Application of Optical Methods for Diagnostics and Therapy of Dentine Caries

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***Abstract* — Experimental data on hemodynamics of dental pulp at different stages of caries treatment are given. The speckle observation of backward scattered light is used as a measurement method. Various statistical characteristics of the random light field are studied as indicators of blood flow changes in dental pulp. The second part of the paper is devoted to the selection of a light source for photodynamic therapy while treating caries. The requirements to the source are to provide the photodynamic effect by light absorption of photosensitizer and to do not cause the excessive heating of dental pulp.**

***Index Terms* — tooth tissue, photodynamic therapy, dental pulp, speckle, caries treatment**

I. I. INTRODUCTION

Experimental results gathered by measuring equipment, which was developed and produced in The Belarus State University of Informatics and Radioelectronics, are outlined. In the first part of the paper, the hemodynamics of dental pulp at different stages of caries treatment is examined. The speckle structure of light field reflected by a tooth is used as a tool for the investigations. A number of statistical parameters of the random light field were studied as indicators of the changes in blood flow. Their variability as a function of the frequency of the Fourier transform of optical signals is examined. The second part of the paper is dedicated to the choice of a light source for photodynamic therapy while one treats caries. Special attention is paid to the search of the optimal exposure power, wavelength, and exposure time of tooth tissues.

II. EXAMINATION OF DENTAL PULP HEMODYNAMICS

Blood flow in dental pulp is studied experimentally by using the designed speckle-optical system «Speckle-SCAN» [1]. The time dependence of a light signal backward scattered by the multi-layered tooth tissue is measured at different stages of caries treatment. After making the Fourier transform $W(f)$ (f is the frequency) of this signal, the following integral characteristics of the transform are calculated: spectral power

,

band coefficient

$$Kb = \int_{f_3}^{f_4} W(f)df \Big/ \int_{f_1}^{f_2} W(f)df\ ,$$

coefficient μ

$$\mu = \frac{\int_{f_{low}-\Delta f}^{f_{low}+\Delta f} W(f)\,df}{\int_{f_{high}-\Delta f}^{f_{high}+\Delta f} W(f)\,df}$$

and mean frequency

$$<f> = \frac{\int W(f)\cdot f}{S}$$

Here f_{max} is the maximal frequency of the spectrum, f_1, f_2, f_{low} и f_3, f_4, f_{high} are the frequencies taken, respectively, in the low- and high-frequency regions, and Δf is the fixed increment. The said parameters were measured before and after the tooth anesthesia, before and after the tooth preparation, after the etching, after the tooth filling, after the irradiation, and after the polishing.

Figure 1 shows the diagrams of changes of some above parameters observed in experiments before (histograms 1) and after the anesthesia (2).

From the preliminary knowledge that blood flow is reduced during the tooth anesthesia, and should recover after it, one note the following:

– at reduced blood flow, the spectral power and coefficient μ increase,

– at reduced blood flow, the parameters Kb and $<f>$ decrease.

The above integral parameters, except for the spectral power, studied for the case of teeth behave similarly to the corresponding parameters for skin. The power increase considerably while blood flow reduces, whereas for skin there is observed the decrease in the spectral power.

Figure 2 illustrates the changes in the considered integral parameters of the speckle structure at various stages of caries treatment, namely before and after the preparation, after etching, after tooth filling, after irradiation, and after polishing. These stages are correspondingly listed from the top in the legends of Fig. 2.

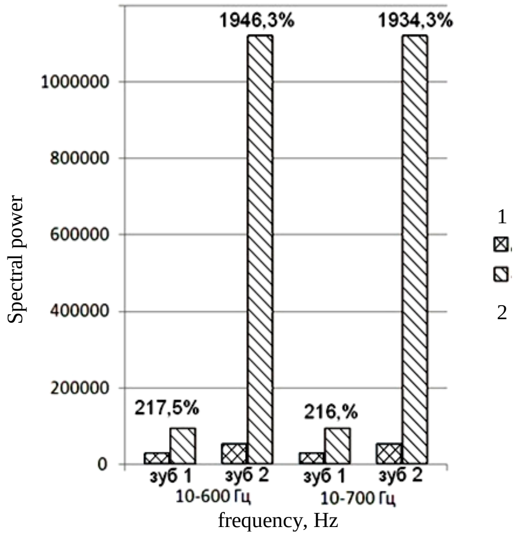

Fig.1a. Changes in spectral power at frequency ranges 10 to 600 Hz and 10 to 700 Hz before (1) and after the anesthesia (2) of tooth 1 and 2

