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Analysis of microcirculatory disorders in inflammatory processes in the maxillofacial region on based of optoelectronic methods

Abstract*. This article discusses the use of photoplethismographic method for the analysis of inflammatory processes. The aim is to show the effectiveness of using of photoplethismographic method in the analysis of the microcirculation level of peripheral vascular in inflammatory processes. As a result of researches that carried out at the Department of Maxillofacial Surgery of the Vinnitsa National Medical University, it was examined 30 patients (21 men and 9 women aged 20 to 60 years) with odontogenic abscesses and phlegmon. Treatment of patients included removal of the causative tooth, opening cellulitis or abscess, ozone therapy with silver ions. Application of this method allows dentists accurately determine: the effectiveness of the treatment; specify the duration of the rehabilitation period; identify various vascular disorders in fractures of the jaw; to evaluate the effectiveness of local anesthesia; to apply this method to plastic surgery and transplantation.*

Streszczenie. *W artykule przedyskutowano użycie metod fotopletyzmograficznych do analizy procesów zapalnych. Celem jest pokazanie skuteczności użycia metod fotopletyzmograficznych w analizie mikroprzepływów w naczyniach obwodowych w procesach zapalnych. W wyniku badań przeprowadzonych w Katedrze Chirurgii Szczękowo-twarzowej Winnickiego Narodowego Uniwersytetu Medycznego przebadano 30 pacjentów (21 mężczyzn i 9 kobiet w wieku 20 – 60 lat) z zębopochodnymi ropniem i ropowicą. Leczenie pacjentów obejmowało usunięcie zębów będących przyczyną zakażenia, otwarcie chorej tkanki łącznej lub ropnia, terapię ozonową z jonami srebra. Zastosowanie tej metody pozwala dentyście dokładnie określić: skuteczność leczenie, określić czas trwania rehabilitacji, zidentyfikować różne zaburzenia naczyniowych przy złamaniach szczęki, ocenę skuteczności znieczulenia miejscowego oraz wykorzystać ją w chirurgii plastycznej i przeszczepach.* ***(Analiza zaburzeń mikrokrążenia w procesach zapalnych w obszarze szczękowym na podstawie metod optoelektronicznych.)***

Keywords: photoplethysmographic signal, peripheral blood circulation, optical electronic sensor, maxillofacial region.
Słowa kluczowe: sygnał fotopletyzmograficzny, krążenie obwodowe krwi, czujnik optoelektroniczny, obszar szczękowy.

Introduction

In order to find out optimal solution, non-invasive methods of diagnostics based on optical registration and transformation of biomedical information, especially in cases, where these methods don't have real alternative have gained wide application nowadays.

Intensive research, carried out in the sphere of "reflective" pulse metering allows to make a conclusion that a number of such devices equipped with universal optical transducers are due to appear in the near future. The main advantage of the given method is the possibility to carry out measurements practically at any point of the body, that permits to apply different modifications of optic devices for the solution of a number of special tasks, connected with the investigation of local bloodstream (determination of hemodynamic indications of bloodstream, diagnosis of microcirculation disorders in spinal-moving segments, determination of disorders of microcirculation level in jaw-facial area ect.) Besides, depending of peculiarities of measurement method being applied, such biomedical indications can be evaluated as general concentration of hemoglobin, relative blood filling of tissue, being investigated, general saturation of the blood (level of blood saturation with oxygen), general concentration of bilirubin.

Thus, it is obvious that the most promising approach regarding registration of physiological parameters is the application of non-invasive methods of diagnostics. Methods, most widely used are optical methods of registration and transformation of biomedical information.

In the pathogenesis of odontogenic inflammatory diseases, an important role plays disruption of blood circulation in the tissues of the maxillofacial region as consider many authors (V.M. Uvarov, M.M. Solovyev, T.M. Alehova). These statements are based on the topographic anatomical, morphological studies and on data of studying the blood coagulation. However, all of these methods allow only indirectly define the state of the regional blood flow [1]. Therefore, use of such actual methods as rheoplethismography and photoplethismography is very perspective. These methods allow studying the pathogenesis of periodontal disease, periodontitis, mumps and other pathological processes in the maxillofacial region.

Materials and methods

In recent years, in the practice of functional diagnostics are introduced photoplethismographic methods for registration of biosignals [2, 3].

