BIOLOGICAL EFFECTS OF CONTACT ACTION OF 1470 vs. 810 nm SEMICONDUCTOR LASERS *in vitro*

UDC 61.001.616:615.849.19:577
Received 15.04.2014

© **N.A. Schumilova,** Postgraduate, the Department of Otolaryngology with Clinic;
Y.S. Fedotova, Resident Medical Practitioner, the Department of Otolaryngology with Clinic;
M.A. Ruabova, D.Med.Sc., Professor, the Department of Otolaryngology with Clinic

Pavlov First Saint Petersburg State Medical University, L'va Tolstogo St., 6/8, Saint Petersburg, Russian Federation, 197022

The aim of the investigation is to identify the character of biological effects of contact action of semiconductor laser with a wavelength of 1470 nm on the tissues with different optical and mechanical properties compared to the exposure to laser radiation with a wavelength of 810 nm.

Materials and Methods. The study was performed on a chicken muscle tissue, liver of the cattle, nasal polyp, removed nasal septum cartilage. While making a linear incision of the tissues by the laser with a speed of 2 mm/s assessment of the width of ablation and coagulation zones, and the crater depth with the following measurement under the microscopy conditions were carried on. Weighing of the tissue specimens before and after the spot action was performed. Standardization of the operating speed was achieved by using uniformly moving recorder chart.

Results. Radiation power increment of 1470 nm wavelength laser contributes to the increase of the ablation and coagulation zone width to a greater degree compared to 810 nm laser. Exposure to 1470 nm laser with a power of 1 W causes the tissue to stick to the fiber. When power is 2 W, coagulation zone of soft tissues is comparable, and in some cases exceeds it after treatment by 810 nm laser. In relation to the crater depth, 1470 nm radiation is inferior to 810 nm radiation, but is superior in relation to vaporization abilities.

Conclusion. For tissue ablation with 1470 nm laser a power of 2 W is optimal, as it provides a sparing superficial effect, and in a number of cases exceeds the action of 810 nm 7 W laser by its coagulation properties. Generation of a crater with a less depth after application of 1470 nm laser allows it to be recommended for superficial coagulation of vascular lesions.

Key words: 1470 nm semiconductor laser; 810 nm semiconductor laser; coagulation; vaporization.

Semiconductor lasers with a wavelength from 800 to 1060 nm became widely used in medicine as they are characterized by a high absorption of radiation in blood hemoglobin and low absorption in water, and because of this property they are sometimes called "hemoglobin-absorbable" [1, 2]. In surgical practice a great experience of using 810 nm wavelength laser radiation has been accumulated, which proved to be successful both for making incisions and performing hemostasis. A number of experimental investigations using live tissue phantoms has been carried out in order to choose optimal parameters when applying these lasers to biological tissues [3]. A wide application of 810 nm laser in various fields of surgery, knowledge of the biological effects of its action allow it to be used in the studies where other types of devices for tissue interventions are compared — cauterodyne, radiofrequency scalpel, lasers with different wavelength [4].

In recent years 1470 nm wavelength laser came into active use in surgery. For laser devices with a wavelength near 1.5 µm, absorption in water is the predominant property, which causes special biologic effects as the result of their action. Such lasers are named "water-absorbable" or "water-specific" [5] and are mainly used in urology and for endovenous obliteration of veins [6–10]. The possibility of application of 1470 radiation lasers for operative interventions in other fields of medicine, e.g. otorhinolaryngology, is reported by some manufacturing companies. In the available literature only solitary experimental investigations of biological effects of laser radiation of this wavelength can be found. Studying the efficacy of laser action on the tissues of the prostate gland in comparison with PTP-laser (potassium-titanyl-phosphate) [11], less marked cutting properties of the diode laser but more significant coagulation capabilities were revealed. Evaluation of the quantity of vaporized tissue, generated under the action of 1470 nm laser radiation on the porcine kidney tissue, as well as the assessment of blood loss for the period of laser action on the model of the blood-supplied porcine kidney were carried out [12]. The zone of necrosis was 1.30 mm, which was much less compared to the values obtained using 980 nm laser — 4.18 mm. Different conditions and methodologies of conducting these published

For contacts: Schumilova Nataliya Alexandrovna, e-mail: schumilov211@yandex.ru

experimental works make it impossible to compare their findings and to prognosticate laser effects on the tissues. In the clinical practice an operating mode of the laser device is usually selected empirically. Knowledge of the specific biologic effects of the laser will reduce the risk of unpredicted impact on the tissues, enable, depending on the spectral radiation characteristics, to widen and justify the field of laser application in surgery, to work out recommendations on the selection of optimal modes of action for tissue ablation and coagulation. Comparison of 1470 nm laser effects with 810 nm laser radiation will help to evaluate in full extent its specific action on the tissues and its feasibilities.