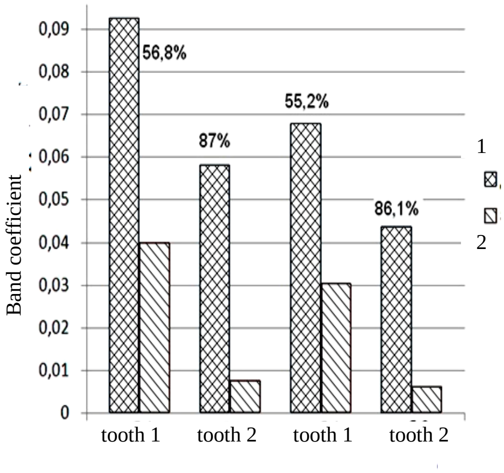

Fig. 1b. Changes in *Kb* at f_1 = 50, f_2 = 100 (or 150), f_3 = 900, and f_4 = 1000 Hz before (1) and after the anesthesia (2) of tooth 1 and 2

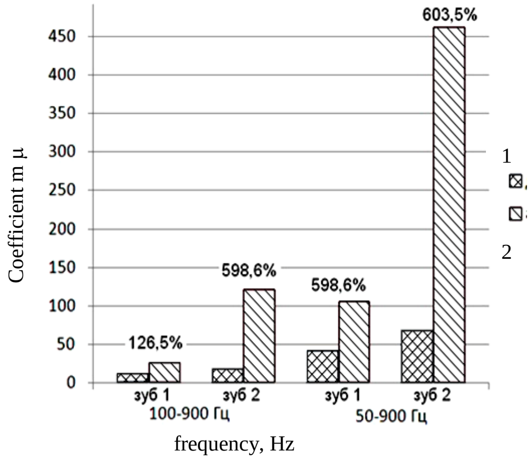

Fig. 1c. Changes in coefficient μ at f_{low} = 100 (or 50), f_{high} = 900 Hz before (1) and after the anesthesia (2) of tooth 1 and 2

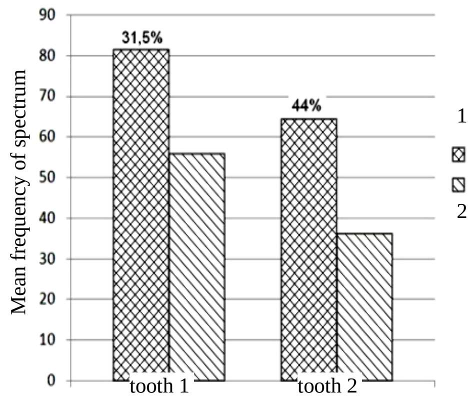

Fig. 1d. Changes in mean frequency of the spectrum in frequency range 10 to 800 Hz before (1) and after the anesthesia (2) of tooth 1 and 2

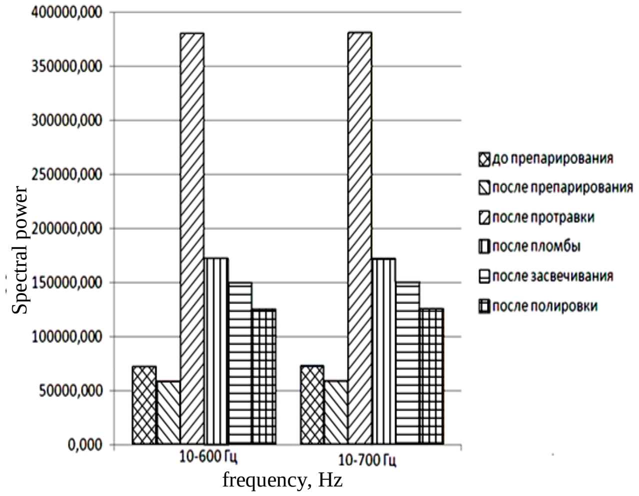

Fig. 2a. Changes in spectral power at frequency ranges 10 to 600 Hz and 10 to 700 Hz for 6 stages of caries treatment (see text)

