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ORIGINAL ARTICLE

Study on the selection of laser wavelengths in the intravascular low-level laser irradiation therapy

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Abstract According to the absorption spectra of blood and hemoglobin, a photon-bond energy formula is established using physical methods and the effects on hemoglobin of low-level laser at different wavelengths are analyzed. The results show that lasers with the peak wavelengths of 200~240, 275, and 342 nm in the whole blood absorption spectra curve are easy to destroy protein molecules and then lead to hemoglobin lose biological activity. While lasers with wavelengths longer than 800 nm will reduce the oxygen carrying capacity of blood, only lasers with wavelengths between 630 and 670 nm have the best efficacy.

Keywords Low-level laser · Blood · Hemoglobin · Photon-bond energy formula

Intravascular low-level laser irradiation therapy (ILLLIT) was first introduced to China in 1991 and was widely applied. Its main roles included the following: improvement on indexes such as erythrocyte deformation index and erythrocyte rigidity index and influences on characteristics of red cell rheology; [1, 2] improvement on capacity of carrying oxygen of RBC and acceleration of blood oxygenation; [3, 4] correcting microcirculation; [5] adjustment of the immune system and enhancement of the immune function; [6] improvement of nerve cell metabolism, conduction, and adjustment of the nerve function; etc. [7]. Clinical research results confirmed that ILLLIT had a good curative effect on some diseases. It has been reported that more than 50 kinds of diseases can be treated by this method, including ischemic cardiovascular and peripheral vascular diseases (such as cerebral infarction, cardiac insufficiency, acute myocardial infarction and angina pectoris, etc.), infectious disease, autoimmune and connective tissue diseases, nervous and mental disorder, endocrine metabolic disease and acute cholecystitis, acute and chronic diseases such as bronchitis and pneumonia, etc. This method had remarkably curative effects on cardiovascular and cerebrovascular diseases, infectious diseases, and some nerve–mental illness [8–21].

Generally, the wavelength of the laser used in low-level laser therapy is not fixed; then, it is worth studying that low-level laser with what wavelength is better in therapeutic efficacy and what the principles are.

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Analysis of blood absorption spectra

Ultraviolet visible light spectrophotometer testing is used for test of absorption spectra; we can obtain the whole blood absorption spectra curve of the low-level laser with wavelength between 200 and 700 nm. As shown in Fig. 1 [22], there are several absorption peaks in the spectra, which are located at the wavelength of 200~240, 275, 342, 416, 540, and 578 nm. Therein, the highest absorption rate exists at the laser wavelength between 200 and 240 nm and the wavelength of 416 nm. The absorption rate is very low at the laser wavelength of more than 600 nm. As we can see from the whole blood absorption spectra, blood irradiation therapy by low-level laser at the peak wavelength of 200~240 nm and 416 nm seems to have the best efficacy. But whether it is true or not, we need to further analyze the effects on human body protein molecules of low-level laser. In low-level laser irradiation, the protein molecule in human blood will absorb a photon; then, the molecule will transit to some excited state from the ground state. And then, the molecule will transfer excessive energy through the relaxation process and returns back to the lowest energy level of the first excited state and then

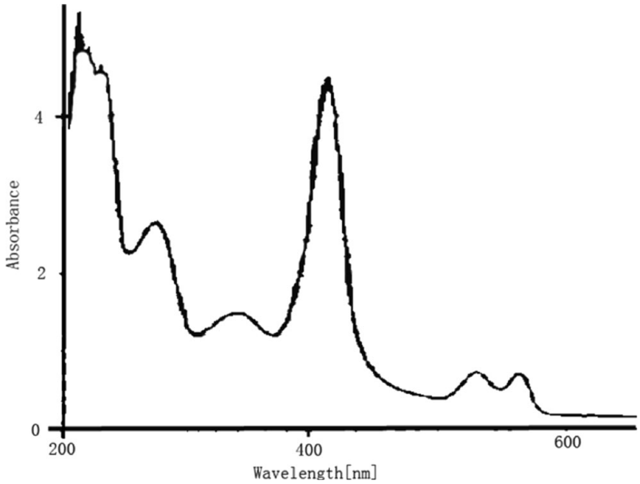

Fig. 1 Whole blood absorption spectra in 200~700 nm waveband

spontaneously back to the ground base by radiative transition. This process may produce the ground state molecules with high activity, which are different from the initial molecules. Those molecules would go into further reaction in the secondary process and play the role of treatment of diseases [23]. At the same time, there is a lot of chemical bonds in the primary structure of a protein, such as C–C bonds, C–H bonds, C–N bonds, C═O bonds, N–H bond, C–O bonds, and O–H bonds [24]. The energy of chemical bonds are roughly as follows: C–C bonds (332 kJ/mol), C–H bonds (414 kJ/mol), C–N bonds (305 kJ/mol), C═O bonds (728 kJ/mol), N–H bond (389 kJ/mol), C–O bonds (326 kJ/mol), and O–H bonds (464 kJ/mol) [25]. If the low-level laser is with high frequency, the photon energy absorbed by the protein molecule would exceed the energy of some chemical bond in the molecule and may cause damage to the chemical bond until the bond breaks. According to this principle, the photon-bond energy formula can be established.

$$N_A{*}hc/\lambda = E_1 + E_2 \tag{1}$$

wherein $N_A * hc/\lambda$ indicates the photon energy of 1 mol absorbed by the protein, E_1 indicates chemical bond energy, E_2 indicates the energy transferred out during the relaxation process, λ is the incident light wavelength, h is the Planck constant, c indicates the light speed, and N_A is Avogadro constant. The peak wavelengths in the whole blood absorption spectra curve are 200~240, 275, 342, 416, 540, and 578 nm, and the corresponding photon energies $N_A{*}hc/\lambda$ are 599~499, 435, 350, 288, 222, and 207 kJ/mol, respectively. According to formula (1), we can realize rupture of each chemical bond of which the bond energy E_1 is less than the photon energy $N_A{*}hc/\lambda$. It is obvious that low-level laser at the wavelengths of 200~240, 275, and 342 nm can break some chemical bonds of the protein and damage the protein structure; the photon energy of low-level laser at the wavelengths of 416, 540, and 578 nm is lower than the common chemical bond energy E_1 of protein; therefore, it will cause little damage to the protein structure. Nevertheless, given that the main content of blood proteins is hemoglobin, it is of vital significance to enhance the oxygen carrying capacity for treatment of many diseases. Therefore, study and analysis of the absorption spectra and oxygen carrying capacity of hemoglobin shall be carried out.