It should be said that the effect of laser action is caused not only by the spectral radiation characteristics, power, laser exposure, but by optical properties of the tissues as well. Therefore, the choice of the operating parameters must be based in each individual case on the results of experimental studies carried out on different biological tissues with various optical and mechanical properties.

The aim of the investigation is to identify the character of biological effects of contact action of semiconductor laser with a wavelength of 1470 nm on tissues with different optical and mechanical properties compared to laser radiation with a wavelength of 810 nm.

Materials and Methods. The work was done at the Department of Otolaryngology with Clinic of the Pavlov First Saint Petersburg State Medical University. The assessment of semiconductor laser operation was made in the contact continuous mode. The effects of 1470 nm laser (Lakhta-Milon, Milon-laser, Russia) with a 5 W maximum output power were studied at a power range from 1 to 5 W with 1 W increment. The work of 810 nm laser (Aktus-15, Semiconductor Devices, Russia) was evaluated at the power values of 3, 5, 7, and 9 W, most commonly used in the clinical practice.

The objects, exposed to the laser action, were biological tissues with different optical and mechanical properties: removed nasal polyps, cattle liver, muscular chicken tissue, removed nasal septum cartilage. The choice of the material could help to predict laser effects on various body tissues — muscular, cartilaginous tissues, parenchymal organs and polypous tissue, characterized by a high content of water. To improve the cutting properties laser treatment was performed by a charred end of the optic fiber.

To estimate the width of ablation and coagulation zones a linear incision was made in the specimen. Standartization of the operating speed was provided by uniformly moving chart of the recorder (Fig. 1). Laser fiber was fixed by supports at an angle of 60° to the surface along the direction of making incision. Speed mode of 2 mm/s, most frequently used in the clinical condition, was chosen for our work.

Measurement of the ablation zone width and the width of the lateral coagulation zone was performed under the microscopy conditions by means of ocular micrometer with ×40 magnification using LKB Ultramicrotome, Model 8802A (Sweden) (Fig. 2). The obtained result was multiplied by the table coefficient, corresponding to the value of one division of the ocular micrometer in micrometers. Three series of experiments were made, 5 measurements in each. The depth of the generated crater was estimated making transverse sections relative to the incision line with the following measurement under microscopy conditions using the above method.

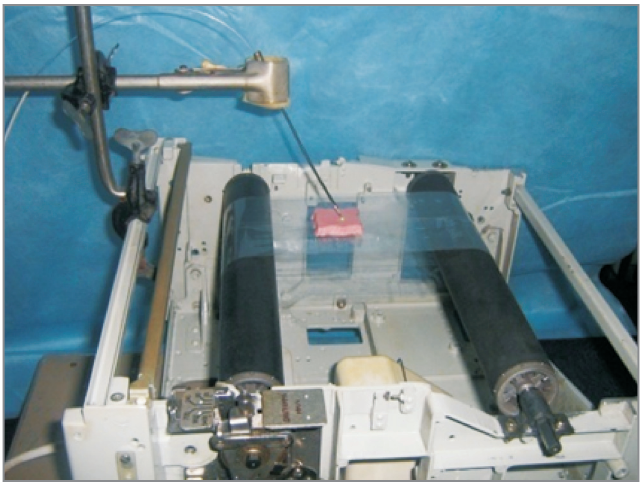

Fig. 1. Making linear tissue incision

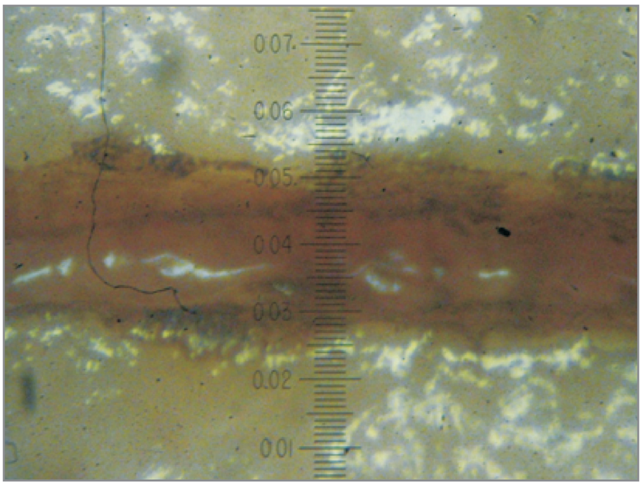

Fig. 2. Measurement of ablation and coagulation zones (in μm) using ocular micrometer, ×40

To determine the degree of vaporization the biological tissue specimen was exposed to spot radiation during 5 s. Laser fiber was fixed by supports at an angle of 90° to the tissue surface. Biologic tissue specimens were weighed on the scales Techniprot (Poland) with the measurement range of 0–1000 mg before and after the spot action.

