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Initial experience of thulium fiber laser in retrograde intrarenal surgery for ureteral and renal stones in Japan: surgical outcomes and safety assessment compared with holmium: yttrium-aluminum-garnet with MOSES technology

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Abstract

Background Thulium fiber laser (TFL) has been used for the treatment of ureteral and renal stones in Japan since October 2023. However, there are no reports on the initial results of TFL in Japan. This study aimed to assess the initial results of TFL in retrograde intrarenal surgery (RIRS) and to compare them with those of holmium: yttrium-aluminum-garnet (Ho: YAG) laser with MOSES technology.

Methods This retrospective single-center study compared perioperative results, complications, and the "stone-free" rate (defined as ≤ 2 mm fragments on computed tomography 1 month after RIRS) between the TFL (60 W) (group A, $n=48$) and Ho: YAG laser with MOSES technology (120 W) (group B, $n=48$) laser. The inclusion criteria were renal or ureteral stones ≤ 20 mm in diameter and those scheduled for single-stage RIRS.

Results The two groups had similar baseline patient characteristics. No significant differences were found in operative time (45 vs. 54 min, $P=0.10$), laser time (15 vs. 10 min, $P=0.12$), stone-free rate (97.9% vs. 95.8%, $P=1.00$), ureteral injury (2.1% vs. 8.3%, $P=0.36$), or postoperative fever (0% vs. 4.2%, $P=0.49$) between groups A and B. However, significant differences were found in basketing time (7 vs. 21 min, $P < 0.01$) between groups A and B.

Conclusions Our study showed that RIRS with TFL had similar results and no difference in complications compared to RIRS with Ho: YAG laser with MOSES technology. The TFL had a significantly shorter basketing time than the Ho: YAG laser with MOSES technology. Furthermore, future research is needed to determine suitable laser settings for the TFL.

Keywords Laser, Lithotripsy, Retrograde intrarenal surgery, Thulium fiber laser, Ureteral and renal stones

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Background

The treatment of ureteral and renal stones has evolved into minimally invasive endoscopic laser lithotripsy. Currently, the holmium: yttrium-aluminum-garnet (Ho: YAG) laser is the standard laser source for lithotripsy [1]. It was introduced approximately 30 years ago [2], and has benefited from many years of subsequent technological development. Retrograde intrarenal surgery (RIRS) has an expanding role in treating urinary tract stones [3]. In Japan, as in the trend worldwide, the ratio of RIRS in the surgical treatment of renal and ureteral stones has been increasing [4]. In the pursuit of safer and more efficient laser technology, thulium fiber laser (TFL) has been developed as the next generation of Ho: YAG laser [5].

TFL has a wide range of energy, frequency, and pulse width settings [6], and has been compared with Ho: YAG laser in several in vitro and in vivo studies [7–10]. Notably, it is reportedly superior in dusting and fragmentation, ablating stones at approximately 1.5–4 times faster and with less stone retropulsion [8, 9]. However, possible side effects of thermal injury have been reported since TFL has a higher water absorption ability than Ho: YAG laser [11]. In Japan, the use of TFL (Fiber Dust®) for treating renal and ureteral stones started in October 2023. However, there are no reports on the initial results of TFL (Fiber Dust®) in Japan. Therefore, we reported our initial experience with the TFL in Japan and compared its surgical results and safety with those of the Ho: YAG laser.

(a)

(b)

Fig. 1 Thulium fiber laser and holmium: yttrium aluminum-garnet (YAG) laser with MOSES technology. (**a**) Thulium fiber laser; (**b**) Holmium: YAG laser with MOSES technology

Methods

Study design

This retrospective study investigated the treatment outcomes of patients with renal or upper ureteral stones who underwent RIRS at Hachinohe Heiwa Hospital in Japan between May 2022 and May 2024. We compared 48 consecutive cases using the Ho: YAG laser with MOSES technology (Lumenis Pulse 120 H® (120 W); Lumenis, Yokneam, Israel) from May 2022 to February 2023 and 48 using TFL (Fiber Dust® (60 W); Quanta System, Samarate, Italy) between October 2023 and May 2024 (Fig. 1). All consecutive patients were included in the analysis without exclusion to prevent a potential selection bias. Here, the surgical indications were ureteral stones < 10 mm in diameter that could not spontaneously pass or renal stones > 10 mm in diameter. The exclusion criteria were stones > 20 mm, complex stones that were initially scheduled for two-stage surgery, and stone formation after urinary diversion. The Ethics Committee of Hachinohe Heiwa Hospital, Aomori, Japan, approved this retrospective study (approval number: 21 – 02), and the requirement for individual informed consent was waived for this retrospective study.

