Contact Laser Lithotripsy Using Strongly Heated Distal Tip of Optic Fiber

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The aim of the study was to evaluate the developed technique of contact lithotripsy using a strongly heated distal tip of a fiber providing controlled fragmentation of urinary stones.

Materials and Methods. Postoperative kidney stones were used as research objects. For renal calculi fragmentation we applied a standard 0.97 µm diode laser with a continuous wave laser regime, laser power 15 W. As a strongly absorbing coating (SAC), we used a solution of graphite carbon microparticles in silicone varnish. SAC was localized at the distal end of the light guide of multimode quartz fiber, d=550 µm. The contact zone of the light guide with a stone (heated to 2000°K) was smeared with a CO_2 gas stream, which made it possible to optimize the high-temperature oxidation of graphite in the destruction of stones. Laser fragmentation was performed *ex vivo* in physiological saline and in liquid-free conditions by means of direct calculus contact.

Results. Large calculus fragmentation was achieved through the carbonization with mechanical destruction of the surface by high temperature of an optical fiber tip. Calculus fragmentation time depended on stone density, cross-sectional dimension, and was from 10 to 80 s. Maximum cross-sectional dimension of calculi was from 6 to 21 mm, X-ray calculus density being 158–1,587 HU. Calculi with X-ray density of over 1,400 HU were unaffected by fragmentation in liquid, however, fragmentation in the atmospheric air proceeded successfully.

Conclusion. The use of SAC of the laser fiber tip enables to develop new calculus fragmentation mechanism and provide the break of a stone along the marked line. The technique excludes small stone fragmentation, therefore enables to prevent intra-operative microbial dissemination of renal tissue from biofilms of potentially infected calculi. New opportunities enable to use various laser types as a lithotripter, and significantly simplify and cheapen the technology of their manufacture.

Key words: laser lithotripsy; urolithiasis; infected nephroliths.

Endoscopic laser technologies in the management of urolithiasis detected in approximately 30% of urological surgical patients [1] have gained popularity. However, the decades the technologies were used have revealed the disadvantages, and one of them is the complication of contact laser lithotripsy in a form of an infectious inflammatory process in kidneys due to bacterial dissemination of flora from calculi biofilms [2]. In the study by Margel et al. [3] in 25% of patients, who underwent percutaneous nephrolitholapaxy, sterile urine was combined with positive stone culture. According to Russian researchers, in 41.3% of cases, microorganisms are found in calculus in sterile urine [4]. In the study [5] among 303 patients with percutaneous nephrolithotomy, 27.4% of patients were recorded to have systemic inflammatory response syndrome, and sepsis was diagnosed in 7.6% of these 27.4% patients. Yang et al. [6] found that 27.4% among 164 patients who had undergone percutaneous nephrolithotripsy had systemic inflammatory response syndrome postoperatively, and 12.2% of patients had fever. Intra-operative calculus destruction can trigger the growth activation of microorganisms integrated in a biofilm.

The foregoing motivated the search for novel approaches and techniques of renal calculi fragmentation aimed at solving the problem of postoperative infectious inflammatory processes. One of the prevention options can be the use of new mechanisms and modes of laser

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breakdown providing controlled fragmentation of calculi avoiding microbial dissemination in pelvicalyceal system and restricting the spread of microflora from biofilms.

The essential fault of known techniques of laser-induced lithotripsy of urinary stones is also the restrictions (particular operating modes) imposed on a laser type used, the design of which is frequently costly and difficult to produce. In recent years, to enhance the efficiency of cutting biotissues and teeth, there have been suggested various converters for an operating end of a laser fiber in order to change modes of exposure to tissue [7–9]. Optic fiber exhibits mechanical flexibility, its quartz core being very strong as it can stand high temperature resulted from contact interaction with a calculus. A strongly absorbing coating (SAC) at an optic fiber tip enables to maintain high temperature in the calculus contact area [10].

The aim of the study was to evaluate the developed technique of contact lithotripsy using a strongly heated distal tip of a fiber providing controlled fragmentation of urinary stones.

Materials and Methods. Postoperative kidney stones from 6 to 21 mm with different X-ray density (n=32) were used as research objects. We used whole calculi after nephrolithoextraction, pyelolithotomy, nephrectomy, cystolithoextraction. X-ray density of calculi was determined after their removal using computed tomography, and expressed in Hounsfield units (HU). Moreover, we used HD (Hounsfield density) parameter, which was calculated as the ratio of HU to the maximum crosswise size of a calculus, since X-ray density of calculi — HU — is known to depend on a calculus size [11], and HD enables to neutralize the relationship [12, 13]. Laser fragmentation was performed *ex vivo* in 0.9% saline solution, and liquid-free, by a direct contact with a calculus.

