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# Impact of holmium fibre laser radiation ($\lambda = 2.1$ μm) on the spinal cord dura mater and adipose tissue*

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*Abstract.* **The impact of holmium fibre laser radiation on the samples of biologic tissues (dura mater of spinal cord and adipose tissue with interlayers of muscle) is studied. The experimental results are evaluated by the size of carbonisation and coagulation necrosis zones. The experiment shows that in the case of irradiation of the spinal cord dura mater samples the size of carbonisation and coagulation necrosis zones is insignificant. In the adipose tissue the carbonisation zone is also insignificant, but the region of cellular structure disturbance is large. In the muscle tissue the situation is opposite. The cw laser operation provides clinically acceptable degree of destruction in tissue samples with a minimal carbonisation zone.**

***Keywords:*** *holmium fibre laser, laser radiation impact on biologic tissues.*

## 1. Introduction

The growing interest in lasers with the radiation wavelength longer than 2 μm is caused by the wide field of their applications (monitoring of the air gas composition, environmental monitoring, spectroscopy, thermal vision, military technical applications, medicine, etc.) [1, 2]. The field of laser technology applications in medicine is permanently expanding. Thus, in urology [3], gynaecology, otorhinolaryngologic surgery [4], and orthopaedics [5], holmium solid-state lasers are widely used [6]. However, they operate only in pulsed mode of generation of high-energy long pulses with a repetition rate up to 20 Hz. Obviously, the existing variety of pathologies require different modes of operation, such that could be provided by fibre holmium lasers. Moreover, fibre lasers allow the reduction of cost of the laser itself and its maintenance.

The interest in lasers generating in the 2 – 2.4 μm range is caused by the specific absorption spectrum of lipid tissue, differing in this region from the absorption spectrum of water (Fig. 1) [7]. This fact allows affecting brain and spinal cord tumours that consist mainly of lipid tissue, without the formation of a considerable carbonisation zone, a distinctly seen black contour of carbonised tissue (increased content of carbon in the organic substance due to the action of heat, light, ionising radiations, or enzymes), and the zone of coagulation necrosis (disturbance of the cellular structure under the effect of laser radiation). These are the main reasons for interest in radiation sources operating in this spectral range. At present, lasing using silica fibres doped with holmium ions was obtained in the range 2 – 2.21 μm [8, 9]. The maximal attained output power amounted to 140 W [10], and the quantum efficiency – to 0.81 [11]. A high-efficiency holmium amplifier was also developed [12]. In Ref. [13] it was shown that under the effect of the holmium fibre laser radiation on biological tissue the haemostatic effect is observed [6].

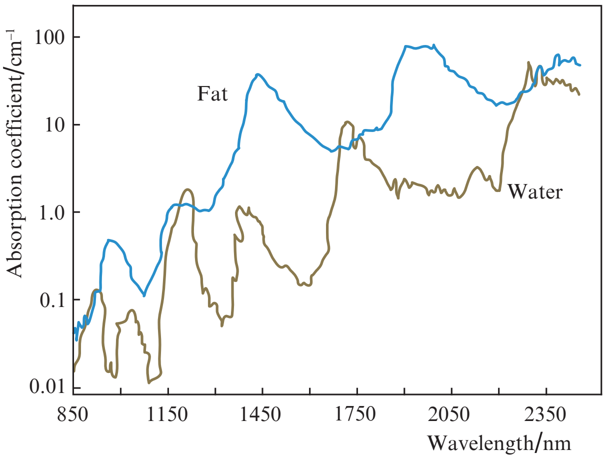

**Figure 1.** Absorption spectra of water and fat [7].

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Note, that one of the main lines of development in modern surgery are endoscopic methods. However, their application is limited by the absence of radiation sources, providing efficient impact on biological tissues (destruction and coagulation) and being compatible with surgical endoscopes. Such instruments can be designed on the basis of fibre lasers, possessing such advantages as high efficiency, stable output power, high quality of the output beam, compactness and lightness of the laser, and allowing the implementation of minimally-invasive surgery. That is why the field of application of fibre lasers for medical purposes is permanently expanding [14].

