Original Article

Holmium: Yttrium–aluminum–garnet laser lithotripsy: Is there a difference in ablation rates between short and long pulse duration?

Panteleimon Ntasiotis[1], Angelis Peteinaris[1], Marco Lattarulo[1,2], Arman Tsaturyan[1], Mehmet Kazim Asutay[3], Constantinos Adamou[1], Athanasios Vagionis[1], Konstantinos Pagonis[1], Georgia Koukiou[4], Abdulrahman Al-Aown[5], Evangelos Liatsikos[1,6], Panagiotis Kallidonis[1]

[1]Department of Urology, University of Patras, Patras, Greece, [2]Department of Urology, Santissima Annunziata Hospital, University of Bari, Bari, Italy, [3]Department of Urology, Tarsus Public Hospital, Tarsus, Mersin, Turkey, [4]Department of Physics, Electronics Laboratory, University of Patras, Patras, Greece, [5]Department of Urology, Armed Forces Hospital Southern Region, Khamis Mushait, Kingdom of Saudi Arabia, [6]Department of Urology, Medical University of Vienna, Vienna, Austria

Abstract

Introduction: The high-power holmium: yttrium–aluminum–garnet lasers provide a wide variety of settings for stone disintegration. The aim of this *in vitro* study is to evaluate the effect of short and long pulse duration on ablation rates on urinary stones.

Materials and Methods: Two types of artificial stones were created by BegoStone™ with different compositions (15:3 and 15:6, stone/water ratio). Stones with a 15:3 and 15:6 powder-to-water ratio were defined as hard and soft stones, respectively. Lithotripsy was performed with different laser settings using a custom-made *in vitro* model consisting of a 60 cm long and 19 mm diameter tube. The ablation rate is defined as the final total mass subtracted from the initial total mass and divided to the time of treatment. Stone ablation rates were measured according to different laser settings with total power of 10W (0,5J-20 Hz, 1J-10 Hz, 2J-5 Hz) and 60W (1J-60 Hz, 1,5J-40 Hz, 2J-30 Hz).

Results: Higher pulse rates and higher total power settings were related to higher ablation rates. Short pulse duration was more effective on soft stones, whereas long pulse duration was more effective on hard stones. For the same power settings, the highest energy–lowest frequency combination resulted in higher ablation rate in comparison to the lowest energy–higher frequency combination. Finally, short and long pulse average ablation rates do not differ so much.

Conclusion: Regardless of the stone type and pulse duration, utilization of higher power settings with higher energies increased the ablation rates. Higher ablation rates were demonstrated for hard stones using long pulse duration, and for soft stones with short pulse duration.

Keywords: Ablation rate, artificial stones, high power laser, holmium: yttrium–aluminum–garnet laser lithotripsy, pulse duration

Address for correspondence: Dr. Abdulrahman Al-Aown, Department of Urology, Armed Forces Hospital Southern Region, Khamis Mushait, Kingdom of Saudi Arabia.
E-mail: aown22@hotmail.com

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INTRODUCTION

Laser lithotripsy is a widely used and effective method for the treatment of urinary stones for over 20 years.[1] It is a preferred method due to its safety and efficacy.[2] The stone-free rate of laser lithotripsy with the addition of the new technologies is comparable even to laparoscopic ureterolithotomy.[3] The advancing field of laser lithotripsy could dominate the treatment of lithiasis as there are many newly introduced high-power laser devices that offer the opportunity of pulse modulation, decrease retropulsion, and increase the ablation rate. As a result, a wide variety of potential combinations of frequency and energy settings with numerous lasering features can be offered. However, there is no consensus about the most efficient settings of laser lithotripter.[4-6] Apart from laser frequency and energy, the change in pulse length can also affect the lithotripsy effectiveness. Updated recommendations should be presented following studies that evaluate properly the newly introduced laser devices. "Best laser setting" can be defined as the setting with the highest ablation rate with the lowest retropulsion and minimum stone dust diameter. The aim of this study is to present the influence of short and long pulse duration on stone ablation rates using a specifically designed *in vitro* lithotripsy model.