Analysis of hemoglobin absorption spectra

The absorption spectra curves at the waveband of 250–1000 nm are as shown in Fig. 2 [26]. There are two curves displayed in the figure, namely the absorption spectra curves of oxygenated hemoglobin (HbO_2) and deoxygenated hemoglobin (Hb). The two curves almost coincide with each other at the waveband of 250–580 nm. The two curves rapidly go down at the wavelength of 630–670 nm, but the HbO_2 drops faster. The minimum of HbO_2 curve appears at the wavelength of about 670 nm, and when the wavelength is longer than 800 nm, it starts to overtake Hb curve and the difference between the two curves is becoming increasingly bigger as the increase of wavelength. According to experience in clinical treatments, the laser has better medical effect at the wavelength between 630 and 670 nm. The He-Ne laser with the wavelength of 632.8 nm is used most commonly [23]. It is also shown in Fig. 2 that the HbO_2 curve and the Hb curve have the biggest interval when the wavelength is between 630 and 670 nm. Deoxygenated hemoglobin and oxygenated hemoglobin have the biggest difference in absorption of light energy at this waveband. In addition, the absorption of light energy by deoxygenated hemoglobin is far better than that of oxygenated hemoglobin. Because the absorption of photon energy causes transition of electron in the hemoglobin molecule and provides energy for chemical reaction processes of

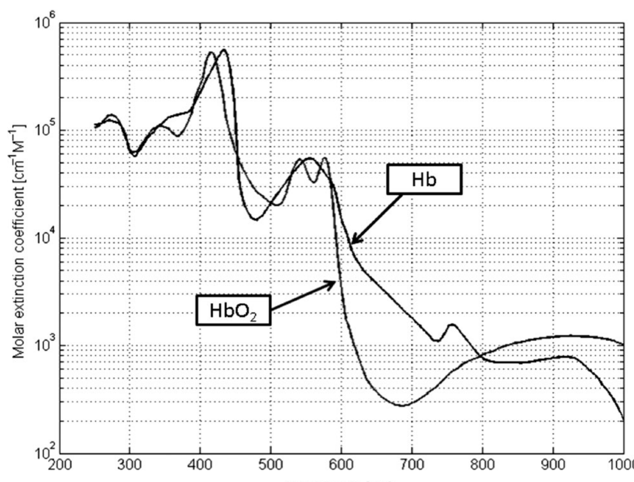

Fig. 2 Absorption spectra of hemoglobin in 250~1000 nm waveband

biomolecules, not only it could improve the combination of deoxygenated hemoglobin and oxygen but also help the oxygenated hemoglobin release oxygen. The two reactions occur at the same time, but since the light absorption rate of deoxygenated hemoglobin is far greater than that of the oxygenated hemoglobin, low-level laser irradiation would produce more oxygen combined than released, thereby the oxygen carrying capacity of erythrocyte. Besides, according to the photon-bond energy formula, the absorbed photon energy $N_A * hc/\lambda$ of low-level laser at the wavelength of 630~670 nm is 190~179 kJ/mol, which is lower than the common chemical bond energy of protein. Thus, it will cause little damage to the protein structure than lasers with the wavelengths of 200~240, 275, and 342 nm. HbO_2 and Hb curves basically coincide with each other at the wavelengths of 250~580 nm, and the difference between light energy absorption of them is relatively small. Therefore, low-level laser at the wavelengths of 416, 540, and 578 nm is not so helpful in promoting the oxygen carrying capacity of hemoglobin. At last, it is shown in Fig. 2 that the HbO_2 curve and the Hb curve intersect at the wavelength of about 800 nm, when deoxygenated hemoglobin and oxygenated hemoglobin have the same absorption rate of light energy. When the wavelength exceeds 800 nm, the HbO_2 curve overtakes the Hb curve, wherein HbO_2 begins absorbing more light energy than Hb and the promotion of oxygen release by oxygenated hemoglobin is stronger than the promotion of oxygen binding by deoxygenated hemoglobin, which means the low-level laser irradiation cannot improve the oxygen carrying capacity of hemoglobin but accelerate the release of oxygen carried by the blood instead.

Conclusion

According to the blood and hemoglobin absorption spectra and the photon-bond energy established in this paper, we can come to the conclusion that low-level laser with the peak wavelengths of 200~240, 275, and 342 nm in the whole blood absorption spectra curve tends to damages protein molecules and deprive the hemoglobin of its biological activity; irradiation by low-level laser with wavelength longer than 800 nm accelerates release of oxygen carried by the blood; only the low-level laser with wavelengths of 630–670 nm can improve oxygen carrying of the blood. This conclusion provide theoretical guidance for clinic selection of wavelength of low-level laser and some reference for treatment of nervous system diseases, cardiovascular diseases, pneumonia, and infectious diseases of each department, in which the blood is involved. While the blood irradiation therapy by low-level laser is highly complicated in that various reactions occur at the same time, therefore, further study is yet to be carried out.

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