

Study of the functional state of peripheral vessels in fingers of rheumatological patients by means of laser Doppler flowmetry and cutaneous thermometry measurements

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ABSTRACT

Vasospastic disorders are a common class of rheumatic disease. These include syndromes such as vegetative dystonia, Raynaud's syndrome, vibration disease and rheumatoid arthritis among others. The aim of this work is to develop an original method of diagnosing the functional state of peripheral vessels of the fingers, based on the simultaneous recording of LDF- and thermograms during the occlusion test, for determining vascular disorders of rheumatological patients.

A diagnostic method was developed for assessing the functional state of the peripheral vessels of fingers, based on carrying out occlusion test in a thermally stabilized environment, with simultaneous recording of signals of laser Doppler flowmetry and skin thermometry. To verify the diagnostic value of the proposed method, a series of experiments were carried out on 41 rheumatological patients: 5 male and 36 females (average age 56.0±12.2 years). The most common diagnoses in the patient group were rheumatoid arthritis, arthrosis, gout and systemic lupus erythematosus. The laser analyser of blood microcirculation “LAKK-02” (SPE “LAZMA” Ltd, Russia) and a custom developed multi-channel thermometry device for low inertia thermometry were used for experimental measurements. The measurements of cutaneous temperature and the index of microcirculation were performed on the distal phalanx of the third finger of the right hand. Occlusion tests were performed with water baths at 25 and 42 °C and a tonometer cuff with a pressure of 200-220 mmHg for 3 min on the upper arm.

The results of experimental studies are presented and interpreted. These data indicate a violation of the blood supply regulation in the form of a pronounced tendency towards microvascular vasoconstriction in the fingers. Thus, the response displaying a tendency toward angiospasm among patients in the rheumatological diseases profile group was observed mainly in the most severe cases (49 % of this group). The prospects of the developed diagnostic method of microcirculatory disorders in rheumatic diseases are evaluated. Thus, cutaneous blood microcirculation and temperature measurements performed together can help in diagnosis of the functional state of peripheral vessels both in a healthy state and when expressing pathology.

Keywords: non-invasive diagnostics, laser Doppler flowmetry, skin thermography, occlusion test, blood microcirculation, peripheral blood flow, rheumatic diseases, rheumatoid arthritis.

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1. INTRODUCTION

Rheumatic diseases are a large group of diseases which display general features including lesions within structures of the human connective tissue and blood vessels, internal organs and, often, the skin and mucous membranes¹. These diseases include syndromes such as vegetative dystonia, Raynaud's syndrome, vibration disease and rheumatoid arthritis among others. Diseases of this class are characterized by affliction of almost all age groups, steady progression, tendency to chronicity, early disability, and reduced quality of life. All this, along with the currently significant growth of prevalence puts the rheumatic disease on a leading position in terms of its negative impact on modern society. In this regard, the development and introduction into medical practice of new techniques and methods of diagnosis of rheumatic diseases are of vital importance, and their relevance is undeniable.

For rheumatologists, there are currently available a fairly wide range of instrumental examination methods, among which the most popular are rheovasography, Doppler ultrasound², nail capillaroscopy, conjunctival biomicroscopy, electrical thermometry and thermal imaging diagnostics. Undoubtedly, the methods of rheovasography and Doppler ultrasound of upper or lower extremities are preferred due to their relative cheapness, availability and sufficient methodological support. Such studies provide data on peripheral hemodynamics in veins and arteries. However, it is known that one of the central areas for development of rheumatic diseases occurs with violations of the blood microcirculation system, first of all in the form of reduced blood flow in the capillaries³. To evaluate microcirculatory disorders, the most suitable methods are nail capillaroscopy and conjunctival biomicroscopy, which allow visualisation of functional features and specific changes in the anatomical structure of the microvasculature. However, for several reasons (relatively expensive equipment, high qualification requirements for staff, the complexity of interpreting the results of the study due to lack of medical experience with similar diagnostic data) these methods are more popular in research than in clinical practice. Thermography and thermal imaging methods allow conclusions to be made about the presence of microcirculatory disorders only indirectly, by using change of temperature in the microvascular projection on the body surface. In practice these are rarely used and are used as auxiliaries⁴.

Laser Doppler flowmetry (LDF) is a method with huge potential in the study of microcirculation. LDF is based on the detection of the Doppler shift of laser radiation produced by reflection from moving red blood cells in the microvasculature⁵. The results of LDF measurements, representing "index of blood microcirculation (I_m)" or "perfusion", assessed in conventional perfusion units (PU), reveal a complex, non-periodic process. With LDF it is possible not only to non-invasively evaluate the intensity of the blood flow in the microcirculation bed of the blood flux, but also to discover and explore the collective rhythmic processes of microcirculation^{6,7}.

In the field of diagnostics of the functional state of the microvasculature, a well proven approach uses LDF and thermometry methods during loading tests, such as occlusion test⁸. As is known, according to LDF estimates the amount of tissue blood perfusion. Since one of the functions of the body's blood is a function of the heat carrier, the possibility in an experiment to evaluate change of the rush of blood to the tissue surface can significantly improve the predictive accuracy of a diagnostic method based on the data of thermometry. At the same time, the method of thermometry measurements allows us to make an integrated estimate of the effectiveness of the blood supply, as skin temperature is influenced by both near-surface and more deep-lying vessels⁹.

