

Laser system for analysis of microcirculation of tissue in the maxillofacial region when assessing the effectiveness of implant treatment

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ABSTRACT

This article examines the prospects of using the photoplethysmographic method to assess microcirculatory changes in peripheral blood circulation in the maxillofacial region to study the processes that occur when assessing the effectiveness of implant treatment. Studies have shown that the combined use of drugs with hepatoprotective (ursochol) and osteoinductive (osteogenon) effects contributes to improving blood supply to the jaw area and soft tissues, increasing the elasticity of blood vessel walls, erythrocyte elasticity, oxygen transport function of blood, activity of cell membranes, acceleration of tissue regeneration processes, reduction of lipid oxidation, normalization of blood rheological parameters, stimulation of ATP formation in mitochondria, which increases the bioenergetic potential of cells, which has a positive effect on dental implants by improving their engraftment and reducing the number of postoperative complications.

Keywords: propagation of laser radiation, optic-electronic system, photonic therapy, microcirculation

1. INTRODUCTION

Modern dentistry, in particular dental implantation, is rapidly developing and is becoming more accessible and in demand among various categories of patients. One of the key factors for successful implant treatment is ensuring full osseointegration, which largely depends on microcirculation in the implantation area and effective blood supply to bone tissue. The microcirculatory bed itself plays a critical role in providing nutrition to osteoblasts, maintaining metabolic activity and forming new bone around the implant. Microcirculation disorders can lead to insufficient blood supply, tissue hypoxia, deterioration of regenerative processes and, as a result, a decrease in the effectiveness of the implantation intervention^{1,2,3}.

Patients with systemic diseases, in particular with chronic liver pathology, are of particular clinical complexity. The liver is the central organ of metabolism, participating in the synthesis of proteins, blood clotting factors, and the regulation of lipid and carbohydrate metabolism. With its functional disorders, systemic changes occur that affect not only the general condition of the body, but also the processes of regeneration, homeostasis and microcirculation. Such patients have disorders of the coagulation system, decreased immune defense, changes in the structure of the vascular wall, which significantly increases the risks of postoperative complications and complicates the course of osseointegration^{3,4,5}.

Despite the large number of scientific works devoted to dental implantation, the specifics of the course of osseointegration processes in conditions of liver pathology, taking into account changes in the microcirculatory bed of the jaws, have not been sufficiently studied. There is a need for a deeper study of the pathogenetic mechanisms of the influence of liver dysfunction on the state of bone tissue, in particular in the areas of planned implant placement. This will not only improve the quality of planning and implementation of implant treatment in complex clinical cases, but will also contribute to reducing the frequency of complications and increasing the long-term stability of implants^{6,7,8}.

Therefore, the study of the microcirculation features in the jaw bones of patients with liver pathology, as well as their impact on the osseointegration process, is extremely relevant. This opens up new prospects for an individualized

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approach in implantology and allows for the improvement of treatment protocols for patients with concomitant somatic diseases^{9,10}.

2. ANALYSIS OF METHODS AND TECHNOLOGIES FOR STUDYING TISSUE MICROCIRCULATION IN THE MAXILLOFACIAL REGION

Currently, there is considerable interest in the development of specific, sensitive, inexpensive and portable optoelectronic devices specifically adapted for optical sensing. Recent developments of new sensitive and selective materials play an important role in measuring optical parameters, in particular tissue microcirculation. In addition, fiber-optic technology is widely used in many optical measurement processes due to its important advantages, such as noise immunity and the possibility of its use for remote and multi-position measurements^{11,12,13}.

Assessment of the state of tissue microcirculation is one of the key problems in the implementation of biomedical technologies for modern medical diagnostics. Many diseases, such as arterial hypertension, atherosclerosis endotoxemia, diabetic nephropathy, sepsis, diabetes mellitus, venous insufficiency, Covid-19 and others, are associated with tissue microcirculation disorders^{14,15,16}.

Assessment of microcirculation when assessing the effectiveness of implant treatment of the maxillofacial region is an important component of monitoring the effectiveness of treatment and timely detection of complications. Microcirculation provides tissue trophism, supply of immune cells, removal of toxins and decay products, therefore its condition directly affects the course of the inflammatory process and healing.