For stone fragmentation we applied a standard diode laser 0.97 µm (Russia) (Figure 1 (a)) with a continuous wave laser regime, with laser power 15 W. A tip of a silica fiber cleared from the cladding layer was used for stones destruction. As a SAC, we used a solution of graphite carbon microparticles in silicone varnish. SAC was localized at the distal end of the light guide of multimode quartz fiber, diameter core 550 µm. To obtain a highly absorbing covering, a distal light guide end was sunk in the solution and dried for several seconds at low power (about 1 W) (Figure 1 (b), (c)). For fragmentation, calculi were put in a saline solution. The contact zone of the light guide with a stone (heated to 2000°K) [8] was smeared with a CO_2 gas stream. The fiber tip resided and moved in the same vertical plane perpendicular to the stone surface.

Results. We demonstrate the first experiments on controlled destruction of stones *ex vivo* in physiological

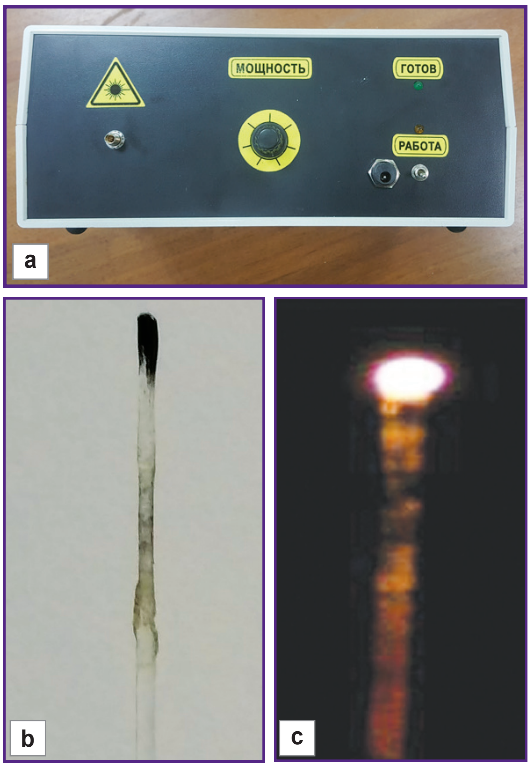


Figure 1. Optothermal fibre converters (Institute of Applied Physics, Russian Academy of Sciences, Russia):
(a) appearance; (b) light guide with SAC on its distal tip; (c) lateral section of a fibre is due to light scatter from a heated tip

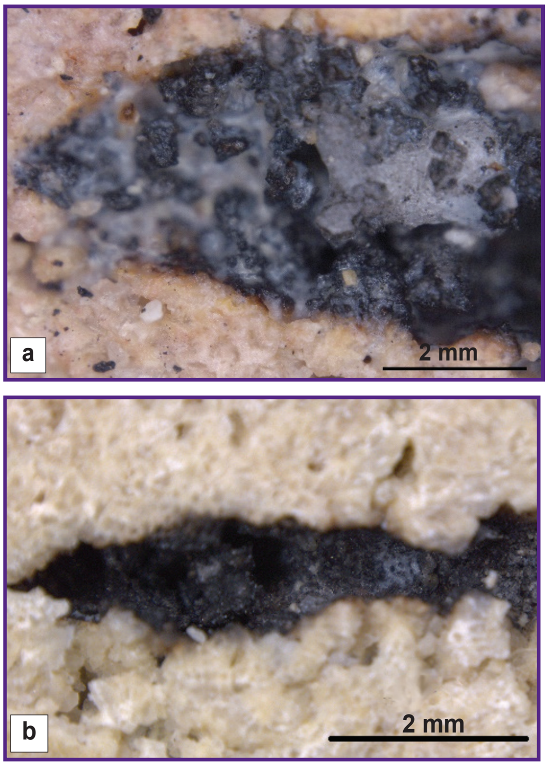
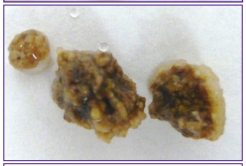
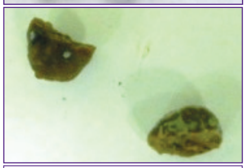


Figure 2. Photo: cross-sectional view of phosphate calculus when exposed to a heated optic fibre, 550 µm in diameter:
(a) dry calculus in atmospheric air is under exposure; (b) a calculus in liquid medium (normal saline) is under exposure

