ISSN: 2469-5742

Solakhan. Int Arch Urol Complic 2019, 5:061
DOI: 10.23937/2469-5742/1510061
Volume 5 | Issue 2
Open Access

International Archives of
Urology and Complications

RESEARCH ARTICLE

Holmium Laser Lithotripsy: In-Vitro Investigation of Optimum Power Settings in Fragmentation, Dusting and Propulsion and Stone Breaking Times

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Abstract

Background: In this study, we aimed to determine the appropriate energy-frequency settings in fragmentation, dusting and propulsion during stone crushing with holmium-YAG laser.

Materials and methods: An experimental urinary system model was created. Stones previously taken during the operation were used for the procedure. For this purpose, stones with Ca-oxalate and Ca-phosphate were used. Kidney and ureter model was prepared under laboratory conditions. Irrigation catheter with a lumen of 15 mm was used for the ureter model. 9F rigid ureterorenoscope (Storz/Germany) was used to reach the stone. DORNIER MEDILAS H SOLVO/30 W-Germany laser was used for stone crushing. 275 and 550 microfibers were used for stone crushing as laser fiber. Eight different stone crushing settings were determined and tested (0.2 J-2 J/5-20 Hz). In each adjustment, stone crushing was applied until the 0.5 cm stone was completely broken. It was tested how far the stone was pushed according to the laser power applied, especially during stone crushing. For both the kidney and the ureter, the optimum power value (J/Hz) and the breaking time of the stone were tested according to the desired fragmentation model of the stone.

Results: With or without stabilization, low energy-low or high frequency settings resulted in an increase in total fragmentation and dusting time ($p = 0.001$). At high energy, the stone breaking time was significantly lower than the time at low energy. Fragmentation of stone was achieved in less time in all frequency settings with stabilization ($p < 0.0001$). No significant difference was found in stone crushing settings made with different fiber diameters ($p = 0.659$). No significant difference was determined between stone breaking settings made with different fiber diameters and stone displacement distances. The lowest fragment size was at low energy low-high frequency settings (0.2 J-20 Hz). As the amount of energy increased, the length of the fragmented fragments of the stone increased. Additionally, at low energy-low or high frequency settings, the stone propulsion rate was the least ($P < 0.0001$).

Conclusion: If we want dusting the stone, we need to use low energy high frequency settings, and if we want to break up the small fragments, we need to use high energy low frequency settings. The operation time is prolonged when low energy is used.

Keywords

Ho:yag laser, Stone fragmentation, Dusting, Breaking time, Experimental study

Abbreviations

Ho: YAG: Holmium: Yttrium - Aluminum Garnet; PE: Pulse Energy; HiFr: High Frequency; URS: Ureterorenoscopy

Introduction

Especially in our country (Turkey), surgical operations are done quite a lot because of the high prevalence of stone. With the advancement of technology, many different treatment alternatives are brought to the agenda and a different endoscopic instrument is introduced each year. While flexible ureteroscope is used for kidney stones, holmium: yttrium - aluminum garnet (Ho: YAG) laser is generally used with it [1]. The Ho: YAG laser is widely used for this application because of its

Citation: Solakhan M (2019) Holmium Laser Lithotripsy: In-Vitro Investigation of Optimum Power Settings in Fragmentation, Dusting and Propulsion and Stone Breaking Times. Int Arch Urol Complic 5:061. doi.org/10.23937/2469-5742/1510061

Accepted: October 12, 2019: **Published:** October 14, 2019

high absorption coefficient at the corresponding wave length. In this way, it provides thermo-mechanical ablation on the stone surface and provides photo thermal fragmentation with the expansion of the water in the urinary stones [2]. One of the most important issues in the Ho: YAG-laser research is to facilitate urinary excretion of fragments and allowing the average stone fragment size to be reduced to increase treatment success. This process is called 'stone dusting'. With the change in laser settings (pulse energy, pulse duration, repetition rate), stone fragmentation, stone crushing time and stone propulsion distance are significantly affected. Different experimental systems have been used to compare different laser systems and laser parameters [3-5]. Such installations are generally used to measure the fragmentation rate and dusting efficiency of the stone. Migration to the kidney occurs in the stones in the ureter with both the introduction of the endoscope and the effect of laser power. This leads to a longer treatment period in the patient. Both the fragmentation and the propulsion rates of the stone are greatly influenced by the selected laser parameters [5]. The stone breaks down better at high energy and low frequency, but the migration is greater in this application at lower energy and higher frequency, stone migration is less and fragmentation occurs as dusting [4].

The main objective of our study was to determine the most effective power settings on the rate of fragmentation, dusting and propulsion and stone breaking times using an experimental laser system.

Method

An experimental urinary system model was created. Stones previously taken during the operation were used for the procedure. For this purpose, stones with Ca-oxalate and Ca-phosphate were used. Kidney and ureter model was prepared under laboratory conditions (Figure 1A, Figure 1B, Figure 1C and Figure 1D). Two separate experimental setups were used. In the first one, the fragmentation and dusting parameters of the stone were evaluated and in the other arrangement the propulsion distances of the stone were evaluated. Irrigation catheter with a lumen of 15 mm was used for the ureter model. 9 F rigid ureterorenoscope (Storz/Germany) was used to reach the stone. DORNIER MEDILAS H SOLVO/30 W-Germany laser was used for stone fragmentation. 275 and 550 microfibers were used for stone crushing as laser fiber. Eight different stone crush-

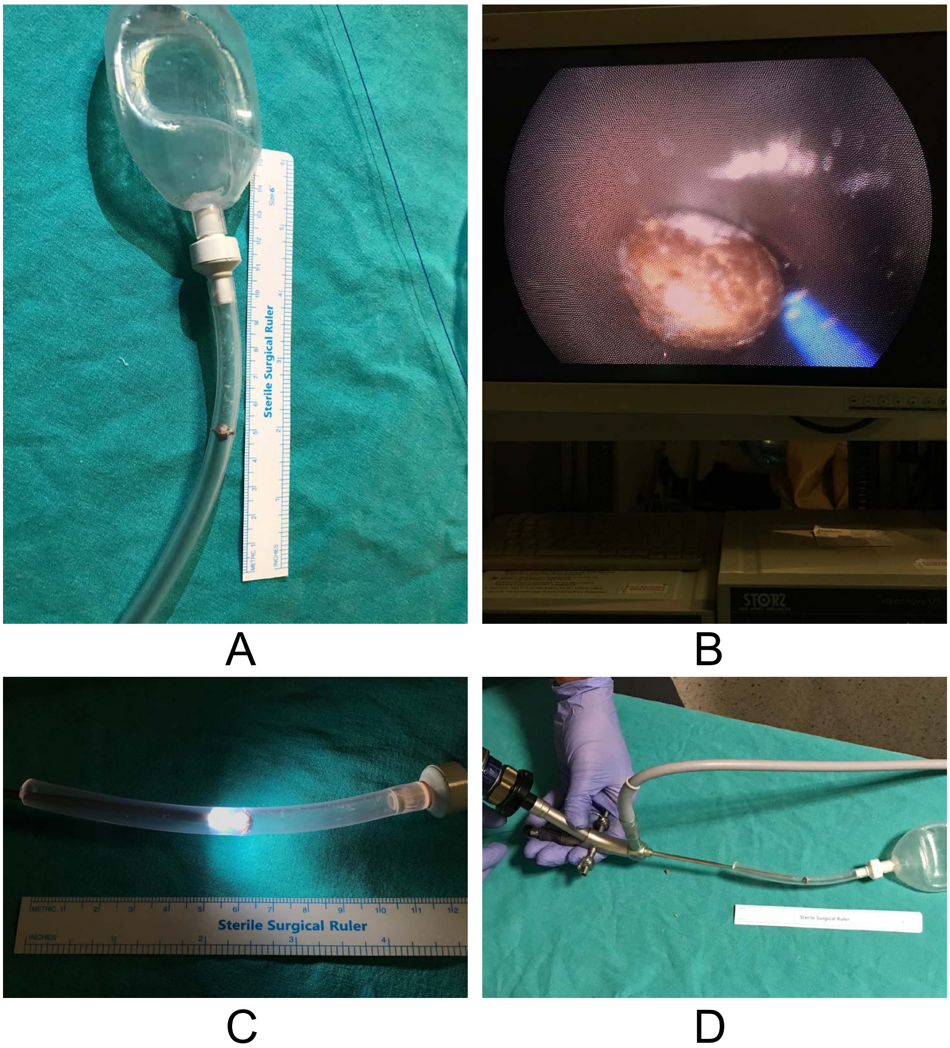

Figure 1: A-D) Images of the process.

ing settings were determined and tested (0.2 J-2 J/5-20 Hz). In each adjustment, stone crushing was applied until the 0.5 cm stone was completely broken. Saline was used for image clarity during the procedure (100 ml/min). It was tested how far the stone was pushed according to the laser power applied, especially during stone crushing. For both the kidney and the ureter, the optimum power value (J/Hz) and the fragmentation time of the stone were tested according to the desired fragmentation model of the stone.

Results

With or without stabilization, low energy-low or high frequency settings caused increase in total fragmentation and dusting time (p = 0.001). At high energy, the stone breaking time was significantly lower than the time at low energy (Table 1). Stone breaking was achieved in less time in all frequency settings with stabilization (p < 0.0001). There were no significant differences in stone breaking times in stone breaking settings with different fiber diameters (p = 0.659). No significant difference was detected between stone breaking settings made with different fiber diameters and stone propulsion distances (Table 1). The lowest fragment size was at low energy high frequency settings (0.2 J-20 Hz). As the amount of energy increased, the length of the fragmented fragments of the stone increased. Stone propulsion rate was found to be the least at low energy-low or high frequency settings (p < 0.0001). It was observed that the propulsion did not change when the laser energy was kept constant and the frequency was increased, but increased when the energy settings were kept constant. The particle size was observed to be less than 1 mm in all experiments at a pulse energy of 0.2 J.

