

Pulsed solid-state thulium: YAG laser compared to holmium: YAG laser during mini-PCNL

Benedikt Becker,^{1,2} Sophia Hook,¹ Carla Dapper,¹ Julius Bergmann,¹ Christopher Netsch,¹ Simon Filmar,^{1*}

¹Department of Urology, Asklepios Hospital Barmbek, Hamburg, 22307, Germany

²Department of Urology, University Hospital Schleswig-Holstein, Campus Lübeck, Lübeck, 23538, Germany

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Background: Holmium: yttrium-aluminum-garnet (Ho: YAG) laser technology has long been employed for urinary stone fragmentation; however, its limitations have prompted the exploration of alternative systems such as thulium lasers. This study aims to compare a novel pulsed solid-state Thulium: YAG (Tm: YAG) laser to the standard Ho: YAG laser in Mini-percutaneous nephrolithotomy (Mini-PCNL) lithotripsy for renal calculi.

Methods: In total, 100 patients undergoing Mini-PCNL were enrolled in this clinical trial. Fifty patients treated with a holmium laser were selected from a retrospective database. These patients were compared to fifty patients who were prospectively enrolled and treated with a new thulium laser. Patient characteristics, stone parameters, operative details, and complications were recorded and analyzed statistically.

Results: Both groups were comparable in demographics and stone characteristics. The Tm: YAG group demonstrated significantly shorter laser-on-time (7.20 vs. 10.46 min; $p < 0.05$) and operative time (32.6 vs. 41.2 min; $p < 0.05$) compared to the Ho: YAG group. There was no difference regarding stone-free rates (SFR) at 24 h, which were 90% in the Ho: YAG group and 92% in the Tm: YAG group ($p > 0.999$). Intraoperative complications did not significantly differ between groups.

Conclusion: The novel pulsed solid-state Tm: YAG laser demonstrates advantages over the Ho: YAG laser in terms of laser-on-time and operation time, while showing comparable results for stone-free rate and complications. Further clinical trials are needed to compare Tm: YAG and Ho: YAG lasers in various contexts and to evaluate the Tm: YAG laser against the thulium fiber laser (TFL) for a comprehensive understanding of each technology's advantages.

Key Words: thulium laser, holmium laser, lithotripsy, mini-percutaneous nephrolithotomy (Mini-PCNL), kidney stones

Introduction

The Holmium: yttrium-aluminum-garnet (Ho: YAG) laser has established itself as a safe and effective lithotripsy tool over the past three decades, being the standard choice for both retrograde intrarenal

surgery (RIRS) and percutaneous nephrolithotomy (PCNL) procedures.¹ However, the low-power Ho: YAG technology entails certain drawbacks, such as stone repulsion and a lack of sufficient dusting abilities.^{2–4} Innovations in stone therapy have introduced novel thulium lasers as potential alternatives. The thulium fiber laser (TFL) has emerged as a prominent contender against the Ho: YAG laser for lithotripsy.^{5,6} By employing high-power laser diodes and a thulium-doped fiber, the TFL efficiently converts electrical energy into laser output.^{7,8}

Another innovative technology lies in the pulsed solid-state Thulium: yttrium-aluminum-garnet (Tm:

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*Corresponding Author: Simon Filmar.

