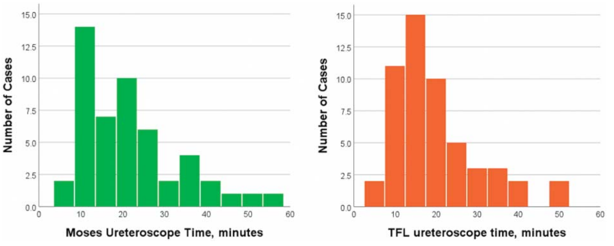

Figure. Histogram comparisons of ureteroscope (URS) times for Moses and thulium fiber laser (TFL). Mean, median (interquartile range) URS time for Moses = 21.4, 20 (11-28) minutes. Mean, median (interquartile range) URS time for TFL = 19.9, 17 (13-24) minutes. Mann-Whitney U P value = .6.

Limitations: While the laser settings were set at standard starting settings, further adjustments were left to the discretion of the surgeon. As the TFL is a newer technology, it is likely that the optimal laser settings are not equivalent to the Ho:YAG laser and require further investigation.

Interpretation for Patient Care: The results of this randomized trial of the high-powered pulse-modulated Ho:YAG laser vs the TFL showed no significant clinical advantage of one technology over the other in ureteroscope time, stone-free rates, or complications. Patients and surgeons can be assured that either platform yields excellent results in skilled hands.

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Pulse-modulated Holmium:YAG Laser vs the Thulium Fiber Laser for Renal and Ureteral Stones: A Single-center Prospective Randomized Clinical Trial

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Purpose: We sought to compare the clinical effectiveness of the pulse-modulated Ho:YAG (holmium:yttrium-aluminum-garnet) laser and the thulium laser fiber for ureteroscopic stone management in a randomized clinical trial. The primary outcome was the ureteroscope time required to adequately fragment stones to 1 mm or less. Secondary outcomes were stone-free rate, complications, subjective surgeon measurement of laser performance, patient related stone quality of life outcomes, and measurements of laser efficiency.

Materials and Methods: An Institutional Review Board-approved randomized clinical trial was conducted to randomize patients to outpatient treatment with either the Moses 2.0 or thulium laser fiber in a 1:1 manner after stratification into groups based on the maximal diameter of treated stone (3-9.9 mm or 10-20 mm). Patient, stone, and operative parameters were compared using the appropriate categorical/continuous and parametric/nonparametric statistical tests (SPSS 25).

Results: From July 16, 2021 to March 11, 2022, 108 patients were randomized and had primary endpoint data available for analysis; 52 patients were randomized to Ho:YAG and 56 patients to thulium laser fiber. Groups were well balanced with no significant differences observed for patient or stone characteristics. Ureteroscope time was not significantly different between modalities (Ho:YAG mean 21.4 minutes vs thulium laser fiber mean 19.9 minutes, $P = .60$), or within subgroup analysis by stone size, median Hounsfield units, or stone location. There were no significant differences observed in the stone-free rate and complications rate between the 2 lasers.

Conclusions: This randomized clinical trial suggests no significant clinical advantage of one laser technology over the other. Surgeon and institutional preference are the best approach when selecting one or the other.

Key Words: randomized controlled trial; ureteroscopy; lasers, solid-state; urolithiasis

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Support: None.

Conflict of Interest: The Authors have no conflicts of interest to disclose.

Ethics Statement: This study received Institutional Review Board approval (IRB No. 2021-0695).

Data Availability: The data sets generated and analyzed during the current study are available from the corresponding author on reasonable request.

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Editor's Note: This article is the third of 5 published in this issue for which Category 1 CME credits can be earned. Instructions for obtaining credits are given with the questions on pages 451 and 452.

WITH its first use for laser lithotripsy described in 1993,[1] the holmium laser has proven to be the gold standard for lithotripsy.[2,3] Incremental improvements in holmium technology have allowed for a wide range of power settings modulating between pulse energy, pulse frequency, and pulse duration.[4] In 2017, pulse modulation technology was adapted for a holmium laser enabling holmium energy delivery over 2 pulses. This technique allows for more efficient energy delivery to the stone while causing less stone retropulsion.[5] Several studies have examined the efficiency of the pulse modulation technology with most demonstrating shorter operative times.[6-9]