These methods based on irradiation the area of the tissue of the biological object (BO) by infrared (IR) beam and recording, transmitted through the tissue or reflected from it radiation by optoelectronic sensor. The use of optoelectronic sensors has provided new opportunities for the diagnosis of the state of the cardiovascular system.

The main advantage of this method – it is the possibility of measuring the microcirculation level almost anywhere in the body surface, that allows to use the different modifications of optical devices to solving a number of specific tasks related to the study of indicators of local blood flow (diagnosis of microcirculation in spinal motion segments, assessing the state of the microcirculation of the lower legs in the disease of the systemic lupus erythematosus (SLE), vascular state assessment in the maxillofacial region in inflammatory processes, analysis of hemodynamic blood flow in pulse diagnosis, and etc.). Furthermore, depending on the particular method of measurement may be estimated such parameters as the biomedical total concentration of hemoglobin, total blood oxygen saturation (the degree of oxygen saturation), total bilirubin concentration. Photoplethismographic curve shows

the phase changes of blood filling of the peripheral vascular in inflammatory processes respectively cardiac cycle.

Quantification assessment of photoplethismographic curve was performed on the amplitude and time characteristics. The most informative indicators that characterize the blood filling and vascular walls state are: duration of anacrotic phase, photoplethismographic pulse (PP), the fast and slow blood filling, an indicator of vascular tone (TCP), the index of peripheral blood filling (IEF), dicrotic index (DI), diastolic index (DS) [4].

Due to its non-invasive, miniaturization of the sensors, speed, simplicity of hardware implementation, these methods are used for monitoring the condition of the microcirculation of the maxillofacial region in inflammatory processes [5, 6, 8].

To improve the reliability of received photoplethismofraphic information uses a priori information, including the physical characteristics of the measurement object, the mathematical relation between the measured values, the data about the spectral composition of informative components and noise and also basic biophysical characteristics of the controlled object.

To solve this problem are used the following approaches:

1. If light emitting diodes and (or) a photodetector in the sensor are in an inoperable state, the signal level in the channel is close to zero.
   Sensor is operational only if the inequalities are performed:

(1) $$\begin{cases} \mathrm{A}_{\max 1}(\mathrm{t}) \geq \delta_1 \\ \mathrm{A}_{\max 2}(\mathrm{t}) \geq \delta_1 \end{cases}$$

   where $A_{\max i}(t)$ – the signals at the outputs of the 1st and the 2nd photodetectors; δ_i – a predetermined positive threshold.
2. Incorrect setting of the sensor on the artery causes sharply increasing the level of background noise. The sensor is setting badly, if at least one of the inequalities is performed:

(2) $$\begin{cases} \frac{\mathrm{A}_{\phi}(\mathrm{t})}{\mathrm{A}_{\max 1}} \geq \delta_1 \\ \frac{\mathrm{A}_{\phi}(\mathrm{t})}{\mathrm{A}_{\max 2}} \geq \delta_2 \end{cases}$$

   where $A_{\phi}(t)$ – is measured in the time t background level; δ_2 – predetermined positive constants
3. The use of additional a priori information on the spectral composition of the arterial pulsations.

In order to decrease the error in case of realization of information-measuring systems with optic transformation of biosignals (photoplethysmograms) to use more completely aprioric information regarding characteristics of measured signals, method of filtration applying such expressions was used:

(3) $$I = \frac{1}{10}\sum_{m=1}^{10}\frac{1}{T_m}\int_{T_{m-1}}^{T_m} i(t)\cdot dt$$

(4) $$A = \frac{1}{10}\sum_{m=1}^{10}[i_{\max}(T_{m-1,}T_m) - i_{\min}(T_{m-1,}T_m)]$$

where *i(t)* – amplitude of measured biosignals (photoplethysmograms); T_m, T_{m-1}, – number of period of measured biosignals (photoplethysmograms), *m* – number of period of measured biosignals (photoplethysmograms); i_{max}, i_{min} – max and min amplitude of measured biosignals (photoplethysmograms).

Based on laboratory and clinical studies have shown that high precision and reliability can be expected in cases where the measurement conditions correspond to the requirements that the arterial pulsation frequency are stable and have a large amplitude relative to noise and motion artifacts.

