

Comparison of Mid Infrared Lasers Effect on Ureter Tissue

H. Jelínková^a, O. Köhler^b, M. Němec^a, P. Koranda^a, J. Šulc^a, V. Kubeček^a
 P. Drlík^b, M. Miyagi^c, Yi-W. Shi^c, Y. Matsuura^c, M. R. Kokta^d
 P. Hrabal^e, M. Jelinek^f

^a*Czech Technical University, Faculty of Nuclear Sciences and Physical Engineering,
 Břehová 7, 115 19 Prague 1, Czech Republic
 e-mail:hjelin@troja.fjfi.cvut.cz*

^b*Central Military Hospital, Clinic of Urology
 169 02 Prague 6, Czech Republic*

^c*Tohoku University, Graduate School of Engineering, Department of Electrical
 Communications, Sendai 980-8579, Japan*

^d*Bicron, Saint-Gobain, Washougal, WA, USA*

^e*Central Military Hospital, Clinic of Pathology-Anatomical
 169 02 Prague 6, Czech Republic*

^f*Czech Academy of Sciences, Physical Institute, Na Slovance 2, 180 00 Prague 8*

Abstract Aim of the work was an investigation of ureter wall perforation possibility by various types of mid-infrared radiations (from 2.01 μm (Tm:YAG) up to 2.94 μm (Er:YAG)) and exploration of the interaction basic characteristic for ureter surface (epithelium) and its deep structures (mesenchym). It can be summarized that Ho:YAG, Er:YAG and CTE:YAG laser radiations accomplish a good wall ureter perforation at comparable energies. But distinguished difference appeared in tissue modifications of both tissues - the epithelium and mesenchym.

Keywords: urology, ureter, solid state lasers, Er:YAG, CTE:YAG, CTH:YAG, Tm:YAG, hollow waveguide.

1. INTRODUCTION

Over the past twenty years a variety of laser systems have been tested for urology surgery, such as for the treatment of urethral and ureteral strictures, treatment of BPH (benign prostatic hyperplasy), and stone desintegration (lithotripsy). So far, the long term results from the strictures treatment are not enough sufficient – high rate of recurrence still existing. Therefore new methods of treatment are highly appreciated. The depth of the vaporized channel mainly depends on the spectral absorption of the radiation in a tissue and, as water is a prominent component of biological tissues, this depth is mainly given by the absorption of laser radiation in water. In mid-infrared region, a family of solid state lasers (based on Er, Tm or Ho ions) is available which radiation has sufficient absorption in OH-containing media [1]. From literature is known hopeful results with Er:YAG laser radiation (from animal treatment [2]).

Therefore the objective of this study was to investigate and compare the ablation effect of selected mid-infrared laser radiation (Tm:YAG, CTH:YAG, CTE:YAG, and Er:YAG) on human ureter tissue. Than an attestation of possibility perforation the ureter wall by these types of lasers and investigation of basic characteristic interaction with its surface and deep structure.

2. EXPERIMENTAL METHODS

2.1 Laser systems

For the experiment four laser systems Tm:YAG, CTH:YAG, CTE:YAG, and Er:YAG generating in mid-infrared region were used. All systems were designed and constructed at the FNSPE* laboratories. Guiding of all systems was performed by an independent He-Ne lasers ($\lambda = 0.63 \mu\text{m}$). Radiation delivery from the laser to the interacting tissue was realized by the special sealed hollow waveguides. All lasers as well as delivery system is described below.

2.1.1 Er:YAG laser system

In Er:YAG laser oscillator ($\lambda = 2.94 \mu\text{m}$), an active crystal 5 mm in diameter and 100 mm long was used along with xenon flashlamp. These elements were placed inside a diffused ceramic pumping cavity. The resonator consists of the plane total reflecting copper mirror and an output coupler with the optimal reflectivity $R_{\text{out}} = 80 \%$. The wavelength generated was 2.94 μm and the pulse duration was measured to be 150 μsec (FWHM). The radiation was delivered to the ureter tissue by the special hollow waveguide (see section 2.2) so, the fluence on tissue reached 26 J/cm^2 .

