Metrological Assurance of Infrared Transillumination of Biological Tissues

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Abstract. The article is devoted to the urgent scientific and technical problem of developing metrological assurance for hardware and software infrared transillumination systems designed to visualize the internal structure of biological tissues in order to detect early stages, measure and control the dynamics of pathological processes. As part of solving this problem, at the Department of Biomedical Technical Systems of the Bauman Moscow State Technical University a set of measures that simulate the optical properties of biological tissues, containing local optical inhomogeneities was developed. Experimental studies were carried out using the developed measures, as a result of which the possibility of visualizing the structural inhomogeneities of biological tissues using the method of infrared transillumination was shown. The approved method for the manufacture of measures can be used to simulate the optical properties of biological tissues in the course of subsequent studies and further stages of the development of metrological assurance for hardware and software complexes of infrared transillumination.

1. Introduction
Transillumination is a method of visualizing inhomogeneities in biological tissues in transmitted radiation of the visible and near infrared wavelength ranges in order to detect pathological areas. The physical basis of the method is the difference in the optical properties of the visualized inhomogeneities in comparison with the surrounding biological tissues. The transillumination method was developed 150 years ago and has since found its application in otorhinolaryngology, oncology, urology, dentistry, ophthalmology.

Currently, in healthcare institutions, especially in dental clinics, the problem of assessing the state of the periodontium and detecting areas of its inflammation at an early stage is very acute. As a result of joint work with the National Research Center "Central Research Institute of Dentistry and Maxillofacial Surgery" and the Department of Biomedical Technical Systems of the Bauman Moscow State Technical University (here and after - BMSTU), work was carried out to assess the need to create a system of metrological support of medical equipment to detect foci of inflammation periodontium, including in the early stages, as well as to control the dynamics of inflammatory processes in the periodontium by infrared transillumination.

As a result of research carried out at the Department of Biomedical Technical Systems of the BMSTU, it was theoretically established and experimentally confirmed the possibility of detecting at an early stage of inflammation of the periodontal by the method of infrared (hereinafter referred to as IR) transillumination (hereinafter referred to as IRT) in the passing non-ionizing laser radiation of the near IR range [1,2].

Thus, an urgent scientific and technical task is the development and implementation into clinical practice of hardware and software complexes for infrared transillumination (hereinafter referred to as
HSC IRT) for visualizing the internal structure of biological tissues in order to detect early stages, measure and control the dynamics of pathological processes.

The introduction of HSC IRT into clinical practice will provide the following improvements in the diagnostic process:

– minimization of the factor of subjective assessment of information during visual observation by a medical specialist;
– detection of changes in the characteristics of the structure of tissues at the earliest, most favorable for diagnosis and treatment stages of pathology;
– automation and increasing the speed and quality of the diagnostic procedure;
– automated control of the treatment effectiveness.

One of the most important tasks that needs to be solved for the possibility of introducing the HSC IRT into clinical practice is the development of metrological support.

2. Materials and methods

Within the framework of solving the problem of developing metrological assurance for HSC IRT, at the department of biomedical technical systems of BMSTU developed a set of measures that simulate the optical properties of biological tissues, containing local optical inhomogeneities.

Local optical inhomogeneities in tissues, as a rule, are areas that differ in the values of the absorption and scattering coefficient from the surrounding tissues. The reason for the formation of such areas can be inflammatory and pathological processes, functional changes in tissues, leading to a local change in blood circulation [3, 4]. Local changes in the values of the absorption and scattering coefficient lead to the appearance of a contrast of inflammation, pathology or altered blood supply areas relative to the surrounding tissues in the images of the visible and near infrared range [1,2]. To ensure the maximum probability of detecting pathological areas, it is necessary to provide the maximum contrast of pathological areas on the IRT images [1,2]. Thus, the design of the measures should provide the possibility of experimental study of the optical inhomogeneities contrast dependence on the registration parameters: wavelength, degree of monochromaticity, polarization, spatial configuration and other parameters of the probe radiation, as well as the parameters of the registration unit.

The matrix for creating the measures was a two-component silicone compound of the «Viksint PK-68» brand and acetoxysilicone manufactured by «Novbytkhim». For modeling the optical properties of biological tissues, the initial parameters are the absorption coefficient and the reduced scattering coefficient.