To reduce the error of biomedical information measurement system with optical conversion there are different methods of filtration, using advanced digital signal processing techniques, when is used of a priori information about the nature of the measured signal [2].

Also, to solve this problem uses the following approaches:

The use of additional light sources with different wavelengths and optimization of the design of the optical sensor, that allows on the basis of a thorough theoretical study and analysis of experimental data to get sufficient information to consider the impact of the above mentioned factors.

The analysis as a constant, as a low-frequency variable component of the reflected from the biological tissue signal. Thus, the presence of a variable component is caused by arterial blood pulsation in blood vessels during systole.

The engineered optoelectronic complex allows to diagnose the state of blood vessels by express method at different stages of the disease and to fix the degree of microcirculation and hemodynamic disturbances in some areas Chloe by comparing the received signals.

This device – is a converter for displaying and comparing the transformed biomedical signals. It is possible to connect the device to PC-via a coupling unit. This significantly expands such functionality of the device as recording of biomedical signals to the archive, their preprocessing (scaling, filtering), comparison and correlation analysis and building the charts and graphs on the PC.

On the Fig. 1 has shown the optical-electronic complex for research of peripheral blood filling in the maxillofacial region.

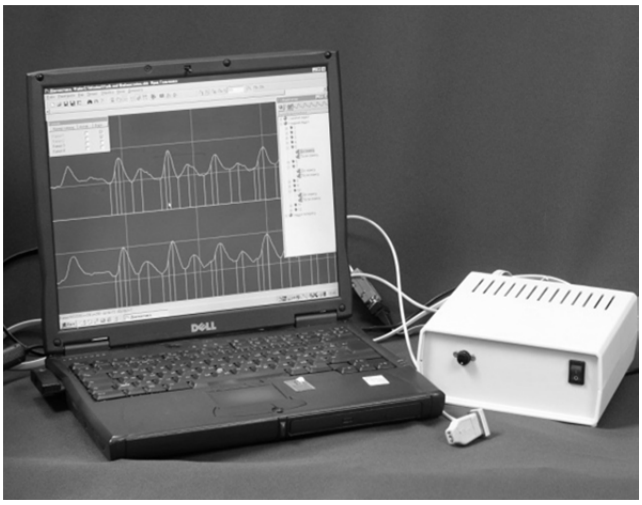

Fig.1. The optical-electronic complex for research of peripheral blood filling in the maxillofacial region

Algorithm of realization

Algorithm of state analysis on the basis of photoplethysmographic data by means of application of fuzzy logic mathematic apparatus has been suggested. Algorithm of biosignals processing in temporal sphere is proposed. It has the following structure: filtration; fragment approximation; segmentation be temporal properties of signals; separation of characteristic points of signal (extremes, points of inflection, points of basic line crossing

etc.); computation by characteristic points of derivative parameters, including form sign; statistic analysis of sequence of classified fragments; structural analysis.

Let's follow the scheme of serial connection (conveyer) while considering the stages of biosignal processing. Scheme is proposed in Fig. 2.

As a result of investigation of a large group of patients ten references were determined. Stages of FP processing in order to obtain references could be presented in the following way (see Fig. 3).

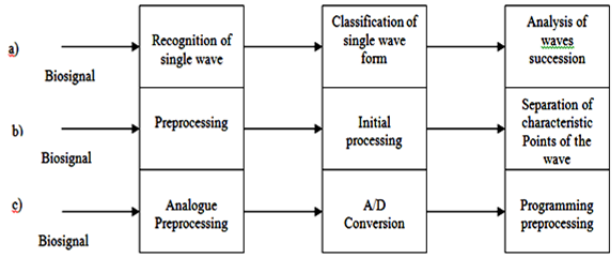

Fig.2. On-line processing of biological signals:
a) general scheme; b) conveyer for recognition of a single wave; c) block-diagram of preliminary processing of biosignal