* FNSPE -Faculty of Nuclear Sciences and Physical Engineering, Dept. of Electronics, Laboratory of Solid State Lasers

2.1.2 CTE:YAG laser system

The laser head of CTE:YAG laser ($\lambda = 2.7 \mu\text{m}$) consists of a Cr:Tm:Er:YAG crystal with a diameter of 5 mm and a length of 100 mm pumped with a linear xenon flashlamp in the elliptical silver coated pumping cavity. The resonator had plane-parallel configuration and was formed by two mirrors with the reflectivity $R = 100\%$ and $R_{\text{out}} = 47\%$. The same delivery system with the similar energy (100 mJ) as in the case of Er:YAG laser was used for contact treatment (see Tab.1) thus corresponding fluence was equal to 26 J/cm^2 .

2.1.3 CTH:YAG laser system

The laser head of CTH:YAG laser ($\lambda = 2.1 \mu\text{m}$) consists of a Cr:Tm:Ho:YAG crystal with a diameter of 4 mm and a length of 89 mm placed along with a xenon flashlamp into a diffused ceramic pumping cavity. The resonator had plane-parallel configuration and was formed by two mirrors with the reflectivity $R = 100\%$ and $R_{\text{out}} = 83\%$. For the interaction experiment we start with the same energy, being measured behind the hollow waveguide delivery system 100 mJ (fluence 26 J/cm^2). Because the perforation was not obtained, the higher energy up to 400 mJ, which corresponds to fluence 104 J/cm^2 , was applied.

2.1.4 Tm:YAG laser system

Tm:YAG laser oscillator was formed by Tm:YAG crystal with a diameter of 5 mm and a length of 79 mm. Like in the previous laser system, for pumping, a xenon flashlamp and one elliptical silver-coated reflecting cavity was used. The planparallel optical resonator was formed by the total reflecting copper mirror and by a mirror, with the optimal selected reflectivity $R_{\text{out}} = 47\%$, serving as an output coupler. The interaction energy and fluence were 100 mJ (26 J/cm^2) and 210 mJ (55 J/cm^2).

2.2 Radiation delivery system

The laser beam was directed to the investigated tissue by a special cyclic olefin polymer-coated silver (COP/Ag) hollow glass waveguide [3]. The inner diameter of this waveguide was equal to $700 \mu\text{m}$ (the outer diameter being equal to $850 \mu\text{m}$) and the length was 1 m. The radiation was focused into the protector by CaF_2 lens with the focus equal 100 mm. The protector was placed in front of the hollow waveguide input to safe the dielectric coating of its wall [4]. By reason of a contact method treatment (in which the end of the hollow waveguide is in straight vicinity of wet tissue), the waveguide end was connected with the special sealed waveguide termination [5]. The laser radiation guiding was performed by He-Ne laser radiation ($\lambda=0.63 \mu\text{m}$).

2.3 Summary of the laser systems and interacting radiations parameters

The summarization of the wavelength, pulse length, maximum generated laser energy, used delivery system, maximum interacting energy and fluences is in Tab.1.

Tab.1. Summary of radiation source and interaction parameters

	Er:YAG	CTE:YAG	CTH:YAG	Tm:YAG
Wavelength [μm]	2.94	2.70	2.10	2.01
Pulse Length [μs]	190	200	250	175
Maximum Laser Energy [J]	2.00	0.97	1.85	1.80
Laser Repetition Rate [Hz]	1.5	1	1	1
Delivery system COP/Ag HGW [$\mu\text{m}/\text{m}$]	$\varnothing 700/1$	$\varnothing 700/1$	$\varnothing 700/1$	$\varnothing 700/1$
Max Interacting Energy [mJ]	100	200	400	210
Max Interacting Fluence [J/cm^2]	26	52	104	55

2.4 Examined Sample Preparation

As examined samples a part of human ureter tissue were prepared in the shape of longitudinal sections with the thickness range from 1 to 1.5 mm. The samples were stored in a refrigerated saline solution and the experiment was performed up to three hours. Prior to the experiments, the specimens were air-dried and mounted on a micro-translation stage.

2.5 Measuring instruments

To investigate the output laser radiation energy, a computer-operated two channel Molecron JD2000 Joulemeter/Ratiometer and Tektronix TDS 3052B oscilloscope with thermal detectors Gen-Tec (ED-200 LA) and Molecron (J25) were used. During the interaction process ablated holes were investigated using the microscope (Nicon SMZ-2T).

2.6 Experimental Methods

The ureter sample was mounted in a special holder that was directly attached to a translating stage with a movement possibility. The end of sealed waveguide was in the contact with the tissue. The specimens of the ureter tissues were gradually irradiated by the Tm:YAG, CTH:YAG, CTE:YAG, and Er:YAG radiations. The input waveguide energy was monitored with a beam splitter placed in front of the waveguide input and the first Joulemeter head. At the same time, the output energy was monitored with the second energy detector placed behind the hollow waveguide termination. After the measurement of the output energy, the investigated tissue sample was inserted between termination and probe (Fig.1). The first coming impuls was monitored on the scope when tissue was perforated.

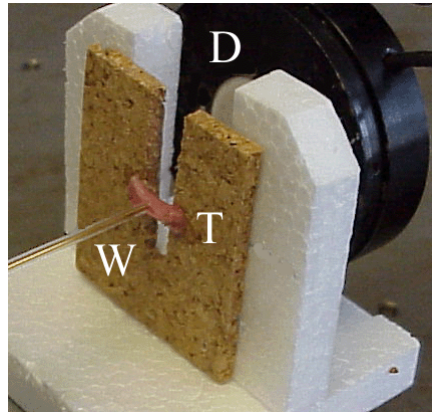


Fig.1. Photo of arrangement: T - ureter tissue, W – waveguide termination, D – energy detector.

2.7 Analysing Methods

After the laser ablation the samples of tissue were photographed and pickled in formaldehyde. Then, the specimens were taken for H&E staining and histological processing.

3. RESULTS

In the case of application of **Er:YAG** laser radiation only 9 pulses was sufficient for the perforation of ureter tissue. The interacting energy used was 100 mJ, fluence 26 J/cm². The whole in ureter tissue is seen in Fig.2a.

When **CTE:YAG** radiation was used, 51 pulses with the interaction energy of 100 mJ was applied to reach the perforation of the ureter tissue. For the higher energy reached 200 mJ, the perforation appeared already for 22 pulses. The result of this interaction done by Nikon microscope is in Fig.2b.

The interacting **CTH:YAG** radiation (energy 100 mJ) did not obtained any perforation even for 200 pulses. The perforation was found when the energy rose to 400 mJ. 68 pulses were applied for forming the hole which is in Fig.2c.

During the interaction of **Tm:YAG** laser radiation (interaction energy 100 mJ) with the ureter tissue no perforation was observed not even for 200 pulses. Therefore the energy was increased up to 210 mJ. Even for this energy the perforation was not obtained. Only hole appeared after 200 pulses applied. The tissue after the interaction process is seen in Fig.2d.