The thulium fiber laser (TFL) has recently emerged as an alternative in

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laser lithotripsy.[10] The TFL's 1,940 nm emission closely matches the near-infrared absorption peak of water resulting in an absorption coefficient ie, more than fourfold higher than the holmium laser.[11] Although current TFL systems have a lower maximum power of 60 W compared to the 120 W of the newer pulse-modulated Ho:YAG (holmium:yttrium-aluminum-garnet) laser, the TFL permits very high frequencies upwards of 2,200 Hz with pulse energies as low as 0.025 J, allowing for a greater range of settings. Due to the physical properties of a flash lamp generated multimode holmium laser, fiber diameter is restricted to a minimum of 200 µm, in contrast to the TFL, which accepts fibers as small as 50 µm.[12] Prior studies have shown that smaller fibers allow for better irrigation flow, better instrument deflection, and less stone retropulsion.[13]

Despite the theoretical technical advances the TFL offers, there is limited evidence demonstrating its superiority in a clinical setting. Several in vitro studies have reported a 1.5-4 times faster stone ablation rate with the TFL compared to the holmium laser[14,15] while other studies have shown less retropulsion due to the difference in bubble dynamics and lower peak power that generates smaller bubbles.[16,17] The majority of clinical trials of the TFL laser are single-arm prospective trials with historical cohort comparisons of holmium laser studies.[18-20] To date, there have been 3 randomized trials done in Russia,[21] India,[22] and most recently Norway[23] comparing lower power holmium laser settings to the TFL. All demonstrated the TFL to have shorter operative times over the holmium laser. To our knowledge, there has been no randomized trial comparing an advanced high-powered pulse-modulated Ho:YAG laser and the TFL while also utilizing high-powered dusting settings.

The primary goal of this randomized study is to determine whether the TFL is clinically superior to an advanced pulse-modulated Ho:YAG laser for ureteroscopic treatment of renal and ureteral stones. The primary measured outcome was ureteroscope time. Secondary outcome measures included laser-on time (LOT), total laser energy, ablation speed (stone volume/LOT), ablation efficiency (total laser energy/stone volume), stone-free rate (SFR), complications, surgeon's subjective ratings of laser effectiveness, and patients' stone related quality of life outcomes.

MATERIALS AND METHODS

A prospective randomized IRB-approved trial was designed to compare the clinical effectiveness of the TFL vs the pulse-modulated Ho:YAG laser. The protocol was designed to randomize patients undergoing outpatient ureteroscopy (URS) with either the holmium laser with Moses 2.0 technology (Lumenis/Boston Scientific) or the SOLTIVE Premium SuperPulsed Laser System (Olympus) after stratification into groups based on the maximal diameter of the largest stone (3-9.9 mm or 10-20 mm). In order to achieve at least an 80%

Table 1. *Comparisons of Study Participants' Baseline Characteristics and Those After Randomization to the Moses 2.0 Holmium Laser or Thulium Fiber Laser Groups*

Variable	Moses (n = 52)		Thulium (n = 56)		*P* value
Patient characteristics					
Female sex, No. (%)	21	(40)	30	(54)	.17
Age, mean, median (IQR), y	61, 62	(54-69)	59, 60	(52-69)	.9
Prior stone history, No. (%)	35	(67)	40	(73)	.5
Prior stone surgery, No. (%)	31	(60)	30	(56)	.7
BMI, mean, median (IQR), kg/m^2	31, 29	(26-35)	34, 34	(27-37)	.063
Diabetes, No. (%)	19	(37)	20	(38)	.9
CKD, No. (%)	6	(12)	2	(4)	.13
Stone group 3-9.9 mm, No. (%)	33	(64)	35	(63)	.9
Stone group 10-20 mm, No. (%)	19	(36)	21	(37)	.9
Stone characteristics					
Number of stones treated, mean, median (IQR)	1.6, 1	(1-2)	1.8, 1	(1-2)	.2
Number of stones, No. (%)					.6
1	35	(67)	32	(57)	
2	9	(17)	11	(20)	
3	5	(10)	7	(13)	
>3		3 (6)	6	(11)	
Largest stone diameter, mean, median (IQR), mm	8.4, 7.4	(5.3-11.3)	8.9, 7.9	(6.0-11.1)	.5
Cumulative stone diameter, mean, median (IQR), mm	11.4, 10.4	(6.1-16)	12.5, 10.9	(7.3-15)	.6
Total stone volume, mean, median (IQR), mm^3	319, 197	(59-521)	288, 202	(77-371)	.9
Ureteral stone(s) treated, No. (%)	27	(52)	26	(46)	.6
Renal stone(s) treated, No. (%)	30	(58)	39	(70)	.2
Lower pole stone(s) treated, No. (%)	13	(25)	22	(39)	.11
Both ureteral and renal stone(s) treated, No. (%)	5	(10)	7	(13)	.6
Maximum Hounsfield units, mean, median (IQR)	1,028, 1,059	(808-1,286)	990, 998	(726-1,203)	.7
Hydronephrosis, No. (%)	23	(44)	16	(29)	.090
Prior indwelling stent, No. (%)	11	(21)	16	(29)	.4