The aim of this work is to develop an original method of diagnostics of the functional state of peripheral vessels of the fingers, based on the simultaneous recording of LDF and thermograms during the occlusion test, for determination of vascular disorders in rheumatological patients.

2. THE METHOD OF RESEARCH

With the aim of improving joint-use LDF and thermometry devices, a series of tests was made with the simultaneous recording of the LDF-gram and the temperature at the distal phalanx of the third finger of his right hand during a standard occlusion test. The laser analyser of blood microcirculation "LAKK-02" (SPE "LAZMA" Ltd, Russia) with two identical LDF-channels with a wavelength probing 1064 nm and a custom developed multi-channel thermometry device for low inertia thermometry were used for experimental measurements (Fig. 1a). Analysis of the results of the experiments showed that environmental conditions - including temperature, air humidity and air flow velocity - have a significant impact on the appearance of the curve of temperature change. This external variable makes the obtained data unusable for further processing and complicates their interpretation. To maintain a constant microclimate, adjustments to the measurement procedure were required. LDF and temperature signals were therefore registered in a thermostabilised

environment with known physical properties (in water). With undoubted advantages, this approach has its drawbacks, one of which is the need for waterproofing LDF probe and temperature transmitters during the experiment. This drawback has been eliminated by donning medical latex gloves on the hand of the investigated patient (Fig. 1b).



Figure 1. Exterior view of the experimental setup (a) and placement of the special tooling on the finger by fixation and waterproofing by using latex glove (b).

Another problem is that the technical implementation of the most of LDF devices, such as “LAKK-02”, provides the location of the optical waveguide of the probe normal to the surface skin, i.e., registration of the LDF signal is impossible without destroying the integrity of the glove. To solve this problem, a special attachment for the “LAKK” device fibre optic probe has been designed and 3D printed. Fig. 2 shows the structural scheme and outward appearance of the special attachment for optical fiber of “LAKK-02” device. Due to mirroring, the proposed attachment refracts the path of light rays at an angle of 90° and thus allows placing of the optical probe of device not perpendicularly, but along the body surface. Furthermore, the attachment allows placing therein two temperature transducers: for recording skin temperature – on the inside, and for controlling the ambient temperature during the experiment – on the outside.

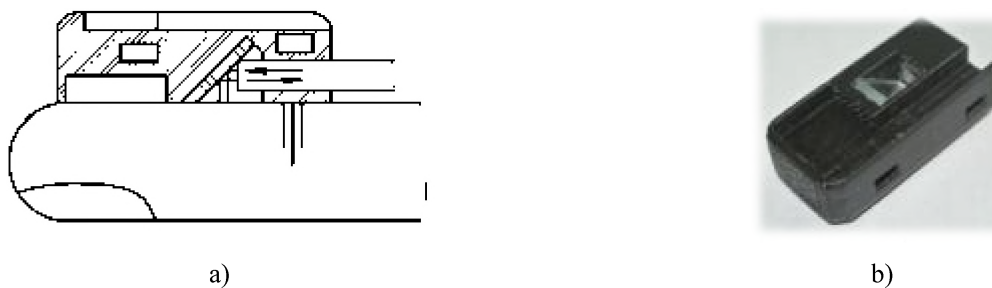


Figure 2. Structural scheme (a) and outward appearance (b) of special tooling for optical fiber of “LAKK-02” device.

Thus, a diagnostics method of the functional state of peripheral vessels of fingers was developed based on carrying out the occlusion test in the thermally stabilized environment, with simultaneous recording of signals of LDF and skin thermometry. Based on the modified Pennes equation, a model of the temperature changes of the human fingers during an occlusion test in thermally stabilized aqueous medium was proposed. One of the changes made to the equation took into account the non-linear response of vascular reaction during changes of the ambient temperature. Low inertia cutaneous thermometry measurement results were proposed to estimate the parameters of the temperature response.

Experiments were carried out on 41 rheumatological patients of rheumatology department of Oryol Regional Clinical Hospital (Oryol, Russia): 5 male and 36 females (average age 56.0±12.2 years). The most common diagnoses in the patient group were rheumatoid arthritis, arthrosis, gout and systemic lupus erythematosus. The measurements of cutaneous temperature and the index of microcirculation (I_m) were performed on the distal phalanx of the third finger of the right hand. Occlusion tests were performed with water baths at 25 and 42 °C according to the study protocol (Table 1) and a tonometer cuff with a pressure of 200-220 mmHg for 3 min on the upper arm.

Table 1. The protocol of the study.

Phase duration, min	2	4	10	3	10	5-11
Environment	Air	Water				
Temperature, °C	25	42	25			42
The period of occlusion test	Before occlusion			Occlusion	Postocclusion	

The research was mainly in the morning, after 2-3 hours after a meal, in a state of mental and physical rