Renal stone disintegration with the new Pulsed Thulium:YAG laser: initial results from "Saint John" Hospital, Bucharest

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ABSTRACT

Introduction and Objectives. Holmium:YAG lasers and Thulium:YAG fiber lasers are commonly used for kidney stone lithotripsy, yet limitations persist. The pulsed-Thulium:YAG (Tm:YAG) laser has emerged as a potential solution to these limitations. This study aimed to evaluate the efficacy, safety, and laser settings of the Tm:YAG laser during retrograde intrarenal surgery (RIRS).

Materials and Methods. A prospective study was conducted on 40 initial patients diagnosed with ureteral and renal stones, undergoing RIRS with the Tm:YAG laser system at a single center. Laser fibers of 272 mm were employed, with meticulous documtentation of stone characteristics, laser parameters, and postoperative outcomes including stone-free rate (SFR).

Results. The study cohort comprised 40 patients with a mean age of 58 (range: 30-76) years. Stone volume ranged from 750 to 4600 mm^3 (median: 1810 mm^3), with a mean stone density of 990 Hounsfield Units (HU; range: 570-1200) mean pulse energy, pulse rate, and total power were 0.6 J, 15 Hz, and 9 W, respectively. "Captive Fragmenting" pulse modulation was consistently employed with mean J/mm3 15.0 (range: 7-22), and mean ablation rate 0.75 mm3/s (range: 0.45-2). Three postoperative complications occurred (one streinstrasse and two urinary tract infections), with an SFR of 92%.

Conclusions. The pulsed-Tm:YAG laser demonstrates promising efficacy and safety as a lithotripsy tool in RIRS, offering the advantages of low pulse energy and frequency.

Key-words: Endourology, RIRS, Urolithiasis, LASER

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INTRODUCTION AND OBJECTIVES

Renal calculi, otherwise known as kidney stones, are a prevalent urological disorder that impacts a significant number of people globally. Their occurrence is on the rise and is associated with modifications in diet and lifestyle [1]. Hard deposits accumulate in the kidneys and can lead to intense discomfort, hematuria, and urinary tract infections (UTIs) as they move through the urinary system [2]. Although little stones may pass naturally, bigger calculi generally require medical intervention to avoid negative outcomes such as hydronephrosis, recurring infections, and renal dysfunction [3]. Laser lithotripsy has come to be recognized as a minimally invasive and very efficient therapy method for fragmenting stones and enabling their extraction [4].

The use of laser lithotripsy has significantly transformed the treatment of ureteral and renal stones by providing patients a less intrusive alternative that results in shorter recovery periods and fewer complications as compared with conventional surgery [5]. The Holmium laser has become the recognized benchmark for laser lithotripsy in the past thirty years. This is because it can effectively break down stones of different compositions, ranging from calcium oxalate to cystine stones, by virtue of its high-water absorption and its capacity to produce powerful shock waves upon impact [6]. The laser functions in a pulsed mode and offers a wide spectrum of laser characteristics, such as energy, frequency, and pulse duration, which characterizes it as a versatile instrument in stone therapy [7].

Regardless of its extensive use, there are certain constraints. Despite its efficacy in stone breakup, the Holmium laser is linked to the possibility of collateral tissue damage because of its relatively high pulse energy and extended pulse length [8]. Furthermore, it necessitates the use of bigger laser fibers, which may have less flexibility and restrict its suitability in smaller or more convoluted regions of the renal collecting system [9]. Another disadvantage is the effectiveness of removing tiny pieces by dusting, since certain stones need multiple procedures to get full removal.[10]

New technologies, such as the pulsed-Tm:YAG fiber laser, have been developed to overcome these constraints. In contrast to the Holmium laser, the pulsed-Tm:YAG fiber laser operates in a continuous-wave laser mode, which provides increased flexibility in delivering energy and greater capabilities for stone dusting. This is attributed to its lower pulse energy and higher frequency [11]. The utilization of smaller, more flexible fibers in the pulsed-Tm:YAG fiber laser enhances maneuverability within the urinary tract, particularly in the context of retrograde intrarenal surgery (RIRS) [12]. This advancement has demonstrated considerable potential in clinical environments, but specific constraints, such as the expenses of equipment and the requirement for specialized training, keep impeded on its wide use.[13]

The pulsed-Tm:YAG laser's promising characteristics warrant further exploration of its clinical uses, including in patients with ureteral and renal stones who are having retrograde intrarenal surgery [14]. Currently, there is a shortage of literature outlining the performance of this laser, and there is a lack of detailed clinical assessments regarding its effectiveness, safety, and ideal laser configurations.[15]

The objective of this prospective study was to address this deficiency by assessing the performance of the pulsed-Tm:YAG laser in a clinical environment. More precisely, the study intends to evaluate the effectiveness of this laser in breaking down stones and dusting the stones, as well as its safety record, especially regarding potential problems after surgery such as steinstrasse and urinary tract infections. Moreover, the work aims to enhance laser settings, such as pulse energy, pulse rate, and total power, in order to identify the precise parameters that are most efficient for treating stones in RIRS. Our hypothesis posits that the pulsed-Tm:YAG laser will exhibit enhanced effectiveness in the process of stone ablation, while simultaneously reducing the risk of adverse effects. This presents a compelling alternative to current laser technologies in the management of kidney stones.

MATERIALS AND METHODS

This prospective study was carried out at a single

urology center, with a specific sample size of 40 patients who had been diagnosed with either ureteral or renal stones. The inclusion criteria required that patients must have kidney or ureteral stones proven by imagistically investigations and be eligible for retrograde intrarenal surgery (RIRS). Participants with substantial coexisting medical conditions, contraindications to RIRS, or pregnant women were not included in the study. Informed consent was obtained from all individuals before the procedure.

The patients had retrograde intrarenal surgery (RIRS) utilizing the pulsed-Tm:YAG system, a specialized equipment for laser lithotripsy. The operation was conducted by experienced urologists, with each patient being administered spinal anaesthesia during the surgical intervention. The technique employed flexible ureteroscopes to navigate the urinary tract in order to identify and treat the stones, therefore minimizing invasiveness to the adjacent tissue.

The diameter of the Tm:YAG laser fibers employed in this work was measured to be 272 µm. The selection of fiber size was determined by the potential to achieve a harmonious equilibrium between flexibility in maneuvering difficult anatomical structures and efficiency in delivering energy to facilitate efficient breakup of stones. The laser parameters, including pulse energy, frequency, and power, were meticulously chosen based on the dimensions, specific position, and density of each stone.

Stone Characteristics: Thorough documentation of the characteristics of each stone was carefully documented, including dimensions (mm) volume (mm3), anatomical position (kidney or ureter), and density assessed in Hounsfield units (HU) using computations of CT imaging before surgery.

Laser settings, including pulse energy, pulse rate, and total power, were modified for each patient according to the specific properties of the stone. Furthermore, the Tm:YAG laser's "captive fragmenting" pulse modulation mode was regularly used to control the equilibrium between dusting and fragmentation during the lithotripsy operation.

Intraoperative Data: The overall process time, laser time, and total energy provided were carefully documented during the surgery for record-keeping purposes. Furthermore, the surgeons recorded any technical complications or modifications implemented during the operation to suit intricate anatomical structures or difficult stone positions.
Postoperative outcomes were evaluated primarily based on the stone-free rate (SFR) obtained from non-contrast CT scans four weeks following the surgery. If no fragments greater than 2 mm were visible, a patient was considered to be stone free. The secondary outcomes assessed were intraoperative problems, postoperative complications (such as steinstrasse or urinary tract infections), duration of hospitalization, and the requirement for additional therapeutic measures (e.g., stenting or repeat lithotripsy). Complications occurring after surgery were assessed using the Clavien-Dindo classification system.
The study strictly followed ethical principles, and all data gathering was carried out in accordance with the parameters set by the institutional review board (IRB). Prior to surgery, all patients provided informed consent, ensuring that they were fully aware of the potential risks and benefits associated with the procedure.