Abbreviations: BMI, body mass index; CKD, chronic kidney disease; IQR, interquartile range.
Chi-squared statistics used for categorical variables and Mann-Whitney U used for continuous variables except for age in which a *t*-test was used, as this variable approximated a normal distribution. Study groups were well balanced with no significant differences observed.

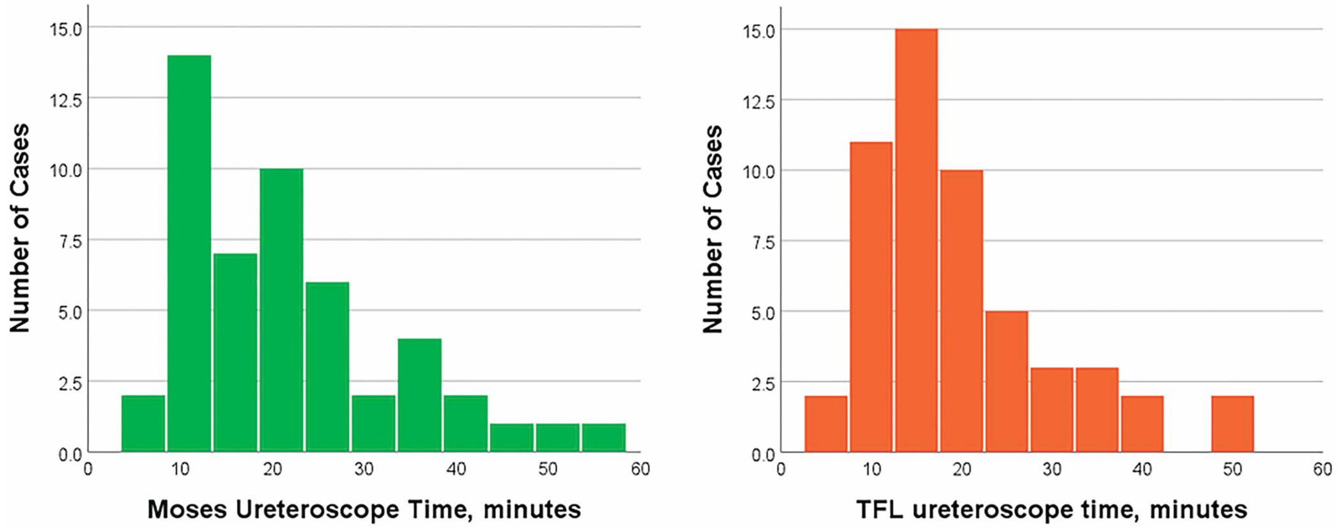

Figure. Histogram comparisons of ureteroscope (URS) times for Moses and thulium fiber laser (TFL). Mean, median (interquartile range) URS time for Moses = 21.4, 20 (11-28) minutes. Mean, median (interquartile range) URS time for TFL = 19.9, 17 (13-24) minutes. Mann-Whitney U *P* value = .6.

power with significance level set to 0.05 using a clinically significant cutoff of 6 minutes of ureteroscope time with a standard deviation of 10 minutes using a *t*-test statistic, the study aimed to enroll at least 45 patients in each laser group. Multiple stones were allowed as long as a single stone's maximal diameter did not exceed 20 mm. Patients who were at least 18 years of age undergoing day-surgery URS were eligible for randomization. Exclusion criteria included pregnancy, stone in a transplant kidney, irreversible coagulopathy, known anatomy abnormality such as ureteral stricture or urinary diversion, and no preoperative CT within 4 months of surgery date.