MATERIALS AND METHODS

Experimental configuration

A clear polyvinyl chloride tube 60 cm long and 19 mm diameter was used. The tube was attached to a solid wooden box with a 20° inclination to the floor to let the bubbles go out easily from the system. The tube with the wooden box was placed inside a bath filled with saline solution. The laser fiber was inserted and stabilized through the lumen of a 22Fr Amplatz Renal Dilator (Cook Medical, Bloomington, IN) [Figure 1].

A 6 Fr ureteral catheter was inserted and gravity irrigation was attached to the ureteral catheter to allow continuous flow of the fluid during the experiment. For each experiment, the artificial stone was placed at the end of the tube and treated with a specific laser setting. The stone was not stabilized but was in contact with the laser fiber. The Lumenis P120 (Moses Pulse, Lumenis Ltd. Israel), a 120W holmium:yttrium–aluminum–garnet laser) with its 365 μm fiber (inserted through the amplatz dilator inside an 8Fr ureteral catheter) was used by a single expert urologist. The total energy of 3KJ was applied in each stone. Different settings were used with total power levels of 10W, and 60W. The used energies were 0.5, 1, 1.5 and 2J and the used frequencies of 5, 10, 20, 40, and 60 Hz. The settings used were non-Moses, contact with single short and long pulse duration. There were 24 different combinations that were tested in this experimental study. BegoStone Plus (Bremen, Germany) artificial stones (7 mm, 400 mg) with two different ratios of 15:3 or 15:6 powder to water were used. They were defined as either hard or soft stones, respectively, according to their stone–water composition. Each stone was soaked at least 1 h at room temperature before the treatment, based on previous experimental data.[7] Each trial was completed three times and the average was calculated and presented. No further statistical analysis was necessary.

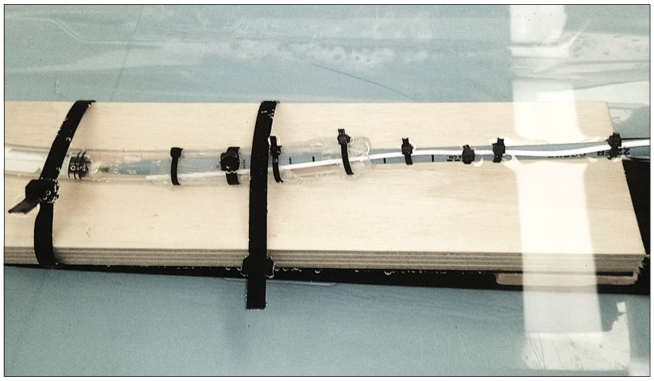
Figure 1: *In vitro* experimental setting

Ablation rate measurements

After the experiment trials, the generated fragments were collected and left to dry for 3 days and then weighted. The final total mass was subtracted from the initial total mass and divided by the time of treatment. The outcome was defined as the ablation rate (mg/s).

Quality analysis of the fragment production.

The stone fragments were collected with the use of three metal sieves, one on top of another. The sieves' hole diameter was 3, 4, and 7 mm from the top to the bottom. The collected fragments were photographed for qualitative analysis of the images. These images [Figure 2] were processed and analyzed using MATLAB routines developed in the Electronics Laboratory, Physics Department, University of Patras. The region of interest (ROI) was firstly isolated and then preprocessed.

For preprocessing, an adaptive thresholding was carried out to isolate the pieces of the stones. The background pixels were set to zero (black). Morphological operations were used to smooth the boundaries of the pieces and eliminate small holes which appeared during thresholding due to noise interference. In addition, the elimination of very small objects (background artifacts) with sizes less

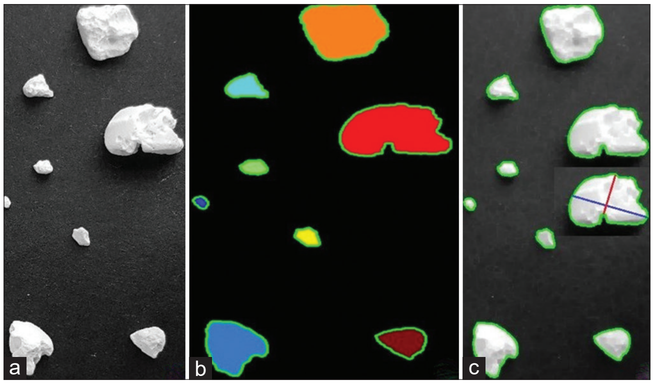

Figure 2: (a) The region of interest, (b) Pseudocoloring according to stone sizes, and (c) Estimated geometrical features. Green lines correspond to the boundaries and consequently the perimeter. Blue line: Major axis length, Red line: Minor axis length

than specific dimensions was performed. The analysis of the ROI included labeling of the pieces of stones according to their area. For monitoring purposes, the pieces were colored according to their sizes (pseudocoloring). Finally, in the analysis procedure, various geometrical features of each piece of the artificial stone were evaluated such as area, perimeter, major axis length, and minor axis length.

To obtain high-quality images, a resolution of 42.5 pixels/mm was considered. Objects smaller than 0.1 mm or 4 pixels were eliminated using morphological processing and defined as background artifacts (noise).

RESULTS

In general, short pulse duration was related to higher ablation rates on soft stones, whereas long pulse duration had a higher ablation rate on hard stones. For the same power settings, the highest energy setting (lowest frequency) resulted in higher ablation rate in comparison to the lower energy (higher frequency) settings.

Higher stone ablation rates were achieved with higher power energy settings and with higher pulse rates. Stone ablation rates seem to have a positive correlation with both total power and pulse rates. The results of stone ablation rates with different settings are fully presented in Figure 3.

When the total power energy was 10W, there was no difference between short versus long pulse duration. This trend was viable on both hard and soft stones. The ablation rates with long pulse duration were higher than the short pulse duration for hard stones at 60W [Figure 3].

There was no clear difference between short versus long pulse duration according to the weight of the ablated stone. The average ablation rate for short pulse for both soft and hard stones was 2.13 and for long pulse 2.26.

DISCUSSION

The majority of studies about optimal laser settings evaluated laser frequency and energy.[8] With new and improved laser devices, additional factors such as pulse duration, laser fiber diameter, and type of stone should be considered to achieve effective outcomes. In the current study, a 365 mm fiber was used. To investigate the influence of different laser settings on ablation rates, not only different combinations of energy and frequency and short or long pulse were used but also soft and hard stones were created and analyzed for this experiment.

In this experimental study, it was demonstrated that short pulse duration was related to higher ablation rates on soft stones. This could be partially explained by the experimental study of Jansen *et al*.[9] The authors of this experimental study observed that the pulse duration was inversely proportional to the magnitude of the collapse pressure wave of the bubble generated by the laser activation. In addition, King *et al*. demonstrated that pressure transients for 1J using non-Moses short pulse could reach 62 bars, calculated at 1 mm from the fiber tip.[10] These data explain the results of short pulse regarding soft stones ablation rates.

Several previous studies have investigated the effect of pulse duration on lithotripsy. The *in vitro* experiment by De Coninck *et al*. investigating the distance between the laser fiber and the stone on ablation volume showed that long pulse duration was more effective in hard stones with no contact to the stone.[11] In our study, laser fiber was fired with a direct contact to the stone. The reported higher ablation rates with long pulse duration were similar to our results. As a difference from our study, the authors utilized only hard stones, so no comparison was available on soft stones. Similarly, in our study, the effect of longer pulse duration was more pronounced at higher power settings.