Email: s.filmar@asklepios.com

YAG) laser.⁹ While it has primarily been employed in continuous wave mode for soft tissue procedures, its application as a pulsed laser in lithotripsy is promising but not yet sufficiently examined.^{10,11} Similar to the TFL, the Tm: YAG laser utilizes laser diodes to stimulate photons, but it incorporates a YAG crystal instead of a fiber. A fiber coupler lens and smart fiber connector then transmit the laser output to the delivery fiber. Operating at a wavelength of 2013 nm, slightly shorter than that of the Ho: YAG laser, the Tm: YAG laser demonstrates improved energy absorption in water.⁶ Consequently, it achieves lower fragmentation thresholds and shallower penetration depths. The Tm: YAG laser offers adjustable pulse durations spanning from 100 to 4750 μ s, can generate frequencies up to 300 Hz, and attains a pulse peak power exceeding 1000 W. In comparison to the TFL, these attributes allow the Tm: YAG Laser to be a more efficient and faster tool for fragmenting and dusting urinary stones.¹² The TFL is capable of delivering the same amount of energy onto the stone/tissue, but due to the lack of peak power, it requires a much longer pulse duration. This leads to longer laser-on time and longer operation duration.¹¹ A recent study conducted by Bergmann et al. affirms the Tm: YAG lasers' safety and effectiveness in PCNL lithotripsy.¹³

Comparing the TFL to the Ho: YAG laser, advantages include significantly reduced retro-pulsion, a fourfold increase *in vitro* ablation volume, and smaller yet more abundant dust particles. Recent trials, particularly in RIRS, have demonstrated the TFL's comparable safety and superior efficiency.¹⁴⁻¹⁶ Presently, guidelines of the European Association of Urology (EAU) still endorse the use of Ho: YAG lasers, while acknowledging the TFL as a "promising" option, contingent upon further clinical investigation.¹

Although TFL has been extensively studied, evidence on pulsed solid-state Tm: YAG in Mini-PCNL is novel; this study addresses that gap. This trial seeks to compare the standard Ho: YAG laser with the Tm: YAG laser in Mini-PCNL lithotripsy for renal calculi measuring 1–4 cm. To date, no prospective evaluation of these devices in the context of Mini-PCNL has been undertaken.

Materials and Methods

Study design and patient selection

We prospectively enrolled all patients from our urological department at Asklepios Hospital Barmbek Hamburg between September 2022 and August 2023 who were treated with a novel solid-state

Tm: YAG laser (RevoLix Hybrid Thulium Laser (HTL) (LISA Laser products GmbH, Katlenburg, Germany)) for lithotripsy during Mini-PCNL. Afterward, we compared these patients with a cohort from our retrospectively collected database of our urological department at Asklepios Hospital Barmbek Hamburg who were treated with a Sphinx Jr. Holmium: YAG laser (LISA Laser products GmbH, Katlenburg, Germany). To enhance methodological rigor and ensure comparability between cohorts, fifty patients were retrospectively selected from the most recent entries in the database, while an additional fifty were prospectively enrolled to minimize the risk of selection bias. A total of 100 patients, with fifty patients in each group, were included.

This study followed a non-randomized, non-concurrent cohort design. The Tm: YAG laser group was prospectively enrolled, while the Ho: YAG group was retrospectively selected from an institutional database. The retrospective data were considered a form of pseudorandomization, as both laser systems were simultaneously available and laser choice was largely based on availability and routine. However, this design may have introduced selection bias, which was addressed through strict inclusion criteria and comparison of baseline characteristics.

Inclusion and exclusion criteria

Only patients with kidney stones and a stone size between 1 and 4 cm were included. Exclusion criteria were age <18 years, concurrent other surgical treatment, a potential malignant kidney tumor, coagulopathy and pregnancy. This trial was approved by the Ethics Committee (Ethik-Kommission der Ärztekammer Hamburg, Weidestr. 122 b, 22083 Hamburg) (protocol code PV5212).

Before surgery urine analysis and culture were taken, as well as a blood sample for serum creatinine and coagulation parameters. Radiological examination with non-contrast computed tomography (NCCT) was performed, and stone burden, stone locations, and stone densities in Hounsfield Units (HU) were documented. It was documented if a Double-J-Uretercatheter was placed prior to the surgery.