All signed informed consent either in clinic or in the preoperative holding area with patients blinded to their randomization. Patients were randomized at their enrollment by sequential assignment to a software generated randomized group order which was available to investigators. After initial cystoscopy, the ureter was first cannulated with a Sensor wire (Boston Scientific) followed by cannulation with either a semirigid ureteroscope alongside the sensor wire or cannulation with a flexible ureteroscope (P6 or P7; Olympus) over the sensor wire in a Seldinger fashion to the level of the stone. The semirigid ureteroscope was primarily used for distal and occasionally mid ureteral stones. A second guidewire and ureteral access sheath are not routinely used at our institution. Our routine practice is to dust stones with the objective of having no residual fragment size >1 mm.

Ureteroscope time was recorded from the time of the ureteroscope entering the ureter to the time leaving the ureter; 200 μm-core laser fibers were used for both the Moses 2.0 laser and TFL. Laser settings for both the Moses 2.0 holmium laser and the TFL were set at default settings of 0.8 J and 8 Hz for fragmentation and 0.3 J and 80 Hz for dusting with further adjustments made to the laser settings left to the discretion of the surgeon. The Moses mode was set to contact for the fragmentation setting and distance for the dusting setting while the TFL was set to the short pulse setting. High-power laser dusting settings were used only for stones in the renal pelvis.

The SFR was primarily deduced from plain film x-rays (KUB) and renal ultrasounds done 4-8 weeks after stent removal. Post URS stents were routinely placed with stent removal carried out 1 week postoperatively. SFR was defined using both the strict criteria of no visible stones or fragments and alternatively having no stone fragment $\geq$3 mm. Complications up to 2 months post URS were recorded. Subjective laser performance was evaluated after each case by the attending or senior resident utilizing a survey consisting of 6 laser performance categories on a Likert scale from 0-5. Patients' stone related quality of life outcomes were assessed preoperatively and 4-8 weeks postoperatively using the Wisconsin Stone Quality of Life Questionnaire Short Form (WISQOL-SF).[24,25]

The Mann-Whitney U test was used to analyze the primary outcome of whether a statistical difference was found

Table 2. *Moses 2.0 and Thulium Fiber Laser Mann-Whitney U Comparisons of Ureteroscope Time Subdivided by Stone Size, Median Hounsfield Units, and Stone Location*

Variable	Moses (n = 52), mean, median (IQR)	Thulium (n = 56), mean, median (IQR)	*P* value
Stone group 3-9.9 mm	18, 16 (10-22)	16, 15 (11-20)	.8
Stone group 10-20 mm	28, 24 (20-35)	27, 25 (17-34)	.8
Hounsfield > median 1,023	24, 21 (18-30)	23, 18 (13-33)	.4
Hounsfield < median 1,023	18, 13 (10-23)	18, 17 (12-23)	.4
Only ureteral stone treated	19, 13 (10-27)	16, 11 (10-19)	.5
Only renal stone treated	24, 22 (15-34)	20, 18 (14-25)	.18

Abbreviation: IQR, interquartile range.
Subgroup analysis revealed no statistically significant ureteroscope time advantage between Moses and thulium fiber laser in these differing clinical scenarios.

Table 3. *Stone-free Rate Chi-squared Comparisons Between Moses 2.0 and Thulium Fiber Laser Using 2 Definitions of Stone-free*

Stone-free Rates	Moses (n = 47)	Thulium (n = 53)	*P* value
No residual fragments ≥3 mm, No./total No. (%)			
Overall	40/47 (85)	40/53 (77)	.3
Only renal stone	17/23 (74)	20/28 (71)	.8
Only ureteral stone	21/21 (100)	15/16 (94)	.3
Lower pole stone	9/12 (75)	12/20 (60)	.4
Zero residual fragments, No./total No. (%)			
Overall	32/47 (68)	35/53 (67)	.9
Only renal stone	12/23 (52)	18/28 (64)	.4
Only ureteral stone	19/20 (95)	14/16 (88)	.4
Lower pole stone	4/12 (33)	10/20 (50)	.4
Primary imaging modality, No. (%)			.5
KUB	30 (64)	36 (68)	
US	11 (23)	14 (26)	
CT	6 (13)	3 (5.7)	
No residual fragments ≥3 mm, No./total No. (%)			
KUB	28/30 (93)	30/36 (83)	.2
US	7/11 (64)	9/14 (64)	1
CT	5/6 (83)	2/3 (67)	.6
Zero residual fragments, No./total No. (%)			
KUB	23/30 (77)	27/35 (77)	1
US	6/11 (54)	6/14 (43)	.6
CT	3/6 (50)	2/3 (67)	.6

Abbreviations: CT, computerized tomography; KUB, plain film x-ray; US, ultrasound.
Additional comparisons were made for stone treatment location. Imaging modality refers to the primary imaging modality used to assess the stone-free status 4-8 weeks after ureteral stent removal.

in ureteroscope time, laser data, and laser survey data. The chi-square test was employed to detect difference in SFR and a 2-way repeated measure ANOVA test was used to detect difference in WISQOL-SF scores. Subgroup analyses were performed to compare stone size groups, ureteral vs renal stone, and median Hounsfield unit subdivisions to determine if differences in ureteroscope time might manifest under certain conditions. Statistical significance was set as 2-tailed P values <.05 and data were analyzed using SPSS 25 (IBM Corp., Armonk, New York).