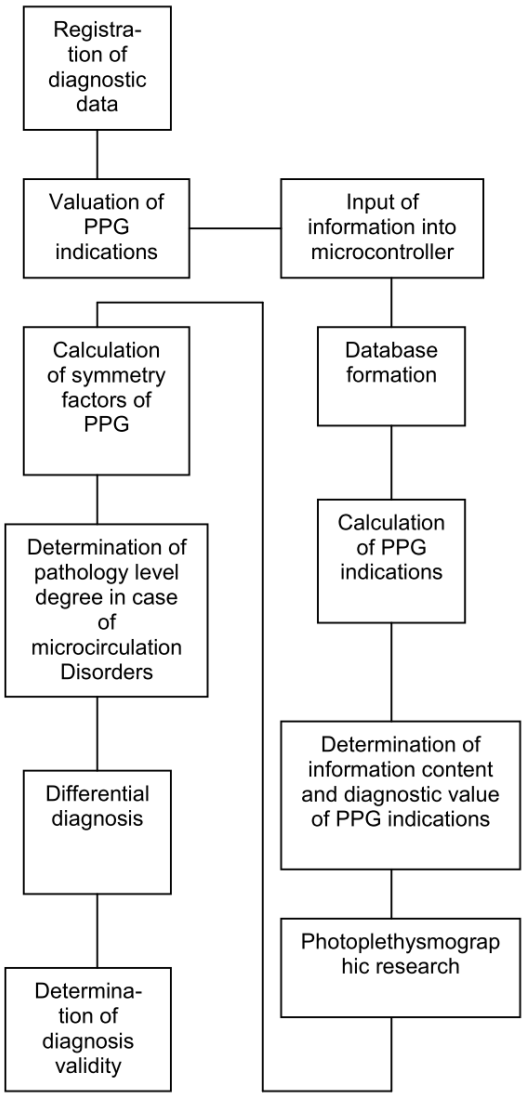

Fig.3 Algorithm of photoplethysmo-graphic data processing for diagnosis of cardiovascular system diseases

From the set of initial FP the first curve us chosen, it is compared with all other curves by means of calculating mutually correlating function and determining correlation factor. After comparison of the first curve with other curves, the sum of these factors is determined. The above mentioned actions are repeated for all initial FP. Then from the array of obtained sums, each of which corresponds to the sum of correlations of given photoplethysmographic curve with others, ten greatest values are chosen. FP that correspond to these values are established references.

Analysis of the methods of biomedical data identification shows that the majority of them is oriented for application, in the best case, of several characteristic parameters.

Algorithmic modeling of method of image recognition based on features separation is carried out , that is the most promising for processing of optic information and allows not only to increase the speed of devices, but also at the expense of reserve doubling to decrease the possibility of mistake while biomedical signals processing.

Results

As a result of researches that carried out at the Department of Maxillofacial Surgery of the Vinnitsa National Medical University, it was examined 30 patients (21 men and 9 women aged 20 to 60 years) with odontogenic abscesses and phlegmon. Treatment of patients included removal of the causative tooth, opening cellulitis or abscess, ozone therapy with silver ions.

Photoplethismographic studies were carried out on the optoelectronic diagnostic complex for analysis of microcirculatory disorders. The optical radiation was directed to the biological tissue at a distance of 10 mm from the edge of the surgical wound or intended cut. As a control point was symmetric point of study. Photoplethismographic signals (PPGS) were registered in the inflammatory focus and in the control point before the operation, and on the third and fifth day after operation. There were recorded 180 PPGS and the obtained data were processed by designed program „WOSTEO".

Example of recorded photoplethismographic signals is shown in Fig. 4 (inflammation (chanel 1), normal (chanel 2), Fig. 5 (signal of phlegmon and abscess (chanel 1) significantly differed of control (chanel 2).

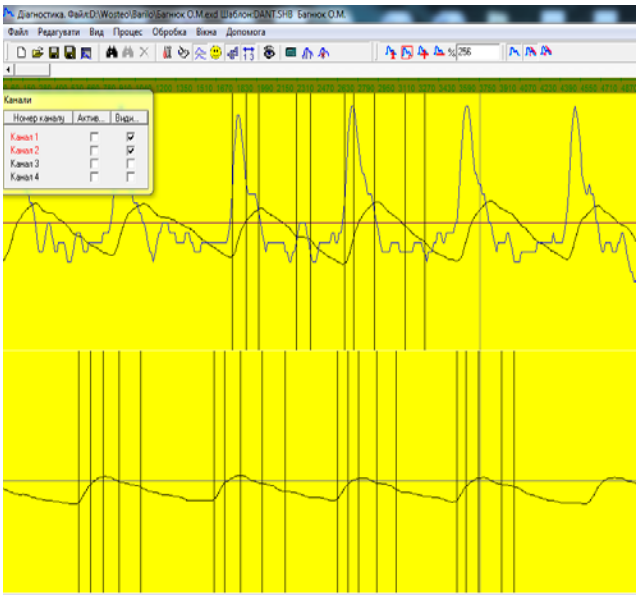

Fig.4. Photoplethismografic signals in the area of inflammation (channel 1) and the area of normal microcirculation (channel 2)