The most widespread are Laser Doppler flowmetry (LDF) and optical tissue oximetry (OTO). From the point of view of physics, optical methods of treatment and diagnostics are characterized by noise immunity to electromagnetic interference of the optical signal and the potential possibility of providing parallel transmission of information. At the same time, these methods allow for fairly accurate determination of qualitative and quantitative indicators and the state of biological objects. The LDF method allows for the assessment of tissue perfusion during blood supply (microcirculation level indicator (MLI)) based on the assessment of the microcirculatory bed of the biotissue, as well as the frequency rhythms of microhemodynamic processes. The OTO method is based on spectrophotometric analysis of hemoglobin indicators in vivo and allows for the assessment of metabolic processes and blood saturation index in microvessels. However, each of these NMS methods is not self-sufficient for monitoring the full range of tissue microcirculation indicators. Some of them have significant limitations, in particular, insufficient accuracy^{17,18,19}.

Some of the above methods have significant limitations, such as insufficient spatio-temporal resolution, limited information during deep scanning of biotissues, as well as a certain invasiveness of measurements, etc. NMS methods and corresponding devices (with the exception of pulse oximeters) are considered indicator ones, since they allow assessing the relative levels of registered biomedical indicators and general trends in the dynamics of measurements without a strict link to their absolute values. The reliability and overall informativeness of diagnostic examinations performed using NMS largely depend on the correct choice of measurement methods and approaches to interpretation and analysis and results of patient examinations^{20,21,22}.

Thus, when conducting differential diagnostics (definition of "norm-pathology"), an important role in the interpretation of the results is played by the selected ranges of examination and careful selection of statistical data of the norm for specific anatomical and topographic points. Since NMS methods are a relatively new diagnostic approach implemented using new technologies, today there are no statistical data that fully assess the value of various indicators for different localizations of optical sensors on the patient's body in the norm, as well as in various pathologies. The optimal solution is the creation and further use in clinical practice of a multispectral laser fiber-optic system (optical tissue oximeter, speckle image contrast analyzer of the biological surface), a fiber-optic pyrometric thermometer, a Doppler fluorometer, which will allow monitoring the widest possible range of indicators of tissue microcirculation in the shortest possible time^{23,24}.

Due to the need for accurate assessment of the main indicators of tissue microcirculation of blood flow in normal and pathological conditions, various researchers have proposed a large number of indirect methods, including, for example, polarographic, thermographic, radioisotope and a number of other methods. The main optical methods include the following methods: biomicroscopic, microcinematographic, photoelectric microplethysmography and photoplethysmographic^{1,3,7}.

In connection with the above, the improvement of photometric methods and the development of optoelectronic devices for the comprehensive study of the spectral characteristics of biological tissues and qualitatively new methods for

measuring the main indicators of hemodynamics of these biological tissues, as well as the creation of measuring devices based on them that combine sufficient accuracy and reliability of the measurements being made, is an urgent task and has practical value²⁵.

3. PHYSICAL MODELING OF THE INTERACTION OF OPTICAL RADIATION WITH BIOTISSUE

The value of the intensity of the optical radiation that is recorded depends on such parameters as the thickness of the biological tissue, the angle of the sensor installation, and the wavelength and is determined as follows

$$I = I_0 - (I_{loss.rad} + I_{loss.scatt.} + I_{loss.abs.}), \quad (1)$$

where I_0 is the intensity of the incident radiation on the biological tissue; $I_{loss.rad}$ is the loss of radiation intensity depending on the angle of the sensor; $I_{loss.scatt.}$ is the loss of radiation intensity during scattering; $I_{loss.abs.}$ is the loss of radiation intensity during absorption.

Figure 1. shows the features of the penetration depth of the optical range at different wavelengths. In this case, the loss of optical radiation intensity is estimated by the value of the sensor installation angle on the studied biological tissue as follows:

$$I_{loss.scatt} = I_0 + I_{loss.scatt,sensor}, \quad (2)$$

$$I_{loss.scatt,sensor} = I_0 \cdot \frac{T_{opt} \cdot \pi \cdot r^2}{L^2} \cdot \cos \alpha \cdot \cos \beta, \quad (3)$$

where I_0 is the intensity of the incident radiation on the biological tissue; ($I_0 = J / l^2$, where J is the power of the source, l is the distance between the light source and the surface of the biological tissue); τ_{opt} is the coefficient that determines the transformation of optical radiation through an inhomogeneous medium ($0.9 \div 0.95$); L is the distance between the biological tissue and the photodetector; α is the angle of the incident light on the photodetector area; β is the angle between the normal to the surface and the incoming light.