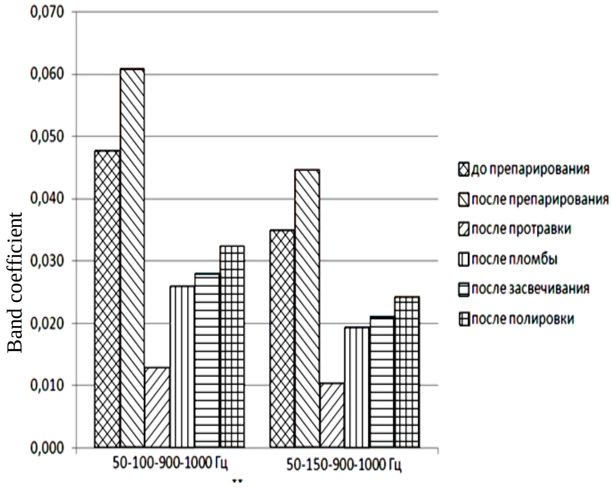

Fig. 2b. Changes in *Kb* at f_1 = 50, f_2 = 100 (or 150), f_3 = 900, and f_4 = 1000 Hz for 6 stages of caries treatment (see text)

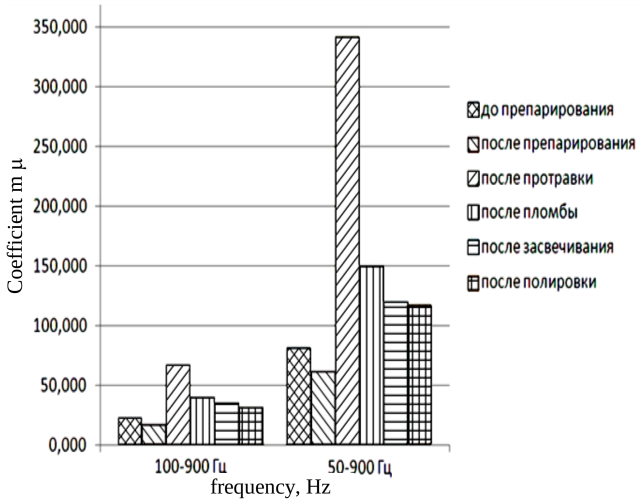

Fig. 2c. Changes in coefficient μ at f_{low} = 100 (or 50), f_{high} = 900 Hz for 6 stages of caries treatment (see text)

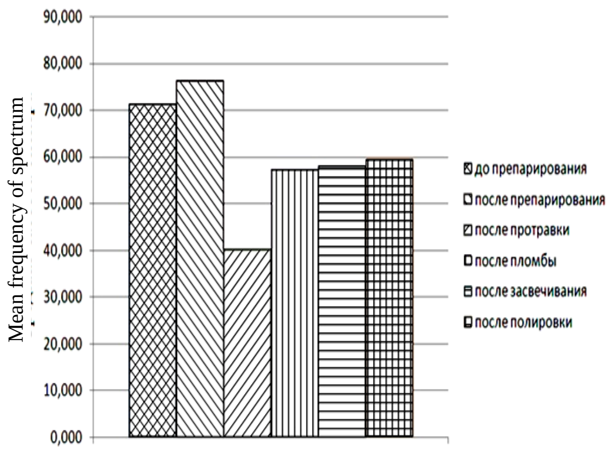

Fig. 2d. Changes in mean frequency of the spectrum in frequency range 10 to 800 Hz for 6 stages of caries treatment (see text)

All the studied statistical parameters show the similar dynamics while treating caries. So, on the base of earlier-made conclusions, one can describe changes of blood flow through the pulp at all stages of the treatment by the following way:

– there is observed an increased blood flow after the preparation, which is the response on the mechanical actions;

– blood flow sharply decreases after the etching, because the chemical acid action strongly depresses the hemodynamics; and

– after the tooth filling, irradiation, and polishing, the hemodynamics increases, blood flow gradually grows, but does not achieve the original level. Due to this, one can conclude that to restore the blood flow requires some time interval, and during the treatment one should monitor the blood flow some time after the procedure.

The results obtained with using the speckles correlate reliably with data on the blood flow gathered by the Doppler method.

III. SELECTION OF LIGHT SOURCE PARAMETERS FOR PHOTODYNAMIC THERAPY

Photodynamic therapy (PDT) is one of the most perspective medical technologies. It is based on the abilities of photosensitizers (PS) to be selectively accumulated in certain cells. Under local irradiation by a wavelength corresponding to the maximum of PS absorption, active oxygen forms are generated, which have a cytotoxic effect on target cells. Thus PDP can be also used for removing cariogenic bacteria from damaged tooth tissues with the help of singlet oxygen. In comparison with usual antiseptic remedies, PDT provides a more vivid removal of pathogenic microorganisms from dentinal tubules that circle the carious cavity. When activating a PS with laser light, the heating of hard tooth tissues and pulp takes place. The temperature increase inside the pulp cell higher than some threshold causes microcirculation breakdown and finally leads to the loss of the pulp. With the purpose of development the methods of PDT while treating uncomplicated caries, one needs to define the maximum power and the duration of laser light exposure that are safe with accounting for the thermal parameters of the oral cavity. Under PDT the alternative to a laser light is a diode emission with the wavelength that corresponds to the maximum of PS absorption. It can also be used for PS activating only with the adherence of an emission safe mode, under which the pulp heating will be minimal.