Investigation findings were processed using Student t-criterion for determining various values of relative and absolute numbers. A critical significance level of null statistic hypothesis (absence of differences and influences) was assumed to be equal to 0.05.

Results and Discussion. Power increment from 1 to 5 W of 1470 nm laser results in the significant crater width increase, and, to a less extent, in the growth of the lateral coagulation zone on all biological objects (Table 1). An exception was a polyp tissue, which has been deformed and shrunk under the action of power increase up to 3 W and higher.

When contact action was performed by 810 nm laser radiation, increment of radiation power increased crater width and lateral coagulation zone to a less degree compared to 1470 nm laser. For example, power increase from 3 to 9 W, when acting on the chicken muscular tissue by 810 nm laser, results in the growth of crater width by 20% and in the growth of lateral coagulation zone by 63% (Fig. 3), whereas increase of radiation power from 1 to 5 W with 1470 nm laser is characterized by the magnification of these values by 256 and 193%, respectively (See Table 1).

Maximum width of ablation zone is formed when muscular tissue of the chicken and cattle liver are treated by 1470 nm laser (differences for the majority of measurements are not statistically significant, $p>0.05$),

T a b l e 1

Width of ablation and coagulation zones after exposure of different tissues to 1470 vs. 810 nm laser radiation

Wavelength, μm	Power, W	Cattle liver (group 1)	Chicken muscular tissue (group 2)	Nasal polyp (group 3)	Nasal septum cartilage (group 4)
		Crater width, μm			
1.47	1	294±65	588±85	70±11^{*+}	343±13$^{+\wedge}$
	2	756±31	1232±65*	147±13^{*+}	707±13$^{+\wedge}$
	3	1302±30	1295±40	126±14^{*+}	798±30$^{*+\wedge}$
	4	1393±36	1477±23	700±22^{*+}	854±14$^{*+\wedge}$
	5	1505±46	1610±66	301±26^{*+}	994±18$^{*+\wedge}$
0.81	3	700±72	893±10*	0	294±14$^{*\wedge}$
	5	1068±117	1005±17	910±18^{+}	854±21^{+}
	7	1225±56	1057±32*	998±28*	875±14$^{*+\wedge}$
	9	1278±55	1075±23*	1071±76*	980±9^{*+}
		Lateral coagulation zone width, μm			
1.47	1	336±36	189±9*	0	0
	2	385±19	308±34	0	0
	3	406±32	371±14	0	0
	4	448±30	364±14	161±28^{*+}	0
	5	476±38	364±18	301±34*	0
0.81	3	224±10	280±26	0	70±6^{*+}
	5	315±9	364±29	35±6^{*+}	70±6$^{*+\wedge}$
	7	294±10	420±23*	70±6^{*+}	70±3^{*+}
	9	403±9	455±26	175±6^{*+}	70±6$^{*+\wedge}$

* — differences of values are statistically significant compared to group 1; $^{+}$ — compared to group 2; $^{\wedge}$ — compared to group 3, $p<0.05$.

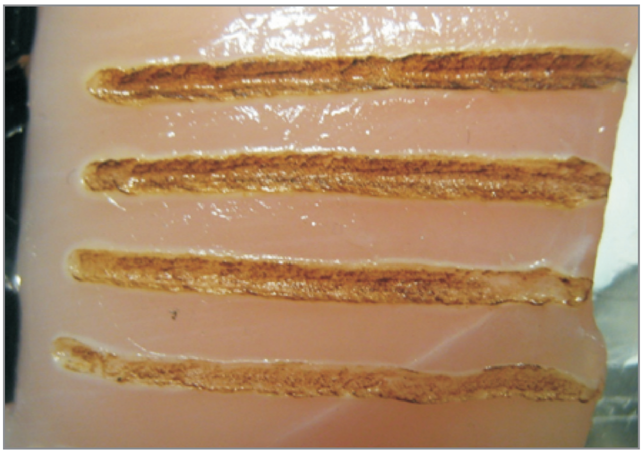

Fig. 3. Linear incision made by the exposure of the chicken muscular tissue to 810 nm laser radiation; power (downward): 9, 7, 5, 3 W (macrophotograph)

Fig. 4. Assessment of ablation zone and lateral coagulation zone on the cattle liver tissue (macrophotograph)

due to a high water content in these biological tissues. When 810 nm laser is used, crater with a maximum width is formed in the cattle liver, characterized by a high content of hemoglobin, which is a target chromophore capable to absorb radiation and transform it to the thermal energy (Fig. 4).