The present paper is devoted to the development of a cw holmium fibre laser with a radiation wavelength of 2.1 μm and to the experiments on contactless impact of laser radiation on porcine dura mater of spinal cord, adipose and muscle tissues. Note that such experiments have been never carried out previously. The results of the experiments were assessed mainly by the size of carbonisation and coagulation necrosis zones.

## 2. Materials and methods

### 2.1. Holmium fibre laser and its parameters

Figure 2 shows the schematic diagram of the used holmium fibre laser, which is pumped by an ytterbium fibre laser (the oscillation wavelength, 1.125 μm; the maximal power, 28.9 W) dual-end-pumped by laser diodes (the wavelength, 0.975 μm; the output power of each diode, up to 26 W).

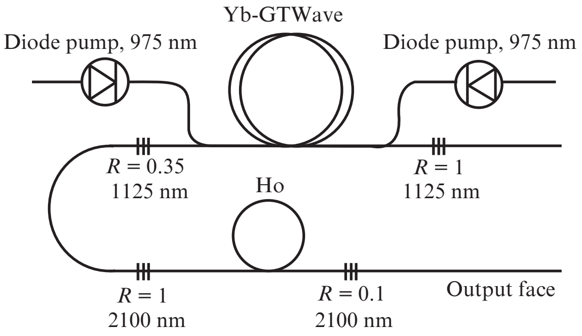


**Figure 2.** Schematic diagram of the holmium fibre laser.

The active medium of the laser was the optical fibre, doped with holmium ions, fabricated at the Perm Research and Production Instrument Making Company. The active dopant concentration was $5\times 10^{19}$ cm$^{-3}$, the core/cladding refractive index difference was 0.01, and the cutoff wavelength of the first higher mode was about 2 μm. The cavity of the holmium laser was formed by two input and output fibre Bragg gratings (FBGs) with the resonance wavelength 2.1 μm and the reflection coefficient 1 and 0.1, respectively. The holmium fibre laser of this design operates in continuous-wave (cw) mode. Its maximal output power reached 8.25 W and the efficiency was 30%. The spectrum of the output radiation from the holmium fibre laser is presented in Fig. 3, and the dependence of its output power on the pump power is shown in Fig. 4.