Longer pulse duration was also related to higher ablation rates when power settings were simultaneously increased in a study by Eisel *et al*.[4] Apparently, different stone ablation rates can be expected when using different lasering modes. In the study by Emiliani *et al*., optimal settings for the popcorn lithotripsy technique were questioned.[5] The longer pulse duration had better ablation rates with popcorn technique. The authors also stated using only one type of artificial stones, only hard stones were investigated. In contrast, Chawla *et al*. demonstrated better ablation rates using the popcorn technique when using 1.5J energy and high frequency (40 Hz).[12]

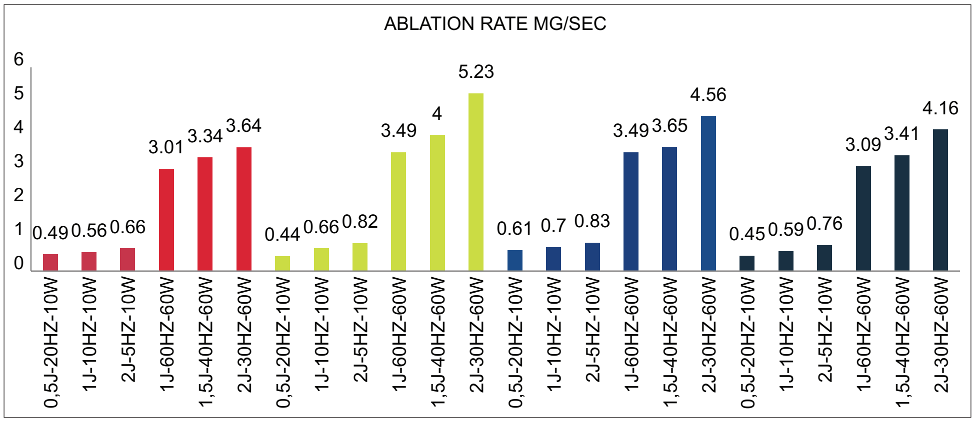

Figure 3: Ablation rate of stones – The red and yellow columns represent the results of hard stones treated with short and long pulse duration, respectively. Blue and black columns show the results of soft stones treated with short and long pulse duration, respectively

It should be noted that our results were in line with the repotted trends. Increasing the power resulted in higher ablation rates regardless of the stone type and pulse energy. Moreover, increasing the energy had more positive effect than the frequency. In general, the energy setting of 2J was better than 1J and both were superior to 0.5J. This was true for hard and soft stones using long and short pulses.

Pulse duration may be associated with other important characteristics of stone lithotripsy. In particular, longer pulse duration was reported to cause less laser tip degradation.[6,13] In addition to the effects on the laser tip degradation, pulse duration can potentially impact stone retropulsion. Especially for proximal ureteral stones, significant retropulsion may result in pronounced stone displacement of the stone in the collecting system and require the usage of flexible instruments.[14] Long pulse was related to a decrease of ablation rates and retropulsion. Less ablation rates may be caused by more retropulsion rates or due to the type of stone that was used.[15]

Our study was associated with several limitations. The applied *in vitro* experimental design limits the translation of the findings in clinical practice. Nevertheless, a clinical assessment of different laser parameters is not feasible before pretesting as they may carry potential harm for the patients. Another criticism can be the investigation of stone ablation rates without the evaluation of Moses technology. Since our study included a closed system, it was not possible to observe the influence of different settings on stone retropulsion. Thus, we feel that this concern is not significant for our study. Finally, our experiment was completed using only a 365 μm fiber. Although previously published findings indicated that surgery time can be shorter with the use of 550 μm fibers, no differences in stone ablation rates were reported. Contrarily, the use of thinner-diameter laser fibers was related to better fragmentation rates in another study by Kronenberg and Traxer.[16] Based on the latter findings and also on our clinical practice, 365 μm fiber was selected for investigations in the current study.

None withstanding all limitations, we believe that this experimental study expands the preclinical evidence for urologists and provides essential information for decision-making on the use of short and long pulses.

CONCLUSION

We found that regardless of the stone type and pulse duration, utilization of higher power settings with higher energies increased the ablation rates. Higher ablation rates were demonstrated with hard stones using long pulse duration, and for soft stones with short pulse duration.

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Conflicts of interest
There are no conflicts of interest.

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