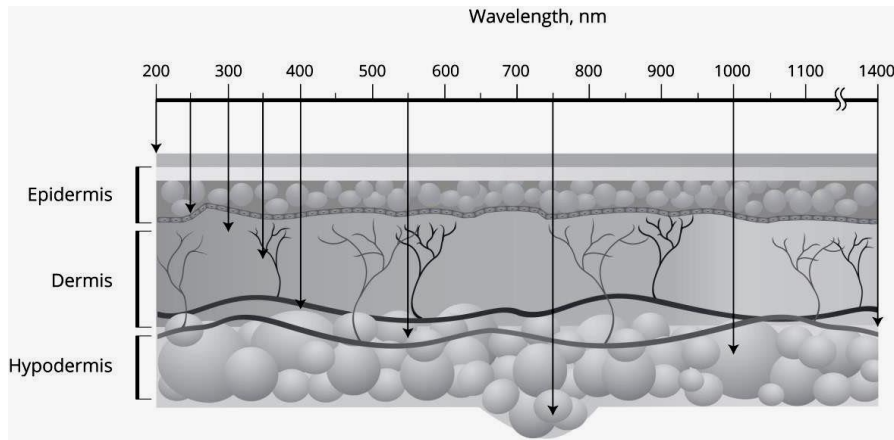


Figure 1. Depth of light penetration at different wavelengths of the optical range

Equation (2) with some transformations has the following form:

$$I = I_0 \cdot \left(1 - \left(\left(1 - \frac{T_{opt} \cdot \pi \cdot r^2}{L^2} \cdot \cos \alpha \cdot \cos \beta \right) + (1 - \exp(-(\mu_{t_1}(\lambda) + (\mu_{t_2}(\lambda) + \dots \mu_{t_n}(\lambda))z))) \right) \right),$$

where $\mu_{t_1}(\lambda) \dots \mu_{t_n}(\lambda)$ are extinction coefficients for different skin layers, and $\mu_t(\lambda) = \mu_s(\lambda) - \mu_a(\lambda)$.

The combination of these wavelengths allows you to effectively study tissue microcirculation, determine the degree of blood oxygen saturation, as well as hemodynamic indicators of peripheral circulation disorders, in particular in field injuries of varying severity.

Figure 2 shows a laser stand for determining the degree of absorption of biotissue (pig skin) in IR (830 nm) and red (658 nm). Figures 3 and 4 present the results of studies of changes in the absorption index μ_{abs} of laser radiation in the red (658 nm) and IR (830 nm) optical range from 200 nm to 1100 nm.



Figure 2. Laser stand for determining the absorption coefficient of biotissue in IR (830 nm) and red (658 nm)

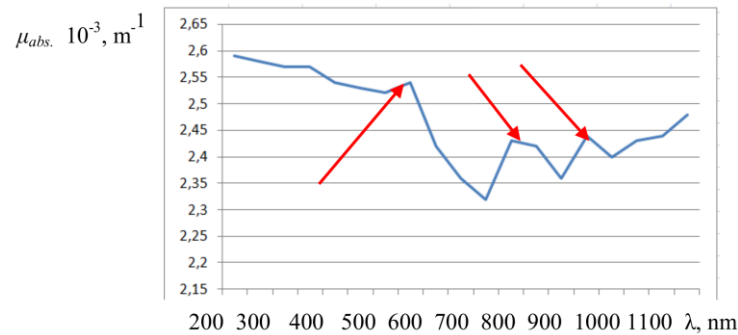


Figure 3. Results of studies of laser radiation absorption in red (658 nm) and changes in the absorption index

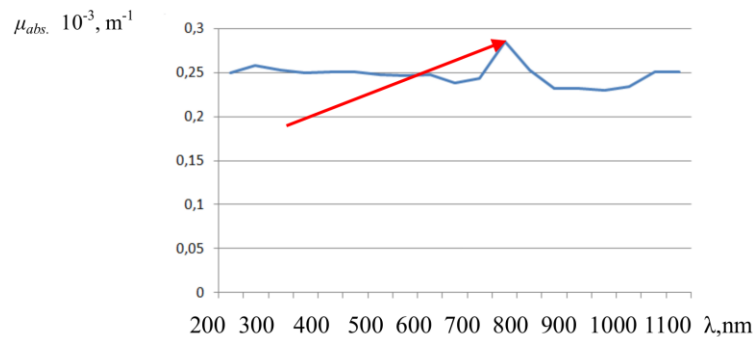


Figure 4. Results of studies of laser radiation absorption in the red IR (830 nm) and changes in the absorption index

4. METHODS OF ASSESSING TISSUE MICROCIRCULATION

1. Capillaroscopy (including videocapillaroscopy) provides visualization of the capillary network on mucous membranes or skin.

