

Laser Lithotripsy For the Controlled Coarse Fracture of Urinary Tract Stones

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ABSTRACT

Development of novel methods for controlled coarse fragmentation of urinary tract stones may help to minimise the risk of urinary tract infection and prevent the small stone fragments, responsible for residual stone formation, from entering into the calyxcalcification system of a kidney. The experimental results demonstrated that the following parameters of a pulsed laser operating at the 2097 nm (or the 1967 nm) wavelength were optimal for a controlled fractioning of the stones in air: the pulse duration of 20-30 ns, the repetition rate of 200-1000 Hz (or more), and pulse energy of 45-55 mJ. The relatively small pulse energy coupled with the high repetition rate enabled the destruction of concrements into fragments small enough to be removed with the amplatz.

Keywords: Lithotripsy; Urolithiasis; Lasers.

INTRODUCTION

Decades of endoscopic surgery of urolithiasis using fine fragmentation of stones have revealed its deficiencies, one of which is the complication of contact laser lithotripsy - the development of an infectious inflammatory process in kidneys due to bacterial dissemination of flora from stone biofilms [1]. Importantly, even in the case of sterile urine, some microorganisms were found in the urinary tract stones in 25% to 41% of all cases according to published reports [2,3]. The problem of the development of complications in the endoscopic treatment of urolithiasis, coupled with increased antibiotic resistance, is becoming more urgent. The search for new methods for controlled coarse fragmentation of stones will minimize the risk of possible infection and help to prevent the loss of small fragments of stones in the calyxcalcification system of a kidney, which were found to be responsible for residual stone formation.

Purpose

Search for the regime of laser lithotripsy that will ensure effective fragmentation of the urinary calculi and at the same time avoid their uncontrolled finely fragmented fracture.

MATERIALS AND METHODS

The effect of a laser crushing of 25 urinary tract stones *ex vivo* was studied. The used stones are crushed after nephrolitho extraction and pyelolithotomy, nephrectomy. In the experiment, only undistracted (entirely extracted) stones were examined, which were placed in physiological saline until the moment of the laser action. A Ho³⁺:YAG laser pumped by a Tm³⁺ fiber laser was used in the first experiments. The Ho³⁺:YAG laser operated in a pulsed regime at the 2097 nm wavelength and the 20-40 ns pulse duration. The Ho³⁺:YAG pulse repetition rate was varied from 0.2 to 40 kHz, while the pulse energy changed within 0.5-55 mJ at the average output power of up to 35 W. In the second experiments, another pump laser based on Tm³⁺-doped Lu₂O₃ ceramic at 1967 nm wavelength was in turn pumped by a Raman-shifted Er³⁺ fiber laser at the 1670 nm wavelength. The pulsed Tm³⁺:Lu₂O₃ laser had a pulse duration of 30-40 ns and the pulse frequency of 14-25 kHz. It operated with the average output power from 100 mW to 10 W. Both Ho³⁺:YAG and Tm³⁺:Lu₂O₃ lasers were manufactured at the IAPRAS (Nizhny Novgorod) [4,5]. The efficiency of the laser stone interaction was estimated by measuring the time required for stone perforation. The created stone channel was inspected visually and by using transmitted light microscopy (Figure 1).

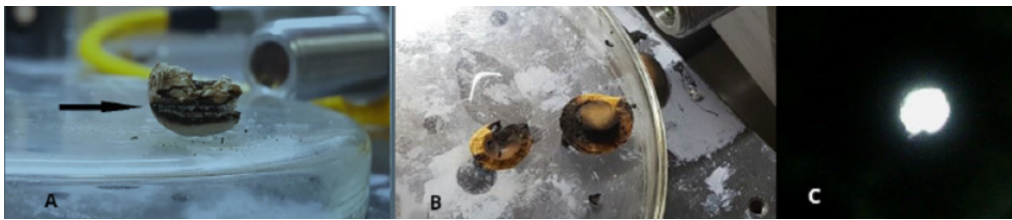


Figure 1: Results of Ho³⁺:YAG laser irradiation of the urinary tract stones; A - stone fracturing along the fault line (indicated by an arrow); B - fragments of a stone; C – examination of the perforated stones using transmitted light microscopy (10× lens, 10× eyepiece).

TECHNIQUE OF THE EXPERIMENT

The stones were removed from the normal saline (0.9% NaCl) and placed on an optical table. The Ho³⁺:YAG laser beam (or the Tm³⁺:Lu₂O₃ laser beam) was focused into the stone using lenses with the effective focal length from 21 mm to 200 mm (the estimated laser beam diameter on a stone changed from 0.1 to 1 mm, measured at the e-2 intensity level). The time required for complete stone perforation or stone fracturing along the fault line was measured. The inspection of the received stone channel was performed visually and by using transmitted light microscopy (Leica DMLS microscope, 10× lens, 10× eyepiece).

RESULTS

The diameter of the stones used in experiments was 8 to 20 mm. Their microstructural density of the stones was from 161 to 1933 HU. The perforation time was measured from 2 to 300 seconds depending on the stone density, spatial dimensions, and chemical composition. The success rate of stone fracturing using the Ho³⁺:YAG laser at 2097 nm with the 10 kHz and 30 kHz pulse repetition rate and 0.17-2.3 mJ pulse energy was 89% (8 out of 9 attempts were successful). The microstructural density of these stones was from 161 HU up to 1566 HU.

The success rate of stone fracturing using the Tm³⁺:Lu₂O₃ laser at 1967 nm with the 15 kHz frequency and

0.4-0.6 mJ pulse energy was 43% (3 out of 7 attempts were successful). The microstructural density of the stones in this set of experiments was from 401 HU up to 1933 HU. A series of experiments revealed that the optimal operation mode of the 2097 nm Ho³⁺:YAG laser for controlled fracturing of urinary tract stones (in air) was a pulsed regime with the repetition rate of 200 to 1000 Hz (or more), pulse duration of 20-30 ns, and pulse energy of 45-55 mJ. In other words, the laser regime with a relatively small pulse energy (a few tens of mJ), but a high repetition rate (hundreds of hertz - kilohertz), enabled coarse fragmentation of concrements into fragments small enough to be removed with the amplatz.

CONCLUSION

Prevention of kidney infections after the nephrolithotripsy procedure can be ensured by a controlled, laser-enabled coarse fragmentation of urinary tract stones. This method allows to avoid scattering of the contents of the stones in a renal cavity system by selecting the laser regime optimal for contact lithotripsy. In the case of a pulsed Ho³⁺:YAG laser operated at the 2097 nm wavelength with the pulse energy of 2-55 mJ, pulse duration of 20-40 ns, and pulse repetition rate of 0.2-1 kHz (or more), the urinary tract stones were efficiently fragmented into pieces small enough to be removed from the kidney by percutaneous puncture nephrolithoextraction which, in turn, allowed to prevent infectious and inflammatory processes in kidneys due to minimal microbial dissemination of tissues.

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