RESULTS

From July 16, 2021 to March 11, 2022, 114 patients were randomized: 56 to the pulse-modulated Ho:YAG group and 58 to the TFL group. Within the pulse-modulated Ho:YAG group, 2 were excluded for stone passage detected at the time of URS and 2 were excluded after requiring a second stage that was subsequently done at a different operative site without both laser capabilities. In the TFL group, 1 patient was excluded for requiring a second stage URS in which ureteroscope time was not captured, and 1 patient was excluded for stone basket extraction without use of lithotripsy. A total of 108 patients thus had data available for primary endpoint comparison: 52 patients randomized to Ho:YAG and 56 patients randomized to TFL. Ninety-five percent of cases were led by endourology fellowship-trained faculty.

Baseline patient demographic and stone characteristics are presented in Table 1. Similar ratios of randomization to stone size groups were seen between Ho:YAG and TFL groups with 64% of cases randomized to stone group size 3-9.9 mm and 36% of cases randomized to the stone size group 10-20 mm. The 2 groups were well balanced with no significant differences detected in patient or stone characteristics. A mean of 1.6 and 1.8 stones were treated with the mean cumulative stone burden treated 11.4 and 12.5 mm within the Ho:YAG and TFL groups, respectively. Total stone volumes were also similar at a median of 197 mm^3 and 202 mm^3 ($P = .9$) for the Ho:YAG and TFL groups, respectively.

No significant difference was observed between the 2 lasers with mean ureteroscope time for the pulse-modulated Ho:YAG laser at 21.4 minutes vs 19.9 minutes for the TFL ($P = .6$; see Figure). Subset analysis comparing ureteroscope times subdivided by stone group size, greater than or less than the median Hounsfield units of 1,023, and stone location also showed no significant differences between the 2 lasers (Table 2).

SFR data were available for 100/108 (93%) of study participants (Table 3). KUB was the primary modality used to assess SFR in 30 (64%) of Ho:YAG cases and 36 (68%) of TFL cases. CT was used for 6

Table 4. *Eight-week Complication Chi-squared Comparisons of Moses 2.0 and Thulium Fiber Laser*

Eight-wk complications	Moses No. (%) (n = 52)	Thulium No. (%) (n = 56)	*P* value
Obstructing fragment requiring unplanned URS	1 (2)	2 (4)	.3
Obstructing fragment, successful trial of passage	1 (2)	0	
Stent colic ER visit and discharge	1 (2)	3 (5)	.3
UTI treated with outpatient antibiotics	2 (4)	1 (2)	.4
Any complication	5 (10)	6 (11)	.9

Abbreviations: ER, emergency room; URS, ureteroscopy; UTI, urinary tract infection.

Table 5. *Laser Effectiveness Mann-Whitney U Comparisons Between Moses 2.0 and Thulium Fiber Laser*

Laser measurement	Moses (n = 52), mean, median (IQR)	Thulium (n = 56), mean, median (IQR)	*P* value
Laser-on time, min	4.8, 2.7 (1.2-6.7)	5.1, 3.6 (1.7-7.3)	.3
Total energy, kJ	3.1, 1.2 (0.5-4.7)	4.3, 2.5 (1.4-5.6)	.046
Ablation speed, mm^3/min	628, 482 (205-868)	483, 413 (273-692)	.5
Ablation efficiency, J/mm^3	1.6, 1.5 (0.7-2.2)	2.4, 1.8 (1.1-3.2)	.009

Abbreviation: IQR, interquartile range.
Total energy used was significantly lower in Moses vs thulium fiber laser, and Moses was found to have superior (lower values) ablation efficiency over the thulium fiber laser.