Allows you to assess:

- capillary density
- blood flow velocity

- presence of microthrombi
- shape of capillary loops

2. Laser Doppler flowmetry (LDF) allows you to quantitatively assess blood flow in microvessels.

Allows you to determine:

- vascular tone
- pulsatile oscillations
- tissue hypo- or hyperperfusion

3. Thermography.

- Indirect method. Using infrared imaging, tissue temperature is recorded, which correlates with blood flow intensity.
- The microcirculatory resistance index is used when combining LDF and blood pressure.

4. Biochemical markers of microcirculation disorders

Clinical significance:

- Allows objectification of tissue condition and treatment effectiveness
- Allows prediction of recovery
- Is critical for identifying the risk of purulent-septic complications

5. RESULTS OF THE STUDY

Clinical examination of patients was carried out on the basis of the Department of Surgical Dentistry and Maxillofacial Surgery of the Vinnytsia National Medical University named after M. I. Pirogov in the Department of Maxillofacial Surgery of the Vinnytsia Regional Clinical Hospital named after M. I. Pirogov. The studies were performed in compliance with the main provisions of the “Rules of Ethical Principles for Conducting Scientific Medical Research with Human Participation”, approved by the Declaration of Helsinki (1964-2013), ICH GCP (1996), EEC Directive No. 609 (dated 11/24/1986), orders of the Ministry of Health of Ukraine No. 690 dated 09/23/2009, No. 944 dated 12/14/2009, No. 616 dated 08/03/2012. All patients gave voluntary written informed consent to the examination in advance.

Patients were referred to departments from various state institutions and commercial clinics, and also applied for consultation and treatment independently. The studies were conducted in the period from 2024 to 2025.

The effectiveness of patient treatment was assessed based on the laser device for tissue microcirculation analysis, developed at the Department of Biomedical Engineering and Optoelectronic Systems of Vinnytsia National Technical University (Fig. 5).

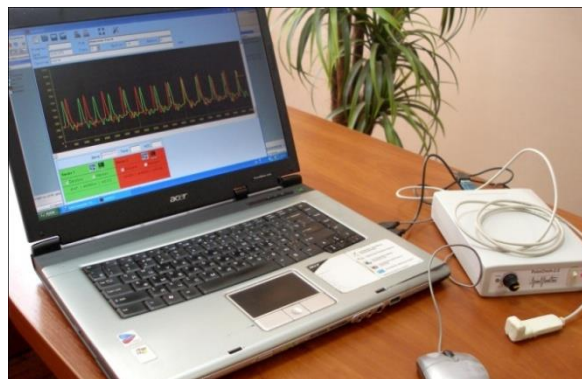


Figure 5. Laser device for tissue microcirculation analysis

During the study, all patients were divided into 4 groups:

1. Control (n=12) – included patients without comorbidities who underwent dental implant surgery.
2. Comparison (n=12) – included patients with hepatobiliary system pathology who underwent dental implant surgery.

3. Main (n=15) – included patients with hepatobiliary system pathology who underwent dental implant surgery, and were also prescribed medication support with the hepatoprotective drug ursocol and the osteotropic drug osteogenon.

Tissue microcirculation studies were performed in all groups in the dynamics of observation – 14 days before dental implant installation (initial state), and 14 and 30 days after dental implant installation against the background of drug treatment.

The results of the study are presented in Fig. 6 and summarized in Table 1 and Fig. 7.