The absorption coefficient of the medium in the manufacture of the measure was controlled by adding pre-ground graphite powder of the «GSL-1» grade with a particle size of 40 μm. [3,4]. To ensure the required values of the reduced scattering coefficient, a mixture of aluminum oxide and graphite powder was used in the ratio of 1 g of the mixture per 100 g of the silicone compound. Grinding and mixing of scattering particles was provided in a ceramic ball mill with 16 mm diameter balls. The uniformity of the distribution of absorbing and scattering particles was increased by stirring them during the solidification of the compound using ultrasonic radiation with a frequency of 22 kHz and a power density of 45 W/cm², generated by the «UZDN-2T» installation for 20 minutes. To increase the uniformity of the distribution of absorbing and remove air bubbles, evacuation was also used for 60 minutes after pouring the solution into the mold. The uniformity of the distribution of absorbing and scattering particles was achieved by stirring them during the solidification of the compound using an ultrasonic disperser «UZDN-2T». Absorbing optical inhomogeneities are imitated by graphite rods 0,7 mm and 1,0 mm in diameter. The rods are arranged in pairs with a pitch of 3 mm in depth to assess the imaging depth (Figure 1).
The scattering and absorption parameters for the developed measure were selected based on the corresponding values of the optical parameters of the periodontal tissues, as well as the calibration block of the ISS «OxiplexTS» spectrophotometer, which simulates the optical properties of biological tissues [5]. The calibration block is provided by ISS and is designed for the Oxiplex TS spectrophotometer relative measurement error periodical checking, which, according to the manufacturer's documentation, is 5% [5]. The measurements of the of the periodontal tissues, the measure and the calibration block optical parameters were carried out according to the approved method [6, 7]. The measurements were carried out at room temperature, therefore, the effect of air temperature on the measurement results was considered negligible. As an estimate of the uncertainty, the confidence interval was used, calculated relative to the sample mean values of optical parameters according to formula (2) for a series of 15 measurements. Optical parameters for periodontal tissues, calibration block and for the manufactured measure are presented in Table 1.

| Periodontal tissues | Absorption coefficient, $\mu_a(834)$, cm$^{-1}$ | Reduced scattering coefficient, $\mu'_s(834)$, cm$^{-1}$ |
|---------------------|-----------------------------------------------|--------------------------------------------------|
| 0,170±0,020         | 5,70±1,00                                      |
| Calibration block   | 0,130±0,005                                     | 4,30±0,10                                       |
| Manufactured measure| 0,160±0,050                                     | 5,80±1,40                                       |

Based on the measurement results presented in Table 1, the following conclusions can be drawn:
- the results of measurements of the calibration block parameters indicate that the measurement error of the «OxiplexTS» spectrophotometer corresponds to the values declared by the manufacturer;
- the values of the calibration block and the manufactured measure optical parameters, do not statistically significantly differ with the significance level of 95% and are consistent with the corresponding values of the periodontal tissues optical parameters, which indicates the possibility of reproducing the optical properties of biological tissues using the approved method of making a measure.

The probability of the optical inhomogeneities detection increases with an increase of the optical inhomogeneities image contrast of relative to the background.

To conduct an experiment to study the dependence of the of the inhomogeneities image contrast on the wavelength, an experimental stand was created that simulates the IR transillumination system (Figure 2).
Figure 2. Stand for studying the dependence of image quality on wavelength:
1) digital video camera of the IR range, 2) measure, 3) shaping lens, 4) emitter

The laser diodes of the near infrared range: 808 nm, 840 nm, 880 nm, 904 nm, and 980 nm with a power of up to 500 mW were chosen as radiation sources. An infrared video camera recorded the radiation passing through the measure. Images were captured for each rod depth. At least three images were recorded for each study area.

The scheme for measuring optical parameters and recording diaphanoscopic images is shown in Figure 3.

![Figure 3](image)

Figure 3. The Scheme for measuring optical parameters and transillumination images registration

Next, the contrast ratio of image areas containing optical inhomogeneities (graphite rods) was calculated.