(13%) of Ho:YAG SFR assessment and 3 (5.7%) of TFL SFR assessment, and renal ultrasound was used in the remainder. A comparable SFR was observed between the 2 lasers for those with no residual stone fragment ≥3 mm (77-85%) or zero stone fragments visible (67%-68%). No differences in SFR were detected when dividing the cohort by stone location or imaging modality.

We observed a low rate of complications for both groups (Table 4). There were no immediate postoperative complications and all patients were discharged home the same day. A total of 3 cases (1 within the Ho:YAG group and 2 within the TFL group) had obstructing ureteral fragments after stent removal that were ultimately treated with a repeat URS while 1 case within the Ho:YAG group had a successful trial of passage for a 3 mm fragment. Additional secondary laser data outcomes are shown in Table 5. While LOT and ablation speed were found to be similar for both groups, the pulse-modulated Ho:YAG laser was found to use significantly less total energy (mean 3.1 vs 4.3 kJ, $P = .046$) and have an improved (lower value) ablation efficiency (mean 1.6 vs 2.4 J/mm^3, $P = .009$) vs the TFL.

There were no significant differences identified for stone-related quality of life at baseline or postoperatively between the lasers. Both lasers demonstrated significantly improved WISQOL-SF standardized scores from pre- to postoperative with a mean improvement of 23.8 standardized WISQOL points for the Ho:YAG laser ($P = .013$) and 35.3 for the TFL ($P < .001$; Table 6). Subjective surgeon laser evaluation scores demonstrated significantly less retropulsion ($P < .001$) and increased overall laser efficiency ($P = .014$) with the TFL compared to the Ho:YAG laser (Table 7).

DISCUSSION

This single-institution randomized trial compared outcomes for URS laser lithotripsy using the Moses 2.0 holmium laser or the SOLTIVE thulium Super-Pulsed Laser System. No significant difference was observed in ureteroscope time when comparing the groups as a whole or when subdividing by stone size, Hounsfield units, or stone location. Furthermore, SFRs were similar between both lasers regardless of the definition used (zero fragments or no fragments ≥3 mm), and the location of stones treated. While we recognize the limitation of using KUB as the primary modality to assess SFR, the similar and low rate of complications supports our conclusion of comparable clinical outcomes for both lasers.

We found comparable effectiveness in routine ureteroscopic laser lithotripsy for nonstaghorn calculi <2 cm for the Ho:YAG laser and the TFL.[26] We did not encounter any stone that could not be fragmented by the TFL and recent literature supports TFL effectiveness in dusting all urinary stone composition types.[27] Anecdotally, the surgeons in this study noted that when encountering dense calcium stones the TFL may be more likely to benefit from an increase in joules to maintain lithotripsy effectiveness when compared to the pulse-modulated Ho:YAG laser. The pulse-modulated Ho:YAG laser did have reduced total energy usage and improved ablation efficiency when compared to the TFL; however, the clinical significance of this finding remains to be determined. An improved ablation efficiency results in less energy expended per

Table 6. *Wisconsin Stone Quality of Life Questionnaire Short Form Preoperative and Postoperative Standardized Score 2-Way Repeated Measure ANOVA Comparisons Between the Moses and Thulium Lasers*

WISQOL-SF standardized scores (0-100)	Moses (77% postoperative response rates), mean±SD	Thulium (75% postoperative response rate), mean±SD	*P* value
Preoperative scores	51.5±32.6	49.0±33.1	.19
Postoperative scores	75.3±33.1	84.3±19.1	.11
P value	.013	< .001	

Abbreviations: SD, standard deviation; WISQOL-SF, Wisconsin Stone Quality of Life Questionnaire Short Form.

Table 7. *Subjective Laser Evaluation Instrument Mann-Whitney U Comparisons Between Moses and Thulium Lasers*

Category Scored from 0-5	Moses (n = 52), mean±SD	Thulium (n = 55), mean±SD	*P* value
Retropulsion	4.0±0.6	4.5±0.4	< .001
Durability	4.7±0.5	4.6±0.6	1
Laser flexibility	4.7±0.4	4.6±0.5	.8
Efficiency	4.3±0.5	4.5±0.5	.014
Reliability	4.8±1.0	4.9±0.4	.9
Ease of fiber passage through scope	4.8±0.5	4.3±0.8	< .001

Abbreviation: SD, standard deviation.
Categories rated on a 0-5 Likert scale with 0=worst and 5=best.

volume of stone treated and is desirable in order to minimize a potentially damaging thermal dose in the urinary tract when using high-powered settings.[28,29]