Surgical technique

Regardless of the choice of the laser, all procedures were performed using an identical surgical technique by the same experienced endourologist. A potential learning-curve bias can be excluded, as the surgeon (BB) had already performed more than 300 PCNL procedures prior to this study. All patients received general anesthesia as well as an antibiotic prophylaxis

with Cefuroxime or according to the antibiogram. After transurethral insertion of a 7F multi-perforated double J catheter and a 22F 3-way irrigation catheter in lithotomy position, the renal pelvic system was filled retrogradely. Patients were then placed in the prone position and the lower calyx was punctured under ultrasound and fluoroscopy. The established percutaneous tract was then dilated by a single step. A minimally invasive PCNL Set (MIP M, 16.5F) (KARL STORZ SE & Co. KG, Tuttlingen, Germany) was used.

Laser systems and lithotripsy parameters

Depending on the treatment group, lithotripsy was performed with the assigned laser as described above. Laser fibers (LISA Laser products GmbH, Katlenburg, Germany) measured 550 μm in diameter. Laser settings were 1 J and 20 Hz in the beginning and were adjusted depending on stone composition. Stone fragments were removed by either the 'vacuum cleaner effect' of the nephroscope or an additionally inserted basket. After removing the instruments, a 16-F nephrostomy tube was placed in the access tract. Radiation dose ($\mu\text{g}/\text{m}^2$), fluoroscopy time (s), laser energy (J) and frequency (Hz), and laser on time (LOT) (min) were measured intraoperatively by the respective device. Intraoperative complications were recorded.

Outcome measures

Primary outcomes were LOT, operative time and stone-free rate (SFR). The operative time was defined as the time between the puncture of the kidney and the placement of the nephrostomy tube. When no residual stones >1 mm could be found endoscopically during the operation and in a postoperative kidney, ureter, and bladder (KUB) X-ray with retrograde filling or NCCT at the first postoperative day, the patient was defined as stone-free. All patients with residual stones underwent RIRS for definitive stone clearance. Secondary outcomes were complications, which were defined and classified in accordance with the Clavien-Dindo Classification.¹⁷

Statistical analysis

For statistical analysis, SPSS version 20.0 (IBM Corp., Armonk, NY, USA) was used. Data were presented as mean \pm standard deviation (SD) and statistically analysed by performing a *t*-test. The significance level was defined as $p < 0.05$.

Results

A total of 100 patients were included in the study. 50 patients underwent Mini-PCNL with the Ho: YAG laser and 50 with the Tm: YAG laser.

Baseline demographics and patient characteristics

Both groups were comparable in terms of sex ($p > 0.99$), age ($p = 0.08$), prestening ($p > 0.99$), stone size ($p = 0.75$), and stone density ($p = 0.78$). Twenty-five (50%) patients in the Ho: YAG group and thirty-eight (76%) patients in the Tm: YAG group had a single stone, which represented a significant difference ($p = 0.01$). Both groups showed no differences with regard to hospitalization time (2.40 ± 1.16 vs. 2.50 ± 1.03 days) (Tables 1 and 2).

Intraoperative and postoperative outcomes

There was no difference regarding SFR at 24 h, which was 90% in the Ho: YAG group and 92% in the Tm: YAG group ($p > 0.999$) (Table 3). In all five patients from the Ho: YAG group and in one of the four patients from the Tm: YAG group, who were not considered stone-free, a residual stone was removed by RIRS. In the remaining patients of the Tm: YAG group, only stone dust was observed, without the possibility of extracting any stone material.

Laser efficiency and operative parameters

LOT (7.20 vs. 10.46 min; $p < 0.05$) was significantly shorter in the Tm: YAG group. Operative time also showed a significant difference between the two groups (32.56 vs. 41.20 min; $p < 0.05$), favoring the Tm: YAG laser. The mean total energy for stone ablation was higher when the Tm: YAG laser was used (13.07 ± 13.23 kJ vs. 9.11 ± 6.24 kJ). On average, the Tm: YAG laser was used at higher frequencies (25 ± 14 Hz vs. 20 ± 4 Hz) and lower energy levels (0.7 ± 0.2 J vs. 1.0 ± 0.5 J) compared to the Ho: YAG laser. Fluoroscopy time and radiation dose did not differ between the two groups (Table 3).