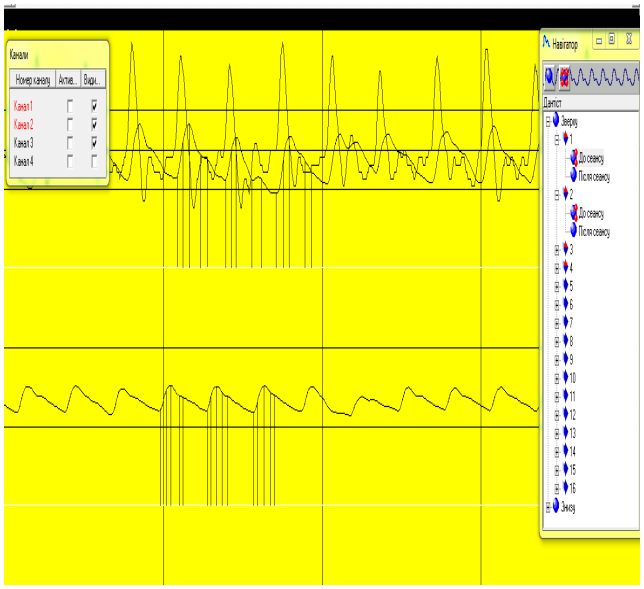

Fig.5 Photoplethismografic signals in the area of of phlegmon and abscess (chanel 1) significantly differed of control (chanel 2).

Discussing of the results

During the analysis of obtained data it was set that photoplethismografic signal of phlegmon and abscess significantly differed of control.

Before surgery, the level of blood filling (photoplethismografic index (PPI) in the inflammatory focus is significantly increased in 2.5–3.5 times. State of venous outflow was sharply deteriorated, that was appeared in the change of form of decaying limb (it that has become more prominent – 73.3%). Dicrotic jag was less expressed and shifted to the top of the catacrotism (70%). In 22 cases is noted the appearance of additional venous waveform.

The blood flow velocity is reduced due to the further deterioration of the venous outflow. In 76.6% of cases there were additional dicrotic waves, 30% were marked small additional jags on catacrotism.

At the 5–6 days after surgery blood flow was improved in all indicators. Additional waves were disappeared in 46.6%, and were weakened in 53.4%. However, in the case of PPGS of inflammatory focus the difference from control point was remained.

Conclusion

Using of the photoplethismografic method is allows to assess accurately the level of blood-filling in inflammatory processes, thus, this method has the such positive properties: noninvasive, high degree of sensitivity and reliability, ease of study. Application of this method allows dentists accurately determine: the effectiveness of the treatment; specify the duration of the rehabilitation period; identify various vascular disorders in fractures of the jaw; to evaluate the effectiveness of local anesthesia (anesthesia causes vasospasm, and reducing of the amplitude of the signal is the feature of the effectiveness of anesthesia); to apply this method to plastic surgery and transplantation.

Experimental and clinical investigations showed high antimicrobic and therapeutic efficacy of ozonized solutions with silver ions. The effect of intensified antimicrobial action of ozone and silver ions was revealed.

Detoxication of inflammation focus was attained owing to the sorption composition which included hydrophobic sorbent – polymethyl – siloxan and hydrophilic sorbent – highly dispersive silicon dioxide and superficially active substance. Proportional structure of the sorption composition depends on the phase of wound process. In phase I of wound process, hydrophilic-hydrophobic sorbent composition was used and in phase II – hydrophobic-hydrophilic one.

There has been worked out an opticoelectronic complex which allows one to diagnose by quick test the state of vascular bed during various stages of purulent – inflammatory process and to fix the degree of microcirculatory and hemodynamic disorders.

The study of clinical efficacy of the developed program of treatment using ozone, silver ions and sorption compositions, has shown the program high efficacy, marked economic effect at the expense of treatment periods shortening, much more less use of costly antibiotics and dressing materials.

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