Minimal values of ablation zone width were found, when 1470 nm laser radiation affected polypous tissue because of its deformation, while 810 nm laser gave minimal values acting upon the nasal septum cartilage because of a low content of target chromophore and a high density of the polypous tissue. Formation of the least crater under the exposure of polypous tissue to 1470 laser radiation because of its shrinkage and deformation may be explained by the intensive evaporation of water, characteristic of this laser radiation spectrum. This conclusion is confirmed by a more marked loss of mass by the polyp tissue specimen in comparison with other biological objects under the spot exposure to the 1470 nm laser (Table 2).

Table 2

Mass loss by biological tissue specimens before and after spot exposure to laser radiation, mg

Wavelength, μm	Power, W	Cattle liver	Chicken muscular tissue	Nasal polyp	Nasal septum cartilage
1.47	1	1	2	1	2
	2	6	2	3	3
	3	8	5	8	7
	4	10	8	10	11
	5	11	10	16	15
0.81	3	6	2	3	1
	5	6	2	3	2
	7	8	5	8	4
	9	13	5	8	4

Table 3

Crater depth after exposure of the chicken muscular tissue to 1470 and 810 nm laser radiation

Wavelength, μm	Laser radiation power, W	Crater depth, μm
1.47	1	163±12*
	2	175±20*
	3	187±31*
	4	315±20*
	5	338±12*
0.81	3	301±24
	5	427±48
	7	525±20
	9	539±26

* — differences of values are statistically significant compared to 810 nm 7 W laser, p<0.05.

When a linear incision was being made by 1470 nm 1 W power laser, a marked sticking of the tissues with a large content of water — cattle liver and chicken muscular tissue — to the laser fiber was noted. This resulted in forming irregular crater width on the mentioned biological objects, and in statistical calculations it was reflected by high error values of the arithmetic mean. Generation of a predicted incision width on the cattle liver and chicken muscular tissue is provided by the power not less than 2 W of the 1470 nm laser.

When 810 nm laser was used, sticking of the tissue was noted only if cattle liver rich, with target chromophores, was exposed to the power of 3 and 5 W. It is possible to avoid tissue sticking and probability of bleeding, when separating the fiber from the tissue of the cattle liver, if 810 nm laser power not less than 7 W is used.

Assessing the depth of the incision, made by the linear action of 810 and 1470 nm lasers, statistically significant differences dependent on the tissue type were not revealed. On all biological objects the depth of the incision, forming under the action of 1470 nm laser even at the maximum power (5 W), did not exceed the depth of the crater made by 810 nm laser. In Table 3 findings of crater depth measurements on the chicken muscular tissue, characterized by a high content of the target chromophores, for both types of semiconductor lasers are presented.

Formation of the crater with a less depth, using 1470 nm laser, is advantageous in case of gentle manipulations with tissues.

The width of the lateral coagulation zone, when using 1470 and 810 nm lasers, was statistically significantly higher on the cattle liver and chicken muscular tissue. Unlike 810 nm laser, 1470 nm laser does not produce coagulation effect on the nasal septum cartilage due to a low content of water in this biological tissue. In case of the nasal polyp, coagulation zone is formed at the power not less than 3 W for 1470 nm laser and not less than 5 W for 810 nm laser.

Thus, contact application of 1470 nm laser radiation in comparison with 810 nm laser is characterized by formation of statistically significantly less deep crater on all biological objects, and therefore, may be recommended for applications in anatomic fields, requiring extremely sparing action, or in making superficial incisions. At the power of 2 W contact action of 1470 laser provides formation statistically significantly less wide crater on all biological tissues except for the muscular tissue and more significant lateral coagulation zone of the liver tissue (p<0.05) compared to 810 nm 7 W laser. In this connection, application of 1470 nm laser in the contact mode is justified for tissue ablation and hemostasis taking into consideration specificity of biological effects, caused by laser radiation wavelength.