Figure 1 – Laser settings

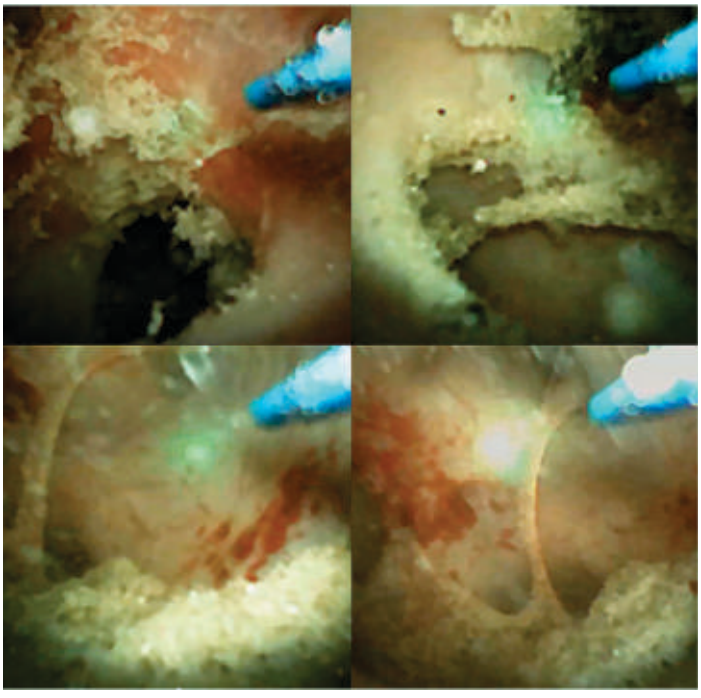


Figure 2 – Intraoperative lithotripsy

RESULTS

The study cohort included a total of 40 patients who underwent retrograde intrarenal surgery (RIRS) with the pulsed-Tm:YAG laser system. The mean age of the patients was 58 years, with an age range spanning from 30 to 76 years. This variation in age reflects the typical demographic affected by ureteral and renal stones, representing a broad spectrum of adult patients with different risk factors and comorbidities.

The stones treated during the study varied considerably in both volume and density. Stone volumes ranged from 750 mm^3 to 4600 mm^3, with a mean stone volume of 1820 mm^3, highlighting the diversity in stone burden among the patients. Stone density, measured using preoperative CT scans, had a mean value of 990 HU, with a range from 570 to 1200 HU. This variation in density, representing differences in stone composition (e.g., calcium oxalate, uric acid), influenced the choice of laser settings and fragmentation techniques used during the procedures.

The pulsed-Tm:YAG laser system was employed using tailored laser settings to optimize stone fragmentation. The mean pulse energy was 0.65 joules (J), with a pulse rate of 15 hertz (Hz), and a total power output of 9 watts (W). These parameters were adjusted intraoperatively based on the characteristics of the stone, allowing for precise energy delivery to achieve effective fragmentation and dusting. The "Captive Fragmenting" pulse modulation mode was consistently employed across all procedures, providing surgeons with enhanced control over energy output, stone relocation and minimizing unnecessary damage to surrounding tissues.

A key metric for evaluating the efficacy of laser lithotripsy is the energy delivered per unit of stone volume, expressed in joules per cubic millimeter (J/mm^3). In this study, the mean energy used per unit volume was 15 J/mm^3, with a range from 7 to 22 J/mm^3, reflecting the variability in stone density and composition. The mean ablation rate, defined as the volume of stone ablated per second (mm^3/s), was 0.75 mm^3/s, with a range from 0.45 to 2.0 mm^3/s. This indicates that the pulsed-Tm laser system was able to achieve rapid and efficient stone ablation, even for larger and denser stones.

The stone-free rate (SFR), defined as the absence of residual stone fragments larger than 2 mm on postoperative imaging, was 92% in this cohort. This high SFR demonstrates the effectiveness of the pulsed-Tm:YAG laser in achieving complete stone clearance in the majority of patients. Despite the overall success, three patients experienced postoperative complications. One patient developed steinstrasse and two other patients developed postoperative urinary tract infections (UTIs), which were managed with antibiotics. These complications were classified as mild to moderate and did not require additional surgical intervention.

No severe complications such as ureteral perforation, bleeding requiring transfusion, or sepsis were observed. The laser system's ability to provide precise control of energy delivery likely contributed to the low complication rate. Hospital stays were typically short, with most patients discharged within 24 to 48 hours postoperatively. The minimal invasiveness of the procedure and the precision of the laser in targeting stones without causing significant collateral damage were key factors contributing to the rapid recovery observed in most patients.

Parameter	Mean / Range
Number of Patients	40
Age (years)	58 (30-76)
Stone Volume (mm^3)	1820 (750-4600)
Stone Density (HU)	990 (570-1200)
Pulse Energy (J)	0.65
Pulse Rate (Hz)	15
Total Power (W)	9
Energy per Stone Volume (J/mm^3)	15.0 (7-22)
Ablation Rate (mm^3/s)	0.75 (0.45-2.0)
Stone-Free Rate (SFR)	92%
Postoperative Complications	3 (1 Clavien III, 2 Clavien II)
Hospital Stay	24-48 hours

DISCUSSIONS

Building upon the technological advancements of the Thulium fiber laser, the pulsed-Tm:YAG laser represents a new frontier in laser lithotripsy. Unlike its predecessors, this laser offers both pulsed and continuous-wave modes, providing flexibility in stone treatment, particularly in terms of stone dusting and fragmentation. Pulsed-Tm lasers emit light at a wavelength of approximately 1.9 microns, similar to the Holmium laser, but with the added benefit of a shorter pulse duration, lower pulse energy, and a higher pulse frequency.