Equipment

This study used a Ho: YAG laser with MOSES technology (Lumenis Pulse 120 H®) with a 200-μm laser fiber, TFL (Fiber Dust®) with a 200-μm laser fiber, flexible ureteroscope (7.5-Fr FlexX2s; Karl Storz, Tuttlingen, Germany or 7.5-Fr EndoView; HugeMed, Shenzhen, China), semi-rigid ureteroscope (6.4/7.8 Fr; Olympus, Tokyo, Japan), ureteral access sheath (UAS) (Biflex 10/12-Fr; Rocamed, Monaco, Navigator HD 11/13-Fr; Boston Scientific, Boston, USA, and Flexor 10.7/12.7-Fr, 12/14-Fr; Cook

Medical, Bloomington, USA), single-use basket holder (M-arm; MC Medical, Tokyo, Japan) and basket catheter (NCircle 1.5-Fr; Cook Medical, Bloomington, USA, and Dormia 1.5-Fr; Coloplast, Minneapolis, USA). A foot-operated irrigation system (Peditrol; Wismed, Durban, South Africa) or a pressure-controlled automatic perfusion system (EndoflowII; Rocamed, Monaco) was also used to control the efficient inflow of perfusion and appropriate intrarenal pressure.

Surgical technique

Patients were anesthetized using general or epidural anesthesia and placed in the lithotomy position for cystoscopy. Intravenous antibiotics were administered immediately prior to the procedure. All patients underwent rigid cystoscopy, and a guidewire was inserted into the upper urinary tract under fluoroscopic guidance. A semi-rigid ureteroscope was subsequently passed over the guidewire to confirm the ureteral stricture due to stone-induced ischemia. Additionally, a ureteral stent was inserted if the semi-rigid ureteroscope could not easily pass through the intramural ureter, and a second RIRS was scheduled for approximately 2 weeks later. This procedure enables the ureter to recover from ischemia, resulting in the success of the second procedure. However, dilators or dilating balloons were not used.

RIRS was performed using the one-surgeon basketing technique for stone extraction during flexible ureteroscopy, as previously reported [12]. The size of the UAS was determined based on semi-rigid ureteroscopy findings. Depending on the condition of the patient's ureter, a UAS measuring 10/12–12/14 Fr was inserted under fluoroscopic guidance. Briefly, the semi-rigid ureteroscope (6.4/7.8 Fr) was passed over the guidewire through the ureteral orifice, advancing as far as safely possible to the renal pelvis or ureteral stone.

Lithotripsy was performed using either the Ho: YAG laser or TFL, with laser fibers of 200 μm for renal and ureteral stones. The laser was generally applied at an initial setting of 0.5 Joules (J), with a pulse rate of 5 Hz (Hz), which was increased as needed. Stones were fragmented or dusted using the lasers and extracted with baskets, and a 6-Fr ureteral stent was placed in all patients.

Regarding the surgical method, the stones were fragmented as small as possible, and the necessary fragments were retrieved using a basket catheter. In this technique, we utilized dual-pulse technology for the Ho: YAG fragmentation to produce as much dust as possible. We selected a minimal pulse duration setting for the TFL to create dust. For the dusting technique, particularly for the TFL, the occurrence of thermal injuries was considered due to its efficient energy absorption to the perfusion [13]. Therefore, we set the upper limits of laser pulse power for TFL at 25 and 12 Watts (W) for renal and ureteral stones, respectively, to prevent postoperative ureteral strictures. All intraoperative ureteral injuries identified perioperatively were treated with stent placement. Stent removal was performed on an outpatient basis under local urethral anesthesia using a flexible cystoscope. Stone-free status and worsening of hydronephrosis were evaluated 1 month postoperatively using computed tomography (CT) after stent removal on an outpatient basis.

Parameters

Preoperative clinical information included age, sex, body mass index (BMI), stone number, stone burden (mm), stone volume (mm [3]), stone location (kidney or ureter), maximum CT attenuation in Hounsfield units, hydronephrosis, and preoperative ureteral stent. In cases of multiple stones, the stone burden was calculated as the sum of the diameters of all stones.

Perioperative clinical information included operative time (min), total laser time (min), total laser energy (kJ), basketing time (min), and ureteral injury. Specifically, perioperative ureteral injury was determined based on intraoperative ureteroscopic findings and evaluated using the post-ureteroscopic lesion scale [14]. Here, the following indicators were used to evaluate the lasers' performance for lithotripsy: Lithotripsy effectiveness [stone volume (mm^3)/operative time (min)], laser speed [stone volume (mm^3)/total laser time (min)], and laser ablation efficiency [stone volume (mm^3)/total laser energy (J)] [15].