The contrast ratio $C$ in the section was calculated by the formula:

$$ C = \frac{I_{\text{max}} - I_{\text{min}}}{I_{\text{max}} + I_{\text{min}}} $$ (1)
where $I_{\text{max}}$ is the average brightness of the background pixels in the section, $I_{\text{min}}$ is the average brightness of the pixels of the graphite rods in the section.

The contrast was calculated in 8-10 sections (Figure 4) and averaged over all sections of all images of each iteration. The black inclusions in Figure 3 are graphite chips (artifacts) that have settled during the solidification of silicone. The sections were set manually in order to exclude the section hitting artifacts.

![Image of graphite rods and cross-sections for contrast ratio calculation](image.png)

Figure 4. Image of graphite rods and cross-sections for contrast ratio calculation

In the case of an artifact hit in the selected section, a local brightness minimum was observed and the section was re-selected.

As an estimate of the measurement uncertainty of the contrast coefficient uncertainty $u_c$, the confidence interval was used, calculated by the formula:

$$u_c = \bar{C} \pm t_{1-\frac{\alpha}{2}, n-1} \frac{S_e}{\sqrt{n}}$$  \hspace{1cm} (2)

where $\bar{C}$ is the average contrast value calculated over $n$ sections, $n$ is the number of sections of the measure images, $t_{1-\frac{\alpha}{2}, n-1}$ is the $\alpha$-quantile of the Student's t-distribution ($\alpha = 0.05$) with (n-1) degree freedom.

3. Results and discussion
The results of measuring the contrast ratio for areas of the measure containing structural inclusions, as well as images of the areas themselves, are shown in Table 2.

The dependence of the contrast on the wavelength is noted - an increase in the contrast ratio with distance into the IR region of the spectrum. The highest value of the contrast ratio was found at a wavelength of 904 nm. The possibility of visualization by the IRT method of structural inhomogeneities located at a depth of 3 mm was confirmed. The rods located at a depth of more than 3 mm could not be visualized due to a large fraction of radiation scattering.
Table 2. The contrast ratio of optical inhomogeneities

| Rods parameters: diameter, depth | Wavelength, nm |
|----------------------------------|----------------|
|                                  | 808           | 840           | 904           | 980           |
| Ø 0,7 mm, depth 3 mm             |               |               |               |               |
| 0,22 ± 0,01                      | 0,22 ± 0,01   | 0,28 ± 0,01   | 0,24 ± 0,01   |
| Ø 1,0 mm, depth 3 mm             |               |               |               |               |
| 0,22 ± 0,01                      | 0,22 ± 0,03   | 0,29 ± 0,01   | 0,27 ± 0,03   |
| Ø 0,7 mm, depth 6 mm             |               |               |               |               |
| Ø 1,0 mm, depth 6 mm             |               |               |               |               |
| Ø 0,7 mm, depth 9 mm             |               |               |               |               |
| Ø 1,0 mm, depth 9 mm             |               |               |               |               |
| Indistinguishable contrast due to low optical power of radiation |

Figure 5 shows the dependence of the contrast ratio on the radiation wavelength for a pair of rods with a diameter of 1,0 mm at a depth of 3,0 mm, plotted according to the values presented in Table 2. The vertical bars half-widths values of the contrast measurement error at the corresponding wavelengths are equal to the values of the half-widths of the confidence intervals, calculated by the formula (2) and presented in table 2 for the corresponding values of contrast.
The approved method for the measures manufacture can be used to simulate the optical properties of biological tissues in the course of subsequent studies and further stages of the development of metrological assurance for the HSC IRT.

An important result of the work is the experimental confirmation of the possibility of using the manufactured measures in the tasks of research and development of metrological assurance for visualization systems for optical inhomogeneities in the thickness of biological tissue in the near-IR range, including transilluminating systems.

Further research should be directed towards solving the following tasks:
- improvement of the technology of manufacturing measures. It is required to ensure a uniform concentration of absorbing and scattering particles in the silicone matrix, to exclude the settling of particles during the hardening of the silicone.
- carrying out a study of the dependence of the optical inhomogeneities contrast ratio on the radiation parameters: power, frequency of spatial and frequency modulation, degree of monochromaticity, polarization, coherence.
- development and clinical testing of a technique for measuring the characteristics of periodontal inflammation areas and pathological changes.

References
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