EFFECT OF THERAPEUTIC DOSES OF OPTICAL RADIATION ON GAS COMPOSITION OF VENOUS BLOOD

G. A. Zalesskaya\textsuperscript{a} and O. V. Laskina\textsuperscript{b}  
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We have studied the effect of in vivo irradiation of blood by radiation at different wavelengths (254 nm, 632.8 nm, and 670 nm), which can be absorbed by blood, on the absorption spectra and gas composition of venous blood for individual patients. We have determined the differences in short-term and long-term changes in both spectral characteristics and the gas composition of blood induced by irradiation. During and immediately after irradiation, for all the patients we observed an increase in the partial pressure of oxygen and a decrease in the partial pressure of carbon dioxide in venous blood. After irradiation was completed, the changes in the partial pressures of blood gases were different for different patients: the gas pressures both increased and decreased, depending on the photo-induced changes in the level of hemoglobin oxygen saturation in venous blood.

Keywords: photobiostimulation, blood irradiation, absorption spectrum, blood gas composition, active oxygen species.

Introduction. To date, laser technologies have been extensively applied in various areas of medicine [1]. In studying the molecular mechanisms of action of low-intensity optical radiation on blood, it has been shown [2–5] that irradiation of blood by radiation at different wavelengths, which can be absorbed by blood, leads to photo-induced modification of the major blood protein hemoglobin. Photo-induced changes in the level of hemoglobin oxygen saturation in erythrocytes change oxygen delivery to the organs and tissues, making it possible to correct it in disturbances of oxygen exchange. Available information on the effect of in vivo blood irradiation by therapeutic doses of optical radiation on gas exchange in patients is sparse and contradictory. The ambiguity of results obtained in measurements of oxygen partial pressure in the blood of patients after irradiation by optical radiation has been discussed in a number of papers (see, for example, [6–9]). Thus in a review of the results of UV blood irradiation [8] obtained by US and German researchers, a discrepancy was noted only in the blood oxygen level. The US researchers reported an increase in oxygen partial pressure in arterial blood \((p_{a}O_2)\) persisting for more than a month, while German authors established an increase in \(p_{v}O_2\) and a drop in \(p_{e}O_2\).

The aim of this work was to study the effect of therapeutic doses of optical radiation at different wavelengths on the blood gas composition in patients with different initial degrees of disturbance of oxygen exchange caused by ischemic heart disease (IHD).

Study Procedure. We analyzed blood samples from IHD patients whose comprehensive treatment included blood irradiation by optical radiation at different wavelengths (254 nm, 632.8 nm, and 670 nm). The blood samples collected for analysis were stabilized by heparin. The course of treatment included five procedures (once daily) of extracorporeal UV irradiation of venous blood (UBI) \((\lambda = 254 \text{ nm}, \text{power density on the surface of the cuvet was 1.5 mW/cm}^2)\) or 10 intravenous laser blood irradiation (LBI) procedures \((\lambda = 632.8 \text{ nm or 670 nm}, \text{radiation power at the output of the optical fiber was 2 mW}; \text{irradiation time was 20–30 minutes}).

We compared the absorption spectra in the 200–1200 nm region of blood samples before and after irradiation; the level of hemoglobin oxygen saturation in venous blood \((S_vO_2)\) and arterial blood \((S_aO_2)\); the oxyhemoglobin level \((F_v(HbO_2))\); the oxygen partial pressure \((p_vO_2)\), the carbon dioxide partial pressure \((p_vCO_2)\). The absorption spectra in the 200–1200 nm region were recorded on a Cary 500 spectrometer (Varian, USA). In the 200–1200 nm range, the thickness of

\textsuperscript{*}To whom correspondence should be addressed.
the blood samples was varied from 40 μm to 1 mm, taking into account the absorption coefficient \( \mu_a \) and scattering coefficient \( \mu_s \), varying from 1300 to 2 cm\(^{-1} \) and from 13.5 to 2.5 cm\(^{-1} \) respectively [10]. The spectra were processed using OMNIC software. The level of the different hemoglobin fractions, the level of hemoglobin oxygen saturation in venous blood were measured spectrophotometrically on an ABL-800 (Radiometer, Denmark), which in a single measurement determines the transmission of the blood sample at 128 wavelengths in the interval 478–678 nm. The partial pressures of the blood gases were measured on an ABL-800 gas analyzer.

Results and Discussion. In the absorption spectra of the samples of irradiated blood, the shape of the Soret band, representing a superposition of the absorption bands from oxyhemoglobin and deoxyhemoglobin, changes and also there are changes in the absorption in the region of the doublet 540, 570 nm and absorption in the 600–1000 nm region, strongly dependent on the blood oxygenation level. In blood samples taken from patients during the irradiation procedure, changes in the spectra suggest increased oxygenation of the blood. For the absorption spectra of blood samples taken after completion of the irradiation procedure, increased absorption of deoxyhemoglobin in response to both UBI and intravenous LBI is characteristic. The maximum of the Soret band is shifted toward lower frequencies, the contribution of its low-frequency component increases; the dip between the bands in the doublet at 540 nm, 570 nm increases; the absorption of blood increases in the 600–1000 nm region (Fig. 1). The changes in the absorption spectra of blood were different over the course of treatment and also for different patients, but were similar for blood irradiation by radiation at the indicated wavelengths.

The results of the \( S_vO_2 \), \( F_v(HbO_2) \) measurements and the partial pressures of gases in venous blood show that blood irradiation initiates different short-term and long-term changes in these parameters. During irradiation or immediately after the end of the LBI or UBI procedure, we observed an increase in \( p_vO_2 \) in venous blood. Before the next procedure, the pressure \( p_vO_2 \) approached the initial value or became even lower than the initial value by the middle of the course of treatment, aggravating the oxygen deficiency in venous blood of IHD patients. The increase in \( p_vO_2 \) during irradiation and the subsequent drop by the beginning of the next session was repeated over the entire course of phototherapy (Fig. 2). The changes in the oxygen pressure during the procedure were accompanied by changes in \( S_vO_2 \) and \( F_v(HbO_2) \) in venous blood. In the samples of venous blood taken during irradiation, the changes in the partial pressure of CO\(_2\) are in a direction opposite to what is observed for O\(_2\). The pressure \( p_vCO_2 \) decreased during both the UBI and intravenous LBI procedure, and then increased by the beginning of the next procedure (Fig. 2).

After the end of the course of UBI, in the venous blood samples for 81% of the test patients both the oxyhemoglobin level \( F_v(HbO_2) \) and the level of hemoglobin oxygen saturation \( S_vO_2 \) decreased. The average values of \( S_vO_2 \) over the group decreased from 40% to 31%, while the average concentrations \( F_v(HbO_2) \) decreased from 42% to 32%. Analysis of the individual changes in \( \Delta S_vO_2 = [S_vO_2 (after) - S_vO_2 (before UBI)] \) and \( \Delta F_v(HbO_2) \) shows that for the same dose, they are different for different patients and depend on the initial values of \( S_vO_2 \). For an initial level of oxygen saturation in venous blood \( S_vO_2 < 40\% \), the photo-induced changes \( \Delta S_vO_2 \) are small. The oxyhemoglobin level \( (F_v(HbO_2)) \) in venous blood also dropped after the end of the course of intravenous LBI by radiation at \( \lambda = 632.8 \) nm and 670 nm, but to a lesser extent than for UBI.