This study differs in outcome with the recent randomized trial by Ulvik et al that showed improved SFR of renal stones (86% vs 49%, $P = .001$) and shorter operative times (49 vs 57 minutes, $P = .008$) for the TFL when compared to the holmium laser.[23] Although this randomized trial had a similar sample size (n = 120), disparate outcomes may have been a result of their utilization of an older low-powered 30 W holmium laser than was used in the present study. Also notable was their substantially lower−powered laser start-up settings of 0.4 J at 6 Hz for both holmium and TFL with maximum settings limited to 0.4 J at 6 Hz in the ureter and 0.8 J at 20 Hz in the renal pelvis. High-powered dusting settings were therefore not utilized as opposed to the present study, in which a dusting setting of 0.3 J and 80 Hz was used in the renal pelvis. Lastly, the 270 µm fiber of the holmium laser used by Ulvik et al may have given a slight irrigation and visibility advantage to the TFL, which used a 200 µm laser fiber.

The current study is not without limitations. Similar starting laser settings were chosen for practicality of comparison and from familiarity with Ho:YAG settings; however, the optimal laser settings for the TFL are still unknown and are likely not identical to that of the Ho:YAG laser, which may have contributed to the improved ablation efficiency observed in the Ho:YAG group. Moreover, while the initial laser settings were the same in both groups, changes in energy or frequency were at the surgeon's discretion with power more often increased in the TFL group. We suspect that the differences in power usage may have biased the results of the apparent diminished ablation efficiency and higher total energy for the TFL when compared to the Ho:YAG laser as increasing power may have diminishing marginal benefit for stone ablation speed resulting in an overall greater amount of joules used per mm^3. Notably, despite the TFL using more energy than the pulse-modulated Ho:YAG laser, this did not translate into shorter ureteroscope time or improved SFR. A further limitation of this study was our use of KUB in the majority of cases to determine SFR, which is less sensitive than CT. Routine postoperative CT scans are not the usual practice in our clinic.

CONCLUSIONS

The results of this randomized trial of the pulse-modulated Ho:YAG laser vs the TFL in outpatient laser lithotripsy for nonstaghorn calculi <2 cm showed no significant clinical advantage of one technology over the other in ureteroscope time, SFRs, or complications. The Ho:YAG laser used less total energy with improved ablation efficiency compared to the TFL, suggesting that more energy was required with the TFL to produce comparable outcomes. As both laser technologies are safe and highly effective, surgeon and institutional preference is the best approach when selecting one or the other.

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EDITORIAL COMMENTS

Thulium fiber laser (TFL) technology has made headlines in the last 3 years because of its remarkable features, and is currently competing with the best top-of-the-line Ho:YAG (holmium:yttrium-aluminum-garnet) lasers on the market, prompting speculation if it might even replace them as the gold standard in endoscopic laser lithotripsy.[1]

The primary goal of this randomized study was to determine whether the TFL is clinically superior to an advanced pulse-modulated Ho:YAG laser for ureteroscopic treatment of renal and ureteral stones using high-powered dusting settings. Similar starting laser settings were chosen for practicality of comparison and from familiarity with Ho:YAG settings, yet the authors recognize that the optimal laser settings for the TFL are still unknown, which may have contributed to the improved ablation efficiency observed in the Ho:YAG group.

As the authors correctly mentioned, previous randomized studies have shown the TFL to have significantly shorter operative times in comparison to the holmium laser. The present study also showed that ureteroscope time was shorter for the TFL, yet it wasn't statistically significant. Despite this shorter ureteroscope time with the TFL, one of the curious aspects of this study is the fact that the TFL still used more total energy, which seems a bit controversial, since one would expect a shorter operating room time to be associated with less energy use, a logical assumption confirmed by other authors.[2]

However, high-powered laser settings, as used in the present study, and the increasing availability of high-power Ho:YAG lasers, TFLs, or any other energy source, for that matter, bear with them the need for more cautiousness in their use due to potential thermal tissue damage. The phrase "With greater power comes greater responsibility" is not only meant for leaders[3] and superheroes, but also for us urologists, and should always be in our minds whenever we use high-power settings, regardless of the technology.

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Conflict of Interest: Peter Kronenberg has participated in advisory board meetings for Olympus and in industry breakout session for Lumenis.

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3. *Collection Générale des Décrets Rendus par l'Assemblée Nationale—Mai 1793.* L'Assemblée Nationale; 1793:72.