Complications

Intraoperative and postoperative complication rates were not significantly different according to the Clavien-Dindo Classification (Table 4).

TABLE 1. Comparisons of study patients' baseline characteristics (Data presented as n (%))

Patient characteristics	Tm: YAG group (n = 50)	Ho: YAG group (n = 50)	p-value
Female sex, No. (%)	19 (38)	20 (40)	>0.99
Age (years)	52.6	56.2	0.08
ASA score			0.62
I	3 (6)	6 (12)	
II	40 (80)	34 (68)	
III	7 (14)	10 (20)	

Note. Tm: YAG, Thulium: yttrium-aluminum-garnet laser; Ho: YAG, Holmium: yttrium-aluminum garnet laser; ASA, American Society of Anesthesiologists physical status classification.

TABLE 2. Stone characteristics and baseline parameters (Data presented as mean \pm SD or n (%)).

Patient and stone characteristics	Tm: YAG group	Ho: YAG group	p-value
Number of stones			0.58
1 stone	38 (76)	25 (50)	0.01
2 stones	9 (18)	14 (28)	0.34
3 stones	2 (4)	8 (16)	0.09
>3 stones	1 (2)	3 (6)	0.62
Median stone size (mm ²)	251.8	262.4	0.75
Median stone density (HU)	899.1	880.8	0.78
Stone location side			0.34
Right	18 (36)	20 (40)	
Left	32 (64)	30 (60)	
Prestenting	3 (6)	4 (8)	>0.99
Hospitalization days (d)	2.40 \pm 1.16	2.50 \pm 1.03	0.65

Note. Tm: YAG, Thulium: yttrium-aluminum-garnet laser; Ho: YAG, Holmium: yttrium-aluminum garnet laser; SD, Standard deviation; HU, Hounsfield Units.

Discussion

This study shows that operative time (OT) and laser-on time (LOT) were significantly shorter using a Tm: YAG laser compared to the Ho: YAG laser for lithotripsy during Mini-PCNL, while there was no difference regarding SFR and complications. Although LOT and OT differences reached statistical significance, the absolute reductions (approximately 3 min shorter laser-on time and 9 min shorter operative time) are relatively modest. From a clinical

perspective, these savings are unlikely to reduce perioperative anesthesia risk in otherwise healthy patients. However, even small-time reductions can contribute to operating room efficiency, lower cumulative anesthetic exposure in high-risk populations, and improve case throughput in high-volume centers. Thus, while the primary impact on individual patient safety may be limited, the system-level benefits in workflow and resource utilization could still be meaningful. These findings correlate with current evidence on novel thulium-based pulsed lasers, which

TABLE 3. Intra- and postoperative parameters (Data presented as mean \pm SD or n (%))

Perioperative parameters	Tm: YAG group	Ho: YAG group	<i>p</i> -value
Operative time (min)	32.56 \pm 19.50	41.20 \pm 23.40	0.048
LOT (min)	7.20 \pm 7.08	10.46 \pm 7.20	0.025
Laser, total energy (kJ)	13.07 \pm 13.23	9.11 \pm 6.24	0.060
Frequency (Hz)	25 \pm 14	20 \pm 4	0.018
Joule	0.7 \pm 0.2	1.0 \pm 0.5	<0.001
Fluoroscopy time (total) (s)	40.58 \pm 27.98	46.13 \pm 34.31	0.378
Radiation dose (total) ($\mu\text{g}/\text{m}^2$)	78.73 \pm 71.66	86.12 \pm 66.45	0.594
SFR	46 (92)	45 (90)	>0.999

Note: Tm: YAG, Thulium: yttrium-aluminum-garnet laser; Ho: YAG, Holmium: yttrium-aluminum garnet laser; SD, Standard deviation; LOT, Laser-on time; SFR, Stone-free rate.