Examples of calculi fragmentation results using a suggested technique

Chemical type of calculus	Maximal size before fragmentation (mm)	X-ray density		Section time (s)	Calculus photo
		HU	HD (HU/mm)		
Magnesium, phosphate*	10	158	15.80	24 (in liquid)	
Magnesium, phosphate	16	355	22.19	13 (in liquid)	
Magnesium, phosphate	9	343	38.11	10 (in liquid)	
Phosphate, calcium, magnesium, oxalate (in atmosphere)	21	1,587	75.57	60 (in air)	
Magnesium, calcium, oxalates (in atmosphere)	14	1,424	101.7	25 (in air)	
Magnesium, calcium, phosphate	10	1,060	106.00	60 (in liquid)	
Magnesium, calcium, oxalates*	20	1,070	53.50	80 (in liquid)	
Oxalates, calcium	9	1,000	111.11	30 (in liquid)	
Phosphate	17	209	12.29	10 (in liquid)	
Magnesium, urates	6	342	57.00	12 (in liquid)	

*Arrow indicates the beginning of fragmentation.

saline. The results of fragmentation of 32 stones after nephrolithoextraction are presented: transverse size ~10–12 mm. Stones of 5 mm are easily removed through the endoscope.

Large calculus fragmentation was achieved by using a carbonization mode with mechanical destruction of the surface by high temperature of the optical fiber end (Figure 2). The figure shows the area of destruction of stone in water about 1 mm.

The presence of liquid medium provides the locality of temperature exposure, reducing the area of thermal damage by several times, which is of great importance when operating in the renal cavity system. Carbonization area was found to be significantly smaller if calculi under exposure were in liquid than those dried in atmospheric air: diameters of carbonized canals can differ by over 8 times (see the Table).

The calculus fragmentation time depended on calculus density, cross-sectional size, and was 10–80 s. The maximum cross-sectional size of calculi under study was 4–21 mm. X-ray density of calculi under fragmentation was 158–1,587 HU, and HD value was from 12.29 to 356.00 HU/mm, respectively.

Discussion. In traditional laser lithotripsy, holmium lasers are used, the radiation of which is well absorbed by water in the stones. The stones are irradiated, the water heats up, transforms into vapor, and the pressure of the water vapor breaks the stone into pieces. However, in the stones there are many pathogenic microbes, scattering fragments infect tissues and inflammation is formed.

The technique of controlled cutting of stones into large pieces is required for medical application [14]. Intraoperative destruction of potentially infectious calculus can trigger the activation of growth and dissemination of microorganisms.

In our Urology Clinic, alongside with holmium laser we use contact pneumatic lithotripsy, which also leads to mechanical cracking of a calculus to different-calibre fragments. The presence of postoperative complications in a form of systemic inflammatory response syndrome in patients inspired us to search for other nephrolith fragmentation techniques.

The used mechanism of “hot spot” enabled to avoid calculi destruction with small flakes scattered by irrigation fluid current in the renal cavity system and provide a controlled break along the marked line. The novel aspect in the developed technique of contact lithotripsy is that a distal tip of the optic fiber is applied by a highly absorbing layer that results in calculus fragmentation due to high temperature localized at the optic fiber tip, i.e. there is calculus burning.

Calculi with X-ray density of over 1,400 HU are hardly fragmented in water, however, in atmospheric air their fragmentation proceeds successfully. On the other hand, potentially infected struvite campuses, apatites, ammonium urates, and others [15] appeared to have an X-ray density at 1,400 HU [16, 17], which is sufficient for their fragmentation by the technique used. Less than 15 s (see the Table) are necessary for the fragmentation of stones with a porous structure containing much microflora.

The suggested technique enables to control the fragmentation of potentially infected calculi in the renal cavity up to the fragments, which can be afterwards taken out mechanically through a nephroscope, or Amplatz tube during percutaneous nephrolithotripsy. It enables to provide minimal microbial dissemination of renal tissue during endoscopy by the content of biofilms associated with calculi. It is expected that under high temperature at the point of light guide contact with a calculus there is no yield of bacterial flora from biofilms contained in a calculus.

Conclusion. We demonstrate the first experiments on controlled laser destruction of stones with the use of carbon-containing optothermal fibre converters. The use of a highly absorbing covering of the laser end enables to provide the break of a stone in lithotripsy along the marked line, and avoid small fragmentation. Therefore it prevents intraoperative microbial dissemination of renal tissue from biofilms of potentially infected calculi.

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Conflicts of Interest. The authors have neither potential nor existing conflicts of interest related to the present study.

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