These attributes allow for more precise control of the laser energy, minimizing thermal damage to surrounding tissues while optimizing stone fragmentation and dusting efficiency. This laser system's smaller fiber diameters improve flexibility and facilitate access to challenging anatomic regions of the kidney, enhancing its utility in RIRS. Preclinical studies and early clinical trials suggest that the pulsed-Tm laser may offer significant advantages in terms of procedural efficacy, safety, and patient outcomes compared to the current gold standard Holmium laser. Notably, the "captive fragmenting" mode, a unique pulse modulation feature of the pulsed-Tm laser, allows for enhanced energy control and ablation rates, potentially reducing procedure time and improving stone-free rates (SFR) in patients undergoing lithotripsy.

The results of this study demonstrate the promising efficacy and safety of the pulsed-Tm laser in treating ureteral and renal stones via RIRS. The high SFR, combined with a low rate of postoperative complications, suggests that this laser system is a viable alternative to the current gold standard, the Holmium laser. The ability to precisely modulate energy, along with the high ablation rate, positions the pulsed-Tm laser as a highly efficient tool for stone dusting and fragmentation.

The findings of our study confirm previous studies about the efficacy of laser lithotripsy in the treatment of ureteral and renal calculi, particularly in the context of retrograde intrarenal surgery (RIRS). The stone-free rate (SFR) of 92% achieved in our cohort closely corresponds with findings from studies assessing the effectiveness of Holmium and Thulium fiber lasers in lithotripsy. A comparative research observed similar high stone fragmentation rates when assessing Holmium laser against Thulium fiber laser in laser lithotripsy [16].

Furthermore, the utilization of pulsed-Tm:YAG laser technology in our research has demonstrated advantages, including its precise energy regulation capabilities using the "Captive Fragmenting" pulse modulation mode. This is particularly beneficial for managing stones of varying densities, as seen by the range of stone densities (570-1200 HU) reported in our patients. Previous research has highlighted the benefits of pulsed-Tm:YAG fiber lasers, which offer diminished pulse energy and shorter pulse durations, hence reducing collateral tissue damage compared to the higher pulse energies typically associated with Holmium lasers [16].

The impact of stone composition on laser lithotripsy results was a crucial factor in our research, especially for calcium oxalate or uric acid stones. Consistent with prior research, the pulsed-Tm:YAG laser system employed in our cohort exhibited enhanced precision in energy delivery across diverse stone densities, hence augmenting its efficacy in fragmenting denser stones. Preclinical investigations have corroborated these findings, indicating that Thulium lasers may surpass Holmium lasers in some instances, particularly in dusting modes for the treatment of more resilient stone forms such calcium oxalate monohydrate [17].

Our results further confirm that the pulsed-Tm:YAG fiber laser's precise energy delivery is especially beneficial in treating stones with higher densities, similar to the findings in Abdelrahim's multi-institutional study, which reported better outcomes for Thulium lasers when applied to more resistant stone compositions like calcium oxalate [18].

The enhanced maneuverability of the pulsed-Tm:YAG fiber laser, due to its smaller and more flexible fibers, significantly improves access within the renal collecting system, particularly in anatomically challenging regions such as smaller calyces. This advantage was evident in our study, where the pulsed Tm:YAG system facilitated complete stone removal in these difficult-to-reach areas, consistent with the findings from prior research. Studies, such as the one by Mues et al., have demonstrated that the Thulium fiber laser allows for both high ablation rates and precise energy delivery, making it particularly suited for retrograde intrarenal surgery (RIRS). Our observed median ablation rate of 0.75 mm^3/s corroborates earlier studies that have highlighted the pulsed Tm:YAG fiber laser's superior ability to maintain both efficiency and precision. These findings further support the role of pulsed-Tm:YAG fiber laser as an optimal tool for complex lithotripsy procedures, particularly in cases where flexibility and high ablation efficiency are required [19].

Postoperative complications in our study were minimal, with only three patients experiencing mild to moderate issues, including steinstrasse and urinary tract infections (UTIs). This low complication rate aligns with results from existing studies that have consistently demonstrated the safety and efficacy of laser lithotripsy, particularly with the use of pulsed-Tm:YAG fiber lasers, which are known for their precise energy delivery and reduced thermal damage to surrounding tissues. Specifically, Arietti et al. highlighted the importance of the Thulium laser's precision in minimizing postoperative complications such as tissue injury, which was reflected in our findings. The ability of the Thulium laser to limit collateral damage likely contributed to the favorable safety profile observed in this study.These results further validate the safety and minimal complication rate associated with the use of pulsed-Tm:YAG fiber lasers in treating ureteral and renal stones [20].

CONCLUSIONS

The pulsed-Tm:YAG laser presents a significant advancement in the field of laser lithotripsy, offering benefits in terms of safety, flexibility, and stone ablation efficiency. With further research, this technology has the potential to become the new gold standard in the treatment of ureteral and renal stones, providing improved outcomes for a wide range of patients.

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