Postoperative clinical information included a stone-free rate, defined as a stone size of ≤ 2 mm based on the CT scan at 1-month post-RIRS, postoperative fever, and postoperative worsening of hydronephrosis. Postoperative fever was defined as a significant fever ≥ 38.0 °C. Complications were evaluated using the modified Clavien-Dindo grading system [16].

Statistical analysis

Patient characteristics are expressed as median (first to third quartile) for each continuous variable. Statistical analyses were performed using JMP software, version 9.0 (SAS Institute Inc., Cary, N.C., USA). Intergroup differences in continuous and categorical variables were assessed using the Mann–Whitney U and Fisher's exact tests, respectively. Statistical significance was set at < 0.05.

Results

Overall, 96 patients were assigned into groups A (TFL group, $n = 48$) and B (Ho: YAG laser with MOSES technology group, $n = 48$). No significant differences were observed in patient characteristics between the two groups, including age, sex, BMI, stone number, stone

Table 1 Patient characteristics

Group	TFL	Ho: YAG laser with MOSES	P-value
Case number	48	48	
Age (years)	60 (51–70)	65 (57–73)	0.07
Sex (male, %)	35 (72.9)	34 (70.8)	0.82
BMI (kg/m^2)	25.1 (22.8–28.2)	24.5 (21.8–27.7)	0.17
Stone number	1 (1–2)	1 (1–2)	0.93
Stone burden (mm)	13 (9–18)	13 (9–18)	0.96
Stone volume (mm^3)	397 (164–828)	284 (195–464)	0.27
CT attenuation value (HU)	1219 (1021–1379)	1344 (1019–1536)	0.16
Stone location			
Renal stones (*n*, %)	32 (66.7)	29 (60.4)	0.52
Upper or middle pole stones (*n*, %)	10 (20.8)	7 (14.6)	
Lower pole stones (*n*, %)	14 (29.2)	16 (33.3)	
Renal pelvis stones (*n*, %)	8 (16.7)	6 (12.5)	
Ureteral stone (*n*, %)	16 (33.3)	19 (39.6)	0.52
Upper ureteral stone (*n*, %)	14 (29.2)	18 (37.5)	
Lower ureteral stone (*n*, %)	2 (4.2)	1 (2.1)	
Hydronephrosis (*n*, %)	20 (41.7)	27 (56.3)	0.22
Preoperative ureteral stent (*n*, %)	27 (56.3)	21 (43.8)	0.22

Data are shown as sample median (first to third quartile)

BMI, body mass index; HU, Hounsfield units; Ho: YAG, holmium: yttrium-aluminum-garnet; TFL, thulium fiber laser

Table 2 Comparison of surgical outcomes

Group	TFL	Ho: YAG laser with MOSES	P-value
Operative time (min)	45 (34–64)	54 (46–64)	0.10
Laser time (min)	15 (7–24)	10 (6–17)	0.12
Max Power (W)	9 (5.5–16)	6.4 (4.6–13.6)	0.09
Basketing time (min)	7 (3–10)	21 (11–24)	< 0.01
Lithotripsy effectiveness (mm^3/min)	8.24 (4.03–15.64)	5.51 (3.52–8.84)	0.06
Laser speed (mm^3/min)	29.5 (17.8–46.6)	34.9 (18.1–48.4)	0.59
Laser ablation efficiency (mm^3/J)	0.13 (0.06–0.22)	0.20 (0.09–0.47)	0.06
Total laser energy (kJ)	3.62 (1.06–8.34)	2.02 (0.60–3.81)	0.06
Stone-free rate (*n*, %)	47 (97.9)	46 (95.8)	1.00
Ureteral injury (*n*, %)	1 (2.1)	4 (8.3)	0.36
Postoperative fever (*n*, %)	0 (0)	2 (4.2)	0.49
Worsening of hydronephrosis (*n*, %)	0 (0)	3 (6.3)	0.24

Data are shown as sample median (first to third quartile)

Ho: YAG, holmium: yttrium-aluminum-garnet; TFL, thulium fiber laser

burden, stone volume, stone location, maximum CT attenuation value, presence of hydronephrosis, and preoperative ureteral stent (Table 1). The median stone size was 13 mm in both groups A and B. There was no significant difference between the two groups regarding the stone composition, with 89% of Group A and 93% of Group B containing calcium.