TABLE 4. Complications (Data presented as n (%))

Clavien-Dindo complications	Tm: YAG group	Ho: YAG group	<i>p</i> -value
Intraoperative			0.14
Grade I			
Mucosal injury	10 (20)	7 (14)	
Grade II			
Perforation of the renal pelvis	0 (0)	1 (2)	
Postoperative			0.63
Grade I			
Bladder tamponade	2 (4)	1 (2)	
Fever	2 (4)	3 (6)	
Transient elevation of serum creatinine	3 (6)	2 (4)	
Total	7 (14)	6 (12)	
Grade II			
Urinary tract infection	3 (6)	4 (8)	
Blood transfusion	1 (2)	0 (0)	
Urinoma	0 (0)	1 (2)	
Total	4 (8)	5 (10)	

show several advantages over the well-established Ho: YAG laser.^{9,11,13,18}

In 2022, Ulvik et al. showed the superiority of the TFL compared to the Ho: YAG laser in RIRS regarding SFR, intraoperative bleeding, and OT.¹⁶ A recent review on the TFL by Mahajan et al. outlined its efficacy due to improved ablation, lower retropulsion and improved dusting, as well as being a safe device for lithotripsy in both RIRS and PCNL.¹⁵ There were no differences in ablation rates and SFRs when a TFL was compared in RIRS versus Mini-PCNL for the

treatment of larger stones (>20 mm). In that study, both treatment groups achieved an SFR of 85%.¹⁹ Similar or higher SFRs in PCNL with TFL were reported by Korolev et al. and Shah et al.^{20,21} Including only the TFL, Korolev et al. compared different frequency regimens and interestingly observed the highest ablation rate between 20 and 49 Hz rather than higher frequencies.²¹ Additionally, they could show that higher frequencies would lead to better visibility in PCNL, despite the previously observed correlation of high frequency and poor visibility in RIRS.^{19,21,22}

Mahajan et al. described shorter laser and operative times with the TFL in Mini-PCNL because of a faster stone disintegration (median stone disintegration time of 20 min 45 s with the Ho: YAG laser vs. 11 min 19 s with the TFL) and also reached a higher SFR with the TFL.¹⁵ While most studies compare TFL to low-power Ho: YAG laser, no significant differences were observed between Ho: YAG and TFL when a high-power Ho: YAG laser with Moses mode was used.^{14–16,23} These modern high-power Ho: YAG laser models, incorporating pulse modulation technology, aim to enhance these drawbacks. These advancements mitigate retropulsion, thereby improving stone ablation rates.^{8,24,25}

Whereas the TFL shows promising results for lithotripsy during Mini-PCNL, to the best of our knowledge, no trial currently exists comparing the Tm: YAG laser with the Ho: YAG laser in this setting. However, two recent non-comparative studies proved the Tm: YAG laser to be safe and efficient in RIRS and Mini-PCNL.^{13,18} Besides, there have been *in vitro* trials showing the Tm: YAG laser to be capable of dusting all types of urinary stones and indicating it to be equally efficient as the TFL.¹¹ With its wider range of settings, it may even be more efficient than the Ho: YAG laser in lithotripsy. Still, parts of these data are based on artificial stone models and therefore should be validated by further clinical investigation.^{26,27} Bergmann et al. presented a high efficacy of the Tm: YAG laser in Mini-PCNL in both dusting and fragmentation mode with an SFR of 84%.¹³ In their study, 50 patients were included regardless of stone size and all were treated with the Tm: YAG laser. In our study, an SFR of 92% was reached using the solid-state Tm: YAG laser, which is equivalent to or higher than data on TFL in PCNL.^{15,19–21} The SFR was primarily assessed by intraoperative endoscopy and postoperative KUB on day 1, with NCCT performed only in selected cases (e.g., radiolucent stones or other clinical indications). Although NCCT has higher sensitivity and specificity than KUB for detecting residual fragments,^{28,29} its routine use is not part of our clinical standard. Our center's experience indicates that early NCCT (day 1) often overestimates residual stone burden and may trigger unnecessary re-interventions, while delayed NCCT (4–12 weeks) is more accurate but not aligned with our patient-oriented concept of single-stay treatment and immediate nephrostomy removal. Consequently, we cannot exclude a potential underestimation of SFR; however, we consider same-hospital re-intervention based on clinical and endoscopic findings to best reflect real-world management and patient quality-of-life priorities. The