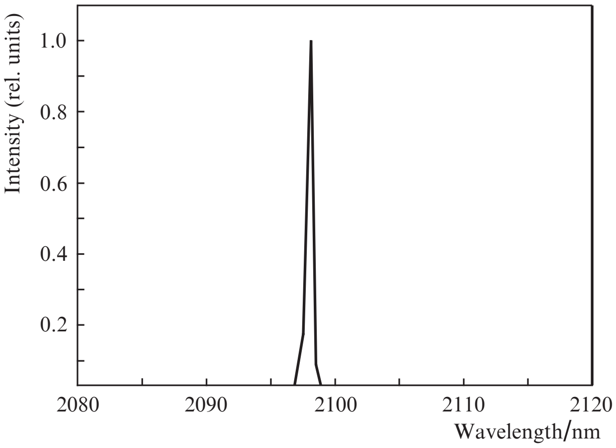


**Figure 3.** Emission spectrum of the holmium laser.

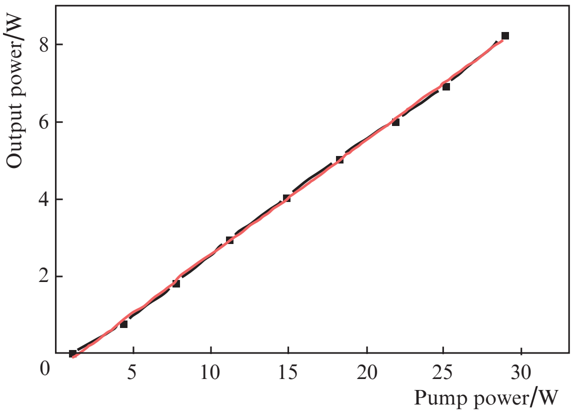


**Figure 4.** Output power of the holmium laser vs. the pump power.

### 2.2. Samples of biological tissues

As a material in question, we used specially prepared samples, namely, ten samples of the porcine spinal cord dura mater (size of 2 × 1 cm, thickness of 200–500 μm) (Fig. 5), ten samples of adipose tissue (2 × 3 cm, thickness of 7 mm) (Fig. 6) and ten samples of muscle tissue (2 × 3 cm, thickness of 5 mm). All samples were kept at room temperature; during the experiment they were placed in an aqueous medium, imitating the natural conditions. The laser beam was incident on the samples top-down strictly perpendicular to their surface. The distance from the face of the emitting fibre to the sample, the radiation power and the exposure duration were varied (3–5 mm, 3–8 W, 10–60 s). After the exposure the samples were frozen for the study of the surface damage. Then, at the site of the laser radiation impact the crosscut slices 20 μm thick were made. At the surface of the slices the dimensions of the carbonisation and coagulation necrosis zones were determined using a microscope. Before starting each experiment, the output face of the fibre was checked for the presence of dirt or surface damage; if necessary, it was cleaned and cleaved.

## 3. Results and discussion

The power of laser radiation, affecting the dura mater of spinal cord, varied from 5 to 8 W. The distance between the output face of the fibre and the tissue was 3 mm. After a few seconds

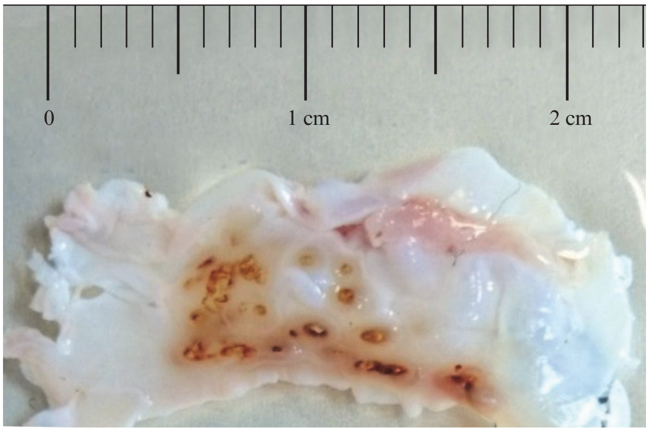


**Figure 5.** Porcine spinal cord dura mater sample after exposure to laser radiation.

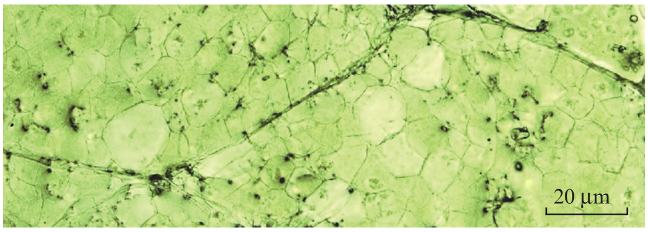
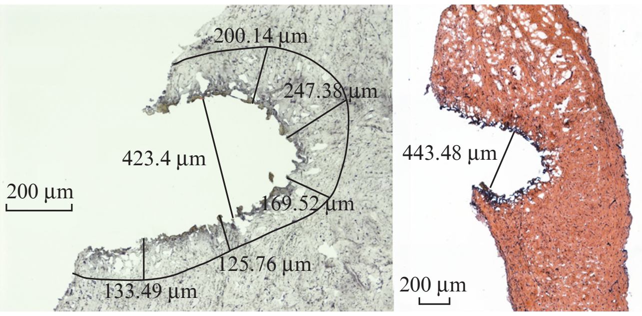


**Figure 6.** Intact sample of adipose tissue.

of exposure the effect of melting, distinct tissue deformation and burning was observed. After 20 s of exposure the through holes appeared in the samples (Fig. 7). The total irradiation time of the samples was 25 s. Figure 7 presents the samples of the spinal cord dura mater after laser irradiation. It should be noted that the resulting holes were mainly oval and had the size of 400–500 µm. In Fig. 7a the black line shows the zone of coagulation necrosis with the size 125–250 µm; one can also see a black contour at the hole boundary – the carbonisation zone, having the size as small as compared to the coagulation necrosis zone (within 10 µm). Figure 7b shows the stained sample of the spinal cord dura mater with a more distinct contour of the carbonisation zone. On average the size of the coagulation necrosis zone amounted to 190 ± 50 µm, and the size of the carbonisation zone – to 15 ± 7 µm.