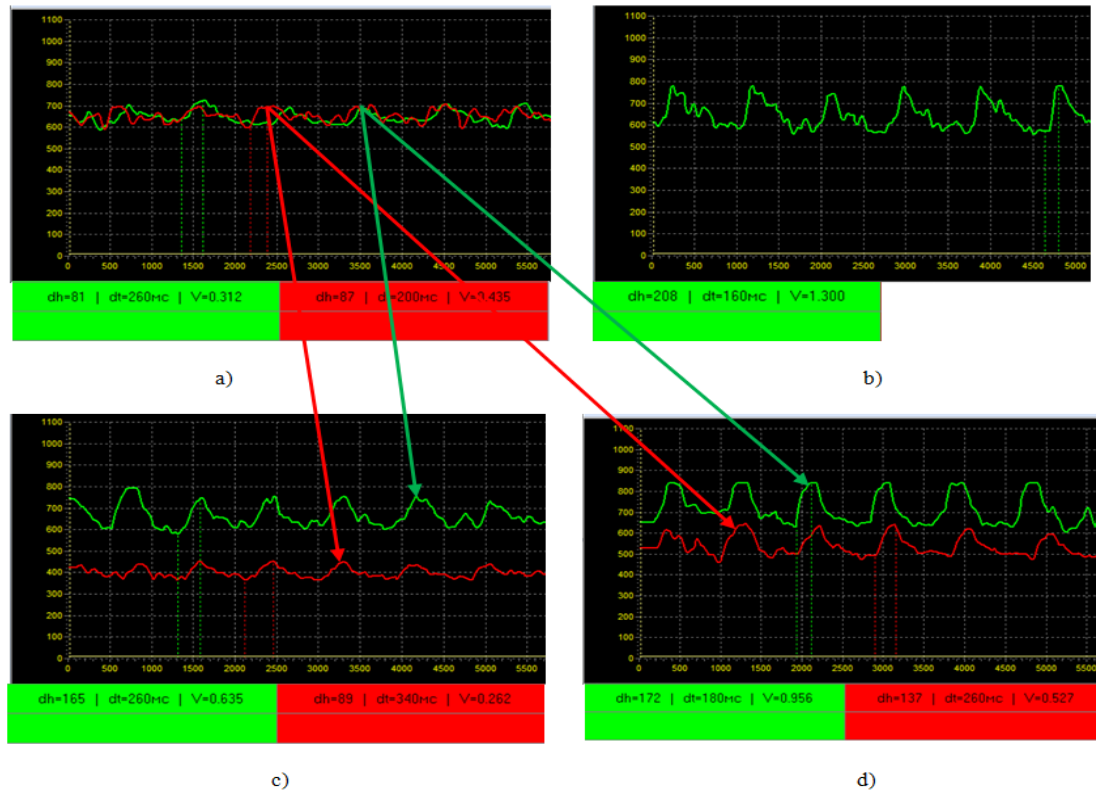


Figure 6. Study results and their comparison a) 14 days before dental implants (baseline), b) control group, c) 14 days after dental implants on the background of drug treatment, e) 30 days after dental implants on the background of drug treatment.

Table 1. Study results

Day of dental implant placement	Blood supply level, conventional units	Comment
After 14 days (1)	$81 \pm 9,5 \%$ ($p < 0.05$)	Hyperperfusion, active inflammation
After 14 days (2)	$165 \pm 8,5 \%$ ($p < 0.05$)	Improvement of venous outflow
After 30 days (3)	$172 \pm 11,5 \%$ ($p < 0.05$)	Normalization of microcirculation
Normal (4)	$208 \pm 10,5 \%$ ($p < 0.05$)	

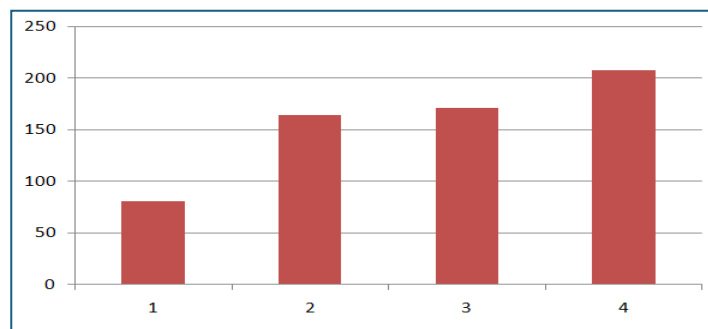


Figure 7. Comparison of the results of the study

The initial values of the microcirculation level indicator (H) 14 days before the installation of dental implants are $81 \pm 9.5\%$ (for 14 days), which is 38.9% ($p < 0.05$) in relation to the microcirculation value (H) in the control group, the initial values of the microcirculation level indicator (H) 14 days after the installation of dental implants (initial state) were $165 \pm 8.5\%$, which is 79.3% ($p < 0.05$) in relation to the microcirculation value (H) in the control group, the initial values of the microcirculation level indicator (H) 14 days after the installation of dental implants (initial state) were $172 \pm 11.5\%$, which is 82.6% ($p < 0.05$) in relation to the microcirculation value (H) in the control group.

6. CONCLUSIONS

The prospects of using the photoplethysmographic method for assessing microcirculatory changes in peripheral blood circulation in the maxillofacial region were considered for studying the processes that occur when assessing the effectiveness of implant treatment.

Studies have shown that the combined use of drugs with hepatoprotective (ursochol) and osteoinductive (osteogenon) effects contribute to improving blood supply to the jaw area and soft tissues, increasing the elasticity of blood vessel walls, erythrocyte elasticity, oxygen transport function of blood, activity of cell membranes, accelerating tissue regeneration processes, reducing lipid oxidation, normalizing blood rheological parameters, stimulating ATP formation in mitochondria, which increases the bioenergetic potential of cells, which has a positive effect on dental implants by improving their engraftment and reducing the number of postoperative complications.

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