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Doppler diagnostics of nonstationary mass removal upon laser ablation of biotissues

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Abstract. **The possibilities of the use of autodyne detection of backscattered radiation for studies of nonstationary mass transfer upon ablation of biotissues by pulses from a CO_2 laser are demonstrated. It is shown that the differences in the character of the laser-induced mass removal are caused by structural features of biotissues.**

Keywords: *laser radiation, ablation, biotissue.*

The laser ablation of biotissues is mainly caused by a local energy input resulting in phase transitions, intense evaporation, and mass removal in the form of a vapour-drop mixture and tissue particles. In the irradiated region, the velocity field of hydrodynamic flows is formed, which depends both on structural properties of the tissue and regimes of its irradiation. We showed earlier that the self-induced modi-fication of the laser output spectrum caused by the entry of backscattered radiation at the Doppler-shifted frequency into the laser cavity (autodyne effect) gives the information on the biotissue type directly in the process of its laser damage [1, 2]. In this paper, we use the autodyne detection of backscattered radiation (Fig. 1) for the real-time study of mass removal upon laser ablation of biotissues of different types.

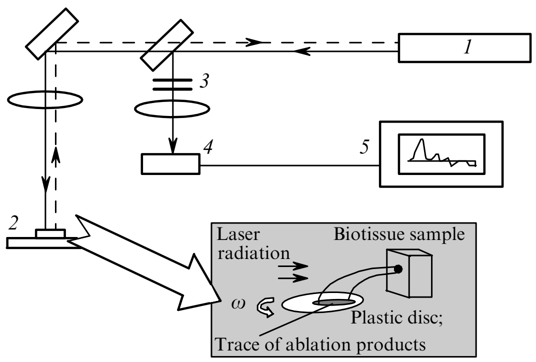

Figure 1. Schematic of the experimental setup: (*1*) CO_2 laser; (*2*) sample; (*3*) attenuator; (*4*) uncooled HgCdTe detector; (*5*) PC.

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Samples of pig liver and fat *in vitro* were irradiated by long ($t \sim 300$ ms) single pulses from a single-mode CO_2 laser. The radiation power density at the laser beam focus was 15 kW cm^{-2}. Directly in front of a sample in the horizontal plane, approximately at a distance of 1 mm from the laser beam axis, a disc rotating with a constant angular velocity was located parallel to the plane. The disc rotation provided the spatial-temporal distribution of the products of tissue destruction deposited on its surface. Simultaneously, a Doppler signal was detected with the help of an uncooled HgCdTe detector. The subsequent Fourier transform of the signal yielded Doppler spectra in the frequency range from 10 to 600 kHz. The integrated power S of the Doppler signal was used as a quantitative characteristic of its change during the laser pulse action.

Fig. 2 shows the change in S during irradiation by a laser pulse upon laser ablation of a fat tissue. The ablation of fat was accompanied by quasi-periodic ejections of the destruction products – fat drops of diameter from 15 to 300 μm. The arrows in Fig. 2 show the moments of the most intense ejections of products ('plumes') observed on the disc. One can see from Fig. 2 that the positions of the plumes coincide with the extrema of the dependence $S(t)$. The laser ablation of liver was accompanied by the uniform removal and deposition of irregular-shaped tissue particles of size 15 – 50 μm on the disc. Note that no oscillatory behaviour of the mass removal was observed. Fig. 3 shows the corresponding dependence $S(t)$.

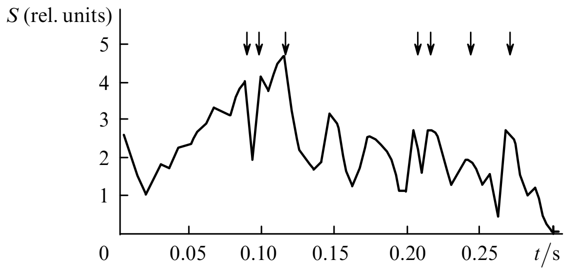

Figure 2. Dependence of the integrated power S of the Doppler signal on the time t of laser irradiation of the fat tissue.

The differences between the types of the mass removal upon laser ablation of fat and liver are caused, in our opinion, by structural properties of these tissues. The main component absorbing radiation of a CO_2 laser is water in tissues (the absorption coefficient $\mu \sim 830$ cm^{-1} at 10.6 μm). In the fat tissue, water is strongly localised and is mainly

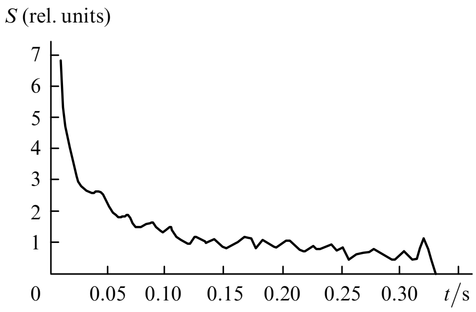

Figure 3. Dependence of the integrated power S of the Doppler signal on the time t of laser irradiation of the liver tissue.

contained in membranes separating fat globules. Its total weight content amounts to $\sim 30\,\%$. For radiation from a CO_2 laser, the fat tissue represents a heterogeneous absorbing medium, because substances contained in globules – fat acids and glycerides – are virtually transparent for this radiation ($\mu \sim 1$ cm^{-1} at 10.6 μm [3]). On the contrary, in liver, water is the main component (80 % in weight) and is uniformly distributed in the liver tissue.

These structural differences determine the character of the mass removal in these tissues. The liver ablation occurs predominantly by intense evaporation from the tissue surface, which is accompanied by the uniform removal of products (Fig. 3) – the mixture of water vapour, droplets, and small organic tissue fragments. The evaporation intensity decreases with increasing depth of a crater. During laser ablation of the fat tissue, the explosive boiling up of water localised inside the tissue dominates. The expansion of the overheated water vapour results in a rapid increase in the intratissue pressure, the destruction of membranes between fat globules and the abrupt ejection of the mixture consisting mainly of water vapour and the content of fat globules. At the initial ablation stage, until the intratissue pressure required for triggering of the mechanism of the volume destruction is achieved, evaporation dominates. The passage from the surface evaporation to the volume explosive boiling up and from a continuous removal of products to their pulsed ejection corresponds to the establishment of the oscillatory behaviour of $S(t)$ (approximately within 70 ms after the laser pulse onset, as shown in Fig. 2).

Thus, the differences in the character of the laser-induced mass removal are caused by structural properties of biotissues. The autodyne detection of backscattered radiation can be efficiently used for obtaining information on the mechanism of laser ablation of real biotissues as heterogeneous multicomponent systems.

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