The purpose of this investigation was the design of a procedure for measuring the temperature inside the pulp chamber while comparing the action of laser and light diode light of the blue spectral range that is utilized during the PDT.

Five intact molars removed owing to orthodontic indications were selected for making the experiments. Cavities with thickness of 1 mm of over-pulp dentine were created on the occlusive surface of the teeth. Through holes to the pulp chamber with diameter 2 mm were formed in the side surfaces of the teeth near the enamel – cement boundary.

The pulp chamber and the tooth root canal orifice were filled with the heat-conducting paste KPT-8. As this paste is considered to provide an X-ray contrast, the X-ray examination made it possible to control the over-pulp dentine thickness of 1 mm and the uniform filling of the tooth chamber with the paste. Then the thermocouple of the precision thermometer TRDA 202 (Oven, Minsk) was set into contact with the paste into the hole in the tooth surface. The thermocouple isolation was heat isolated with base wax. A special digital device measuring the light power monitored the emission power of the laser and light diode. A laser diode with maximal output power 250 mW, wavelength 660 nm and light diode lamp LEDEX WL-070 emitting ultraviolet at 460 nm with power 1000 mW were used as light sources. Exposure time was 8 min. To create the same conditions that exist in the mouth cavity, teeth samples were placed into a thermostat with temperature kept at 37^{o} C and air humidity 90%.

The tooth specimens were irradiated by laser light with wavelength 660 nm and power 50, 75, 100, 120, or 150 mW and by light emitting diode at 460 nm with light power 1000 mW. The temperature values were recorded on the base of four sequential measurements, each of which was made in 5 s intervals during 4 min exposure. This was implemented by applied dedicated software of the computer.

The threshold temperature value of 40°C (temperature rise $\Delta t = 3°C$) was achieved at output laser light power 120 to 150 mW. At 150 mW, the temperature inside the pulp chamber was equal to the threshold of 40°C in 379 ± 3.5 after the irradiation start, and at 120 mW it did in 415 ± 3.2 s. The action modes at 50, 75, and 100 mW in all the measurement series did lead to the temperature rise in the tooth cavity less than by 3°C during 8 min exposure. So, at laser output power values of 100, 75, and 50 mW, the temperature rises by 2.4 ± 0.1, 1.9 ± 0.06, and 0.88 ± 0.04°C were observed. In all the experiments of tooth heating by the irradiation, the temperature was stabilized in some time duration after the irradiation start. This is due to the balance between the thermal energy generated in the teeth specimens and the heat transfer from the specimens to their surroundings.

Under the action of the light emitting diode at wavelength 460 nm with output 1000 mW during 60 ± 4 s exposure, there was observed the temperature rise in the pulp chamber up to 40°C ($\Delta t = 3°C$).

IV. CONCLUSIONS

1. Investigation of the speckle structure of scattered light enables the changes in blood flow through tooth tissue to be evaluated. The most informative statistical parameters are the spectral power, the band coefficient, the μ coefficient, and the mean frequency. There were selected the optimal frequency rages of 10 to 600, 10 to 700, and 10 to 500 Hz (this range is not shown in the Figures, but it gives satisfactory results too) for the spectral power, of 50 to 100 and 900 to 1000 Hz for the band coefficient, of 50 to 150 and 900 to 1000 Hz for the μ coefficient, and of 10 to 800 Hz for the mean frequency.

2. The reduction of blood flow leads to the increase in the spectral power, contrast, and μ coefficient, and to the decrease in the mean frequency and band coefficient.

3. During dentine caries treatment, blood flow responses vividly to mechanical and chemical actions. According to the gathered data, the most noticeable effect is by the etching that strongly depresses the tooth hemodynamics.

4. From all the considered modes of laser light action during PDT, the maximally safe should be assumed the irradiation by light power 50 mW, since the temperature rise in the tooth chamber remains tolerable to show a tendency to the stabilization. Under the irradiation by 150 mW laser power, the expose time should be limited to 379 s, and at 120 mW – to 415 s. When using a light emitting diode with wavelength 460 nm and light power 1000 mW, the expose time should be limited to 60 s.

REFERENCES

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