a b

**Figure 7.** 20-µm-thick samples of spinal cord dura mater after exposure to laser radiation.

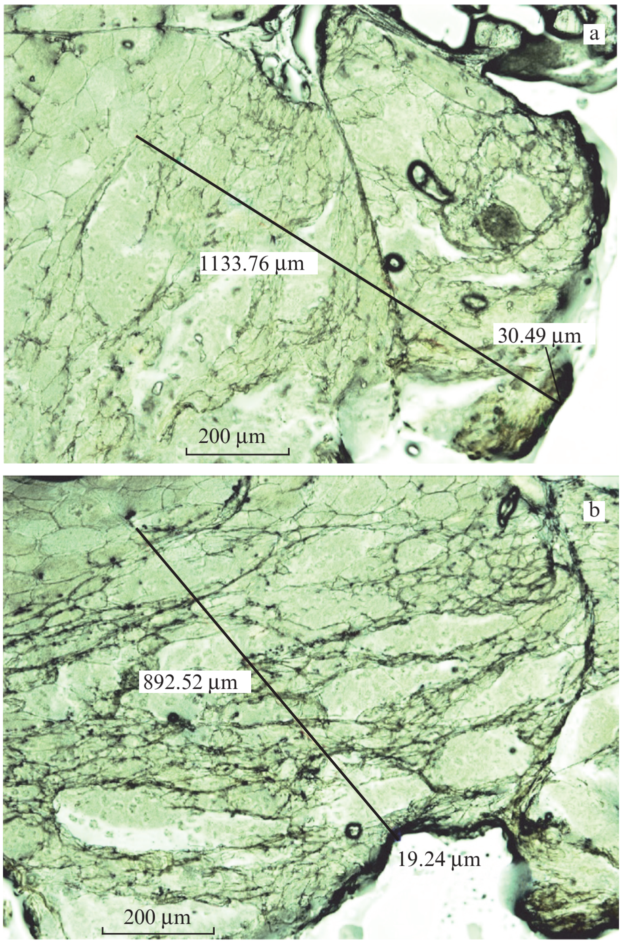


**Figure 8.** 20-µm-thick samples of adipose tissue after exposure to laser radiation.

The samples of adipose tissue after being exposing to laser radiation with a power of 3.5–5.5 W at a distance 5 mm are shown in Fig. 8. The result of the exposure is visible after the first 5 s of the experiment, the surface of the samples is gradually modified, the heating, melting and destruction of the adipose tissue occur. The total exposure time for the samples amounted to 50 s. After irradiation of the samples the depth of the adipose tissue destruction was 4–5 mm, the diameter of the resulting holes being equal to 3–4 mm.

In both figures the carbonisation area is clearly seen; the size varies from 20 to 35 µm. From the its of the resulting structure of the tissue surface with the surface of the adipose tissue in its usual condition (see Fig. 6) it is seen that after the laser impact the deformation (fusing) of adipose cells (coagulation necrosis) occurs, propagating into the tissue to the depth of 800–1200 µm. On average the coagulation necrosis zone size amounted to 1000 ± 200 µm, and the size of the carbonization zone was 20 ± 10 µm.

The experiments on contactless exposure of the adipose tissue to cw radiation of a semiconductor laser diode with the wavelength 0.91 µm and power 10 W were also carried out. No effect of such radiation could be observed. During the irradiation (5–10 min) the surface of the tissue did not change its structure significantly.