shorter LOT of 7.2 min for the Tm: YAG laser in our study corresponds to the reported range of 5–10 min for the TFL used during PCNL in the current literature.^{7,14} With 32.6 min, the OT with the Tm: YAG laser in our study was significantly shorter than what is actually described for PCNL.³⁰ Our trial showed no significant differences between Tm: YAG laser and Ho: YAG laser regarding complications. These findings resemble the data in current literature referring to PCNL with a TFL, especially as most of the complications seem to be independent of the chosen laser.^{15,20,31} The greater reduction in operative time, despite only a 3-min shorter laser-on time, can be attributed to the superior water absorption of Tm: YAG, which enables faster lithotripsy and produces smaller fragments that can be flushed more efficiently. Similar effects have been demonstrated by Panthier et al., who also reported that the physical properties of Tm: YAG facilitate quicker fragment clearance beyond the laser ablation time itself.¹⁸ Altogether, this indicates the Tm: YAG laser to be an equivalent player in stone lithotripsy, and based on our data, superior to the Ho: YAG laser. Regarding stone therapy, Panthier et al. demonstrated in a prospective study that the pulsed Tm: YAG laser achieves high stone-free rates with satisfactory ablation efficiency and a favorable safety profile in RIRS. These findings underline the clinical feasibility of this novel laser system; however, the relatively small sample size and the lack of a comparator limit the generalizability of the results.³² The most recently introduced pulsed thulium: YAG laser (Thulio™, Dornier) was launched into clinical endourology in 2021 as a novel solid-state laser system for lithotripsy.³³ It represents a recent addition to the armamentarium of laser technologies and was developed to expand treatment options beyond the conventional Ho: YAG standard.

Wavelengths of the new pulsed thulium lasers are slightly shorter than those of Ho: YAG lasers and therefore closer to the water absorption peak, which means that fragmentation threshold and penetration depth are lower. The resulting higher energy absorption leads to smaller stone fragments and can explain a faster stone disintegration and therefore shorter operative time as observed in our and other clinical trials.^{15,16,34} Both TFL and Tm: YAG lasers can operate at a higher frequency range than the Ho: YAG laser and offer adjustable peak power, pulse energy and pulse durations, so that they can provide different pulse profiles. These pulse profiles are more consistent with a constant peak power. This improves dusting qualities and ablation efficiency and decreases the retropulsion effect.^{12,18,27,34} Moreover, an *in vitro* trial of Kraft et al. suggests

the Tm: YAG laser has a higher fragmentation efficacy than the TFL due to its higher peak power, which could lead to a gain in importance when both fragmentation and dusting modes are needed.⁹ TFL and the pulsed thulium: YAG system differ in peak power despite similar water-absorption wavelengths (~1.94–1.96 μm vs. ~2.01 μm). TFL typically delivers 0.025–6 J per pulse at 0.2–50 ms, with average power up to 60 W and peak optical power around 0.1–0.5 kW. In contrast, the pulse Tm: YAG Laser operates at up to 2.5 J per pulse and 300 Hz, with 100 W average power and ~3.7 kW peak power. Further benefits relate to its everyday use. While slightly heavier than the TFL, the Tm: YAG laser is lighter than the Ho: YAG laser, relies on air cooling, and operates through a standard power outlet, as it is more energy efficient. Because it can operate in either pulsed or continuous wave mode, its utility for clinical applications is further enhanced.