This randomized clinical trial of thulium fiber laser (TFL) vs pulse-modulated Ho:YAG (holmium:yttrium-aluminum-garnet) lithotripsy showed similar ureteroscope time, stone-free rates, and quality of life scores. TFL produced less retropulsion. Ho:YAG used less total energy with higher ablation efficiency. Overall, the results imply clinical equivalence between TFL and pulse-modulated Ho:YAG lithotripsy.[1]

Despite the apples-to-apples comparison, I note some differences: at the stated settings, optical pulse durations for TFL would be 0.5-1.6 milliseconds vs 300-350 microseconds for pulse-modulated Ho:YAG.[2,3] It is unclear if these differences are relevant.

Urologists may interpret these findings with different take-home messages. At face value, this-well conducted trial by experienced endourologists shows (SuperPulsed) TFL and pulse-modulated Ho:YAG lithotripsy yield equivalent outcomes.[3] Urologists who use either platform should feel reassured that they have effective laser lithotripters. Alternatively, TFL diode technology is new and developing. Just as Ho:YAG has evolved from low-power, single-pulse machines to high-power, pulse-modulated technology, it is possible that with enhanced understanding of optimal power, pulse duration, and waveform settings an enhanced TFL may emerge.

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One of the draws of urology has always been the utilization of novel technologies for treatment of urological diseases and the rapidity with which these technologies are constantly advancing. However, it is important to remember that a smaller camera, bigger robot, or stronger laser doesn't always lead to improved patient outcomes.

Over the last 5 years, pulse-modulated high-power holmium laser (PMHPHo) has become a mainstay of ureteroscopic lithotripsy, although there have been mixed results in the clinical sphere regarding its superiority.[1,2] Similarly, the thulium fiber laser (TFL) has risen in popularity over the last few years due to its improved dusting capabilities, small form factor, simpler power requirements, and quieter cooling system. There is constant debate surrounding the utility of one novel technology over the other, with a recent trial suggesting superiority of TFL for intrarenal stone-free rates (SFRs).[3] This article suggests that, for stones less than 2 cm, TFL and PMHPHo had similar operative times, similar SFRs, and similar postoperative quality of life scores.

Of note, in this study, x-ray of the kidney, ureter, and bladder was used as the primary method of assessing SFR, suggesting that perhaps more accurate postoperative imaging may have produced a different result. Additionally, while the TFL and PMHPHo arms started at standard energy settings, further modification of energy settings was left to the discretion of the surgeon; as holmium settings are more well known to urologists, this freedom to modify settings may have been more frequently and appropriately utilized in the holmium group, artificially improving holmium outcomes. Still, this article remains a powerful signal that there may not be 1 single "best" laser for ureteroscopic lithotripsy at this time. Each of these technologies remains a useful tool for the enterprising endourologist and, at the end of the day, it is up to the skill of the surgeon to determine patient outcomes.

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REPLY BY AUTHORS

Our study compares 2 of the most advanced laser technologies used in ureteroscopic surgery for non-staghorn kidney stones <2 cm in the present day. We sought to achieve an equitable comparison by using identical 200 μm laser fiber diameters and identical starting laser parameters of joules and hertz. We believe this study provides the most accurate comparison between thulium fiber laser (TFL) and current Ho:YAG technology to date, likely more balanced than the study by Ulvik et al,[1] which compared a 30 W Ho:YAG 270 μm fiber without pulse modulation to the 200 μm fiber TFL.

We found little difference between the 2 technologies despite in vitro reports of the TFL having improved ablation rates.[2] Ureteroscope time was not statistically different overall and on subset analysis of stone size, Hounsfield units, and stone location. There was no difference in other standard measures of clinical efficacy including stone-free rates and complications. Better laser ablation efficiency with the pulse-modulated high-power holmium laser was observed—thus more energy was required using TFL to produce comparable clinical outcomes. We advise more thermal injury caution when using the TFL—especially when encountering harder stones where increases in pulse energy may improve fragmentation.

This trial was designed to mirror the clinical circumstances that occur in practice, using an approach derived from the AUA guidelines. We therefore used plain film x-ray and ultrasound as the primary stone-free rate assessment and acknowledge that this approach is less sensitive in detecting residual stone fragments than CT.

We are confident that our study shows that both lasers can achieve excellent outcomes in skilled hands, and that the decision of which laser to use should be based on surgeon and hospital preference. Further experience and reports will facilitate a better understanding of optimal settings and thermal thresholds.

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