Discussion

With this study, the most appropriate settings of dusting, fragmentation and propulsion during stone crushing were determined. The optimal setting for propulsion and dusting was 0.6 J 20 Hz, and for fragmentation 2 J 10 Hz. The difference of our study from other studies in the literature; the use of real kidney stones in the process and the time taken for the stone crushing process measured at exactly different settings.

URS with holmium laser allows surgeons to use a variety of strategies to treat ureteral and kidney stones. There are two most commonly used techniques in this field: first, fragmentation using low frequencies and high pulse energy (PE) to break stones into small pieces, the other is dusting. This is then done using high frequency (HiFr) and low PE to form fine dust particles that pass through the ureter spontaneously [6]. To set the dusting parameters, the frequency and PE can be changed. PE and frequency multiplication indicate total performance in watts. Frequencies between 10 and 40 MHz are used in conventional (low PE) dusting settings. Dusting with a frequency of at least 40 Hz (usually low PE around 0.2-0.5 J used) is called HiFr dusting. In fragmentation settings higher PE around 0.6 to 2.0 J and lower Fr around 6 to 10 Hz is used [7]. HiFr stone crushing, known as dusting has become an accepted method in the treatment of urolithiasis with flexible URS. Dauw, et al. It has been shown that approximately 67% of urologists use this technique as the gold standard for the treatment of kidney stones [8]. It has also been shown that Low-Fr results in a rate of decomposition six times higher than High PE and High-Fr Low PE [4].

Table 1: Results of the experiment.

	0.2 J 5 Hz	0.2 J 20 Hz	0.6 J 5 Hz	0.6 J 20 Hz	1 J 20 Hz	1 J 5 Hz	2 J 20 Hz	2 J 5 Hz	P 15 Hz
Dusting time (sec)									
No device									
275	1120	1026	940	910	815	798	605	578	0.03
550	1105	998	882	869	745	712	583	545	0.012
Stone cone									
275	1010	966	880	855	740	700	468	426	0.023
550	998	920	845	812	702	662	422	402	0.042
Fragmentation time (sec)									
No device									
275	920	910	880	850	720	690	420	415	0.014
550	870	845	822	780	705	642	400	398	0.025
Stone cone									
275	810	785	760	720	660	622	282	275	0.001
550	798	460	732	697	640	600	278	270	0.001
Propulsion (cm)									
275	0.9	1.0	1.2	1.4	2.4	2.3	3.1	3.4	< 0.001
550	1.0	1.1	1.4	1.6	2.6	2.5	3.4	3.5	0.001

The biggest limitation of the use of holmium laser in the treatment of urolithiasis is that the stone is pushed towards the kidney. It is known that these settings have an effect on the propulsion distance that occurs at different frequency and energy settings. Therefore, it is desirable for every urologist to limit propulsion as much as possible, especially when working in the ureter. White, et al. have shown that lower PE leads to significantly less propulsion and smaller fragmentation of the stone [9]. In addition, Li, et al. have made a study about propulsion effect on the different settings. In this study, they showed that retropulsive force was not affected when the frequency was increased from 15 HZ to 50 Hz [10]. In our study, it was observed that propulsion was minimal at low energy settings and propulsion increased as the energy value increased (Table 1). Changing the frequency settings did not change the propulsion in our study at the same power setting.

In the studies, different stone crushing results with different fiber diameters are given. In one study, it was observed that large and small diameter laser fibers differed at the smallest energy level tested. Large fiber at 0.2 J was seen less effective. This may depend on the energy distribution. Since the tip of the large laser fiber has a much larger contact area (7.5 times larger) than the small fiber, it is stated that can cause it because the amount of energy given at 0.2 J does not exceed the ablation threshold [4]. In our study, it was found that different fiber diameters did not change the dusting, fragmentation and propulsion properties of the stone. In this study, unlike the others, we evaluated the frequency and power settings and the time of stone breakage and dusting.

Treatment time is an important parameter for most surgeons. The short operating time makes a significant contribution to the overall treatment cost, and reducing treatment time has positive effects for patients and health care institutions. Moreover, shorter operative time reduces the rate of peroperative and postoperative complications [11]. In this respect, our study is different from other studies. Because we measured the total time for full fragmentation in the experimental model using various pulse energy and frequency settings with 8 different laser settings (Table 1).

In addition to this, a ruler was used to measure the distance of the propulsion that occurred during the time required to completely shred the stone. This method is consistent with the methods used by others in *in vitro* stone propulsion studies.

There are of course some limitations of our study. Although the *in vitro* environment does not fully reflect the conditions during live surgery, it allows us to control a variety of variables that would not be possible in clinical trials. With *in vitro* settings; factors such as stone size, treatment environment and fragmentation measurements can be standardized. However, in clinical use, a performance similar to simulation in the *in vitro* setting may not always be observed. Treatment times may not reflect actual treatment times in the clinical setting.

Conclusion

If we want dusting the stone, we need to use low energy high frequency settings, and if we want to break up the small fragments, we need to use high energy low frequency settings. The operation time is prolonged when low energy is used.

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