Limitations

The major limitation of this study is the comparison between a high-power to a low-power laser. Low-power holmium: YAG (Ho: YAG) lasers ($\approx 20\text{--}30$ W) typically operate with pulse energies of 0.2–1 J and pulse durations of 200–800 μs , yielding peak powers of ~0.25–1 kW. In contrast, the pulsed Tm: YAG system delivers up to 2.5 J per pulse at ≤ 300 Hz with 100 W average power and peak power around 3.7 kW. However, the low-power Ho: YAG laser is the standard in laser lithotripsy in most urological departments and therefore represents the appropriate reference for comparison with a novel technology.¹ Although the same laser settings were applied at the beginning of the surgery for both lasers, significant differences were observed, with faster disintegration of the stones when using the Tm: YAG laser.

Further limitations are the single-center design and a relatively small group size. In determining the sample size, we oriented ourselves toward other studies. Nevertheless, we did not calculate a sample size a priori to ensure sufficient statistical power for the analysis. However, to overcome surgeon-related bias, only one endourologist performed all procedures included. While stones of all compositions were included, stone density did not differ between the treatment groups, so this parameter is unlikely to have biased the comparison. A further limitation of this study is that stone volume was not assessed; only two dimensions and the surface area were measured. While we do not believe that using surface area instead of volume has a relevant impact on surgical

technique or operative time, we acknowledge that it is a less accurate parameter compared to volume.

There was a significantly higher proportion of single-stone cases in the Tm: YAG group, which may have contributed to the improved SFR, lower OT and LOT, as such procedures are generally less complex and may therefore have introduced some bias in the results. We used intraoperative endoscopy and postoperative KUB or NCCT at day 1 to define the SFR as described above. Even though the NCCT has a higher sensitivity and specificity than the KUB in this context, it is not part of our clinical standard.^{28,29} Accordingly, only certain clinical circumstances, such as complicated cases or radiolucent stones, lead to the performance of an NCCT to exclude remaining fragments. As an experienced center for PCNL, we have observed frequent misjudgments of remaining stone masses on early NCCT after PCNL, which would lead to unnecessary re-operations. A more meaningful NCCT should therefore be carried out 4–12 weeks after surgery, which, however, does not correspond to our patient-oriented treatment. We believe that any necessary re-operation should be performed during the same hospital stay due to the better quality of life without a nephrostomy tube.

Conclusion

The novel pulsed solid-state Tm: YAG laser showed significant advantages over the Ho: YAG laser in terms of both LOT and OT, while demonstrating comparable results for SFR and complications, making it a promising new player in future laser lithotripsy. With its peak power of up to 1000 W, it may even be the better choice than the TFL for treating harder and larger stones. Additionally, the fact that it offers two operating modes (pulsed and continuous wave) makes it more versatile for both stone treatment and soft tissue applications. More clinical trials are necessary to compare the Tm: YAG laser with the Ho: YAG laser in different settings, as well as to compare the Tm: YAG laser with the TFL, in order to clearly define the advantages of each technology.

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Author Contributions

The authors confirm contribution to the paper as follows: Study conception and design: Benedikt Becker; Revision, Writing: Sophia Hook; Writing, Data collection: Carla Dapper; Writing, Data analysis: Julius Bergmann; Revision: Christopher Netsch; Writing, Draft manuscript preparation: Simon Filmar. All authors reviewed the results and approved the final version of the manuscript.

Availability of Data and Materials

The data that support the findings of this study are available from the corresponding author, Simon Filmar, upon reasonable request.

Ethics Approval

All subjects gave their informed consent for inclusion before they participated in the study. The study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the Ethics Committee (Ethik-Kommission der Ärztekammer Hamburg, Weidestr. 122 b, 22083 Hamburg) (protocol code PV5212).

Conflicts of Interest

Benedikt Becker and Christopher Netsch are consultants for Richard Wolf GmbH. All other 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.

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