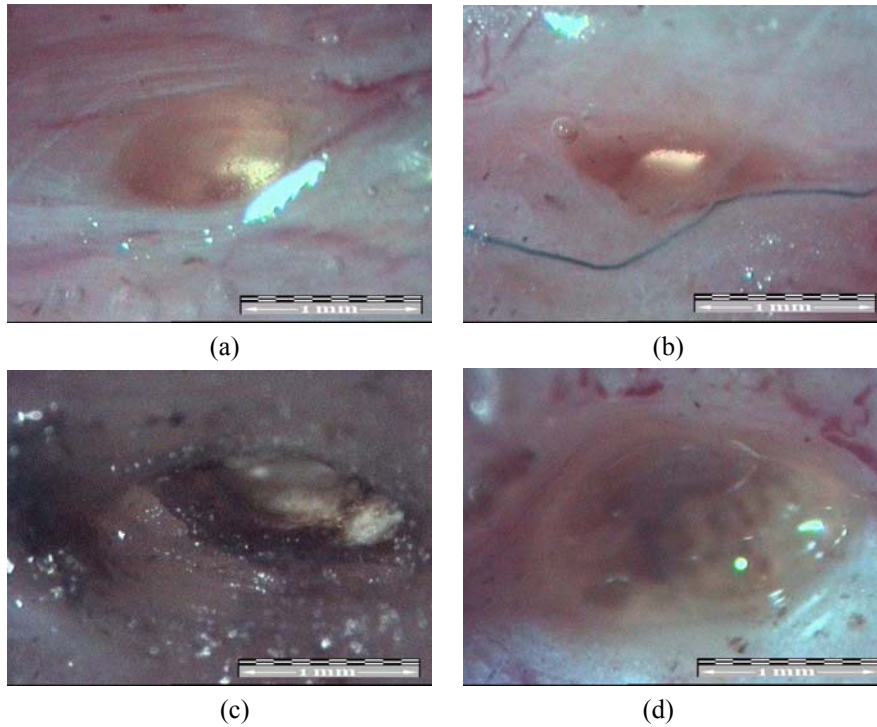
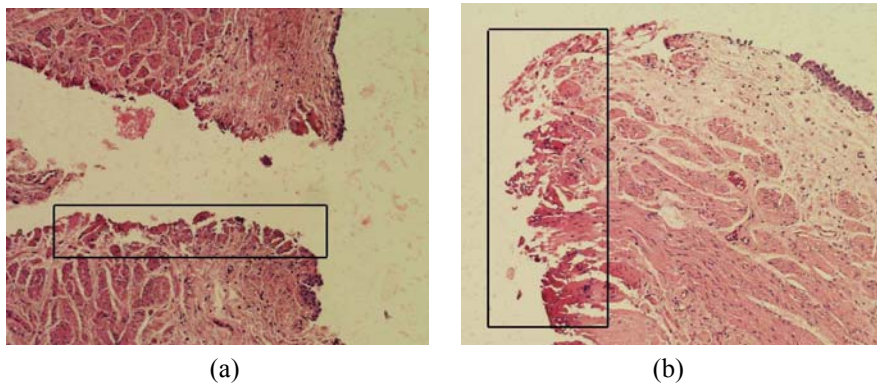


Fig.2. Microscope view of the results of the interaction of laser radiations with the ureter tissue. Interacting radiation: (a) Er:YAG, (b) CTE:YAG, (c) CTH:YAG and (d) Tm:YAG.

3.2. Histological evaluation

From the histological evaluation of the irradiated tissue samples (Fig.3) follows that the tissue irradiated by Tm:YAG was considerably damaged and only shallow hole was created (Fig.3d). The small arrow indicates the carbonization bellow which the deep structure reaction exists. The similar histological results were found in CTH:YAG laser irradiation. The same carbonization (arrow Fig.3c) and deep structure reaction was found.

Fundamentally different results were obtained in Er:YAG (Fig.3a) and CTE:YAG (Fig.3b) interaction with ureter tissue. The surface layers carbonization in both samples is only minimal. The deep structure reaction was not higher than 0.05 mm and 0.2 mm for Er:YAG and CTE:YAG laser radiation, respectively.