Conclusion. Optimal power of 2 W, providing formation of craters with a predictable width, is recommended for making incisions on all kinds of biological tissues by means of 1470 nm lasers. Formation of incisions with a less depth and width using these parameters in comparison with 810 nm 7 W laser is advantageous in anatomic fields requiring sparing action on the tissues. Coagulation effect of 1470 nm 2 W laser is comparable, and in some cases, superior to the action of the 810 nm 7 W laser radiation, and may find its application for superficial coagulation of vessel lesions or vaporization of soft tissues.

Study Funding and Conflict of Interests. The study was not funded by any sources, and there are no conflicts of interest related to the present study.

References

1. Ryabova M.A. The role of the study of laser effects on biological tissue in the development of laser surgical techniques in otolaryngology. *Vestnik otorinolaringologii* 2008; 4: 13–17.

2. Köhler B., Kissel H., Flament M., Wolf P., Brand T., Biesenbach J., et al. High-power diode laser modules from

410 nm to 2200 nm. *Proc SPIE* 2010; 7583, http://dx.doi.org/10.1117/12.841846.

3. Nevorotin A.I., Pluzhnikov M.S., Ryabova M.A., Plotkina O.V., Krasnikov A.G. Comparative analysis of minimally invasive surgical interventions in the use of infrared laser and radiofrequency scalpel (clinical and experimental study). *Folia Otorhinolaryngologiae et Pathologiae Respiratoriae* 2007; 13(1–4): 26–32.

4. Karpishchenko S.A., Ryabova M.A., Shumilova N.A. Comparative assessment of biological effects of laser radiation, radiofrequency devices and electrical knife. *Folia Otorhinolaryngologiae et Pathologiae Respiratoriae* 2011; 2: 55–64.

5. Sokolov A.L., Lyadov K.V., Lutsenko M.M., Lavrenko S.V., Lyubimova A.A., Verbitskaya G.O., et al. The use of 1.56 µm laser radiation for endovasal venous obliteration in varicose vein disease treatment. *Angiologia i sosudistaa hirurgia* 2009; 1: 69–76.

6. Merseburger A.S., Herrmann T.R., Liatsikos E., Nagele U., Traxer O. *Lazery i lazernye tekhnologii*. Klinicheskie rekomendatsii Evropeyskoy assotsiatsii urologov [Lasers and laser technology. Clinical guidelines of the European Association of Urology]. *2011*.

7. Doganci S., Demirkilic U. Comparison of 980 nm laser and bare-tip fibre with 1470 nm laser and radial fibre in the treatment of great saphenous vein varicosities: a prospective randomised clinical trial. *Eur J Vasc Endovasc Surg* 2010; 40(2): 254–259, http://dx.doi.org/10.1016/j.ejvs.2010.04.006.

8. Pannier F., Rabe E., Maurins U. First results with a new 1470-nm diode laser for endovenous ablation of incompetent saphenous veins. *Phlebology* 2009; 24(1): 26–30, http://dx.doi.org/10.1258/phleb.2008.008038.

9. Rasmussen L.H., Lawaetz M., Bjoern L., Vennits B., Blemings A., Eklof B. Randomized clinical trial comparing endovenous laser ablation, radiofrequency ablation, foam sclerotherapy and surgical stripping for great saphenous varicose veins. *Br J Surg* 2011; 98(8): 1079–1087, http://dx.doi.org/10.1002/bjs.7555.

10. Almeida J., Mackay E., Javier J., Mauriello J., Raines J. Saphenous laser ablation at 1470 nm targets the vein wall, not blood. *Vasc Endovascular Surg* 2009; 43(5): 467–472, http://dx.doi.org/10.1177/1538574409335916.

11. Seitz M., Bayer T., Ruszat R., Tilki D., Bachmann A., Gratzke C., et al. Preliminary evaluation of a novel side-fire diode laser emitting light at 940 nm, for the potential treatment of benign prostatic hyperplasia: ex-vivo and in-vivo investigations. *BJU Int* 2009; 103(6): 770–775, http://dx.doi.org/10.1111/j.1464-410X.2008.08066.x.

12. Wezel F., Wendt-Nordahl G., Huck N., Bach T., Weiss C., Michel M.S., Häcker A. New alternatives for laser vaporization of the prostate: experimental evaluation of a 980-, 1,318- and 1,470-nm diode laser device. *World J Urol* 2010; 28(2): 181–186, http://dx.doi.org/10.1007/s00345-009-0499-5.