The samples of muscle tissue were exposed to the laser radiation with the power 3–5 W during 50 s from the distance 5 mm (Fig. 9). After 20 s of exposure the deformation of the tissue surface and its burning with smoke release was observed. The carbonised edges of the resulting hole are pro-

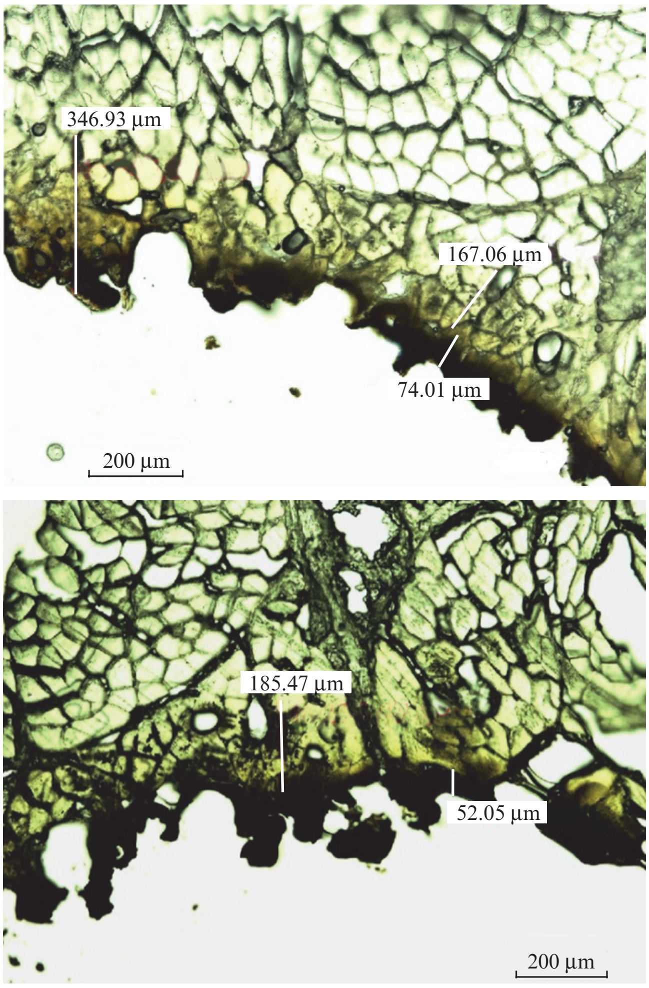


**Figure 9.** Samples of muscle tissue after exposure to laser radiation.

nounced, the size of the carbonisation zone being within the limits of 50–80 μm, which is larger than in adipose tissues. The zone size of coagulation necrosis (disturbance of cellular structure) equals 150–370 μm, which is considerably smaller than in adipose tissue. On average the size of the coagulation necrosis zone amounted to 170 ± 40 μm, and the size of the carbonisation zone was 60 ± 20 μm.

It should be noted that the result of the exposure of different biological tissues to the laser radiation depends, first of all, on their optical and thermal properties, namely, on the absorption and scattering coefficients, the density of the tissue and its components, as well as on the tissue saturation with water. Thus, in adipose tissue the absorption of radiation is determined by the absorption by haemoglobin, lipids and water (10.9% ± 1.4%), while in the muscle tissue – by haemoglobin and water (52.0% ± 0.3% and 73% ± 0.5%) [15]. This fact determines the different character of tissue destruction under the effect of laser radiation. The studies of the biological tissue destruction mechanisms (carbonisation and coagulation necrosis processes) under the action of cw laser radiation will be continued in more detail.

## 4. Conclusions

Thus, we have performed experiments on the impact of the holmium fibre laser radiation on the samples of different biological tissues. The evaluation criterion was the size of the carbonisation and coagulation necrosis zones. The experiments have shown that in adipose tissue the carbonisation is insignificant, but the region of cellular structure disturbance is large; in the muscle tissue the result is opposite. In the case of laser irradiation of the spinal cord dura mater tissue the zones of carbonisation and coagulation necrosis are not large. The preliminary results have shown that the cw regime of laser operation provides clinically acceptable character of the tissue sample destruction with minimal carbonisation. We can conclude that the radiation of the holmium fibre laser efficiently destructs the adipose tissue, but for better destruction efficiency the laser power should be increased.

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