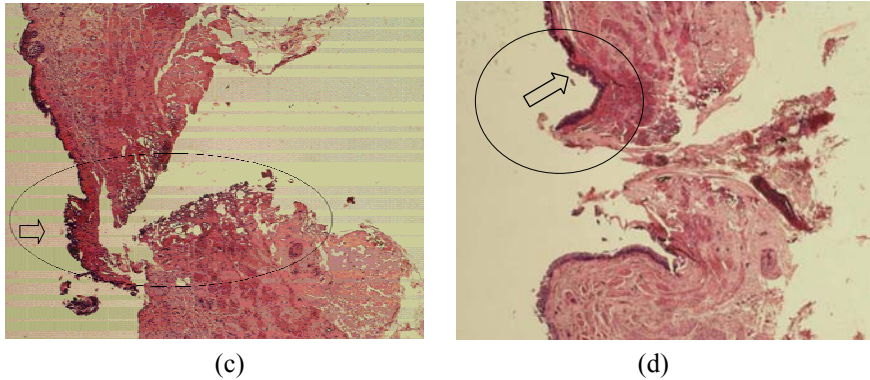


Fig.3. Histological evaluation of ureter tissue after laser treatment by (a) Er:YAG (magnification 200x), (b) CTE:YAG (magnification 200x), (c) CTH:YAG (magnification 100x), and (d) Tm:YAG (magnification 100x) laser radiation.

4. DISSCUSSION

Pulse energies, which can create perforation in ureter wall, were found for CTH:YAG, Er:YAG and CTE:YAG laser radiation. For Tm:YAG laser, ureter wall perforation wasn't caused nor application 200 pulse (210 mJ/pulse). Only hole was achieved (Fig.2d). Our Tm:YAG laser system did not generate more energy than 210mJ and therefore we cannot reach perforation. This possibility was used in the case of CTH:YAG laser. Nevertheless, from first microscopic results it is seen, that CTH:YAG and Tm:YAG laser irradiation induce significant surface carbonization upper tissue layers and destruction deeper structures. Both laser radiations, Er:YAG and CTE:YAG, demonstrate the minor surface carbonization in comparison with CTH:YAG and Tm:YAG radiations. Applications of those radiations lead to quite minimum deep structures alteration not exceeding 0.2 mm.

5. CONCLUSION

As a conclusion it can be summarized that CTH:YAG, Er:YAG and CTE:YAG laser radiation accomplish a good wall ureter perforation at comparable energies. The differences were observed in the quality of the ablated surface. From the histology investigation have been distinguished great differences in tissue modifications of both - the epithelium and mesenchym. Thus, from our study follows that the CTE:YAG and than Er:YAG laser could be considered as a good candidates for the urology treatment. Next investigation of radiation effects and tissue interaction is able to lead to development of optimum therapeutic laser for cut soft tissue.

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7. REFERENCES

1. Boulnois J. L., 1986, Lasers in Medical Science, 1.
2. Fried N.M., Long G.M., 2002, Lasers in Surgery: Advanced Characterization, Therapeutics, and Systems XII, Kenneth E. Bartels D.V.M., Lawrence S. Bass M.D., Werner T. de Riese, Kenton W. Gregory M.D., Abraham Katzir, Nikiforos Kollias, Michael D. Lucroy D.V.M., Reza S. Malek M.D., George M. Peavy, Hans-Dieter Reidenbach, David S. Robinson M.D., Udayan K. Shah M.D., Lloyd P. Tate V.D.M., Eugene A. Trowers M.D., Brian J. Wong M.D., Timothy A. Woodward M.D.; Editors, Proc. SPIE, 4609, 122-127.
3. Shi Y.W., Hanamoto K., Wang Y., Abe Y., Matsuura Y., Sato S., Miyagi M. 1998, BiOS Europe'98, Abstract book Paper No. 3570-01, Stockholm, p.82.
4. Jelínková H., Miyagi M., Šulc J., Černý P., Shi Y., Matsuura Y., Takada G., In: Optical Fibers and Senzore for Medical Applications, Israel Gannot, Editor, Proceedings of SPIE Vol. 4253, p.58-67, 2001.
5. Jelinkova H., Nemeč M., Sulc J., Miyagi M., Iwai K., Abe Y., Shi Y.W., Matsuura Y., Pasta J., In: Optical Fibers and Sensors for Medical Applications II, Israel Gannot, Editor, Proceedings of SPIE Vol.4616, p.135-142, 2002