No significant differences were found in operative time (45 vs. 54 min, $P=0.10$), laser time (15 vs. 10 min, $P=0.12$), total laser energy (3.62 vs. 2.02 kJ, $P=0.06$), stone-free rate (97.9% vs. 95.8%, $P=1.00$), ureteral injury (2.1% vs. 8.3%, $P=0.36$), worsening of hydronephrosis (0% vs. 6.3%, $P=0.24$), or postoperative fever (0% vs. 4.2%, $P=0.49$) between groups A and B. In contrast, significant differences were found in basketing time (7 vs. 21 min, $P < 0.01$) between groups A and B (Table 2). No cases of Clavien-Dindo grade III ureteral injuries were found in either group. Furthermore, no cases of poor visibility due to hematuria occurred during RIRS.

The total laser energy and lithotripsy effectiveness were higher in group A, though not significantly, than in group B. However, the laser ablation efficiency was higher in group B, though not significantly, than in group A (Table 2).

Discussion

This study suggests that the initial outcomes of RIRS for treating ureteral and renal stones using TFL in Japan were comparable to those of RIRS using the Ho: YAG laser with MOSES technology, and the safety of the treatment was confirmed. Patient characteristics did not significantly differ between the two groups. No significant differences were found in surgical outcomes, such as stone-free rate and operative time, between the two groups. The total laser energy was higher, whereas the basketing time was significantly shorter in the TFL group than in the Ho: YAG laser with MOSES technology group. TFL has a lower peak pulse power than the Ho: YAG laser with MOSES technology; therefore, TFL must be used at higher laser energy (J). Postoperative worsening of hydronephrosis suggests ureteral stricture due to thermal injury, a potential side effect of TFL. Therefore, we compared the degree of hydronephrosis at 1 month postoperatively and found no significant difference between the two groups. However, 1 month after RIRS may be too short to evaluate worsening hydronephrosis, and long-term evaluation is necessary.

In this study, the basketing time was significantly shorter in the TFL group, and the operative time was shorter but not significantly. The shorter basketing time in the TFL group was possibly due to fewer basketing tasks since most of the fragments were small. The advantages of TFL compared to the Ho: YAG laser include fine dusting, faster ablation speed, and a higher ablation rate [6–10]. The TFL rapidly fragmented renal stones partly due to its high pulse rate, power density, and average power and the observation of reduced stone retropulsion and may provide a clinical alternative to the conventional

Ho: YAG laser for lithotripsy [13]. Regarding laser efficiency, after 3 min of continuous lasering, the overall ablation rate was significantly higher with the TFL technology than with the Ho: YAG laser [8]. Higher ablation speeds were more consistently produced at 0.8 J/12 Hz than at 0.2 J/100 Hz; specifically, TFL ablation efficiency is significantly better at high pulse energy and low pulse frequency settings, owing to increased cavitation damage with less char formation [9]. TFL may be safe and effective for lithotripsy during RIRS, using low pulse frequency [17]. Additionally, the TFL has significantly less stone disintegration time, which effectively reduces the operative time of RIRS and mini-percutaneous procedures [18, 19]. Moreover, RIRS and mini-percutaneous nephrolithotomy with Fiber Dust® could be performed effectively and safely in clinical practice [19–21].

In this study, intraoperative bleeding did not obstruct endoscopic vision in the two groups. The incidence of intraoperative bleeding obstructing endoscopic vision was significantly less frequent in the TFL group (5%) than in the Ho: YAG laser group (22%) [20]. Since TFL absorbs water approximately 4 times higher than the Ho: YAG laser [21], the photomechanical effect is weak, and the photothermal effect predominates. In an experimental ex vivo study, tissue penetration was found to be greater with the Ho: YAG laser than with the TFL; therefore, the TFL is considered to cause less bleeding than the Ho: YAG laser [22]. The histological analysis found greater tissue penetration with the Ho: YAG laser than with the TFL and different coagulation properties between the two lasers [22]. Several meta-analyses suggest that RIRS with TFL is effective and safe for treating renal and ureteral stones [23, 24].

Two prospective randomized control trials (RCTs) have compared TFL with Ho: YAG laser [20, 25]. One of the RCTs compared TFL (60 W) with Ho: YAG laser without MOSES technology (30 W) and found no difference in the stone-free rate for ureteral stones; however, TFL had a significantly higher stone-free rate and shorter operative time for renal stones [20]. The other RCT compared TFL (60 W) with Ho: YAG laser with MOSES technology (120 W) and found no difference in stone-free rate and operative time for renal and ureteral stones between the two types of lasers [25]. Notably, the results of these studies are compatible with our findings. The laser settings were standardized for both laser types. In these two RCTs, the two laser settings were considered optimal for the Ho: YAG laser. Although the optimal laser settings for the Ho: YAG laser are known, the settings for the TFL are unknown. Therefore, comparing the two lasers using the same laser setting is impractical. Further studies should determine the types of cases that could benefit from the laser characteristics, including the appropriate laser settings.

Because the TFL absorbs water approximately 4 times more effectively than the Ho: YAG laser, thermal injury around the laser is a concern. Depending on the laser settings and perfusion conditions, laser use in a confined environment without a UAS may lead to an increase in the ambient urinary tract temperature [26, 27]. The presence or absence of a UAS can significantly change the temperature rise in the kidney. In RIRS without a UAS, a pulse power exceeding 20 W may increase the risk of thermal injury [26, 27]. Specifically, RIRS, in the absence of a UAS, poses a high risk of an increase in urinary tract temperature. Therefore, laser settings should be tailored to individual situations to reduce the risk of urinary tract temperature increase, depending on the urinary tract situation, including the presence of a UAS and the size of the urinary tract [26, 27]. The laser setting of 0.8 J/12 Hz was the optimal setting, resulting in a two-fold increase in treatment efficiency, a 39% reduction in energy expenditure per unit of ablated stone mass, a 35% reduction in residual fragments, and a 36% reduction in total procedure time compared with the 0.2 J/50 Hz setting in an in vitro study [28]. Using high pulse energy (J) and low pulse frequency (Hz) laser settings maximizes treatment efficiency and minimizes potential thermal injury [29]. In our study, a UAS was implanted in all patients, a flexible ureteroscope was used, and both TFL and Ho: YAG laser were used under appropriate perfusion. Therefore, the thermal injury was appropriately prevented in this study.

We set the upper limits of laser pulse power for TFL at 25 and 12 W for renal and ureteral stones, respectively, referring to previous reports [30]. Two important parameters for laser settings in RIRS are pulse energy (J) and pulse frequency (Hz). The pulse power (W) was determined accordingly using the formula $J \times Hz = W$. Therefore, surgeons must consider these values, particularly pulse power, which is the main factor in intrarenal temperature rise [29]. No uniform standard for appropriate laser settings for TFL currently exists. However, expert opinion suggests that up to 1 and 2–2.5 J for ureteral and renal stones, respectively, may be safe [30]. For ureteral stones, raising pulse energy (J) may be more effective and safer than raising pulse frequency (Hz). Even for dusting renal stones, a theoretical TFL value of 2500 Hz should not be used for actual RIRS; however, it is safer to use ≤ 50 Hz [30]. Because the peak pulse power of TFL is relatively low compared with that of Ho: YAG laser, the same pulse energy (J) setting as that of Ho: YAG laser is usually inadequate power. Therefore, high pulse energy (J) and low pulse frequency (Hz) levels may help maximize treatment efficiency and minimize potential thermal injury [26].

This study had some limitations. First, this was a retrospective study with a relatively small sample size and short follow-up period; therefore, prospective studies with a larger number of cases should be conducted. Second, owing to the initial experience with TFL, no uniformity exists regarding the appropriate laser settings for TFL, and laser settings were based on Ho: YAG laser. However, to the best of our knowledge, this is the first report from Japan on the efficacy and safety of TFL for renal and ureteral stones. We showed that RIRS with TFL yielded comparable results and no difference in complications compared with the Ho: YAG laser with MOSES technology from these initial results of TFL in Japan where the laser settings for TFL have not been standardized.

In conclusion, these initial cases in Japan suggest that the TFL could be employed for RIRS with results equivalent to and with low complications as the Ho: YAG laser with MOSES technology. Therefore, we plan to identify patients who would benefit most from TFL. Further studies are needed to determine optimal laser settings for TFL.

Abbreviations

BMI	Body mass index
CT	Computed tomography
Ho:YAG	Holmium: yttrium-aluminum-garnet
RCT	Randomized control trial
RIRS	Retrograde intrarenal surgery
TFL	Thulium fiber laser
UAS	Ureteral access sheath

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Author contributions
D.K. and G.A. made study conception and design. D.K., Y.O., and T.M. collected data and G.A. performed statistical analysis. D.K., G.A., and T.K drafted the first version of the manuscript and Y.O. and T.M. helped to draft the revised manuscript. All authors reviewed the manuscript.

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Data availability
The data supporting this study's fndings are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate
This retrospective study was approved by the Institutional Review Board and Research Ethics Committee of Hachinohe Heiwa Hospital (21 – 02) and was conducted according to the tenets of the Declaration of Helsinki. Informed consent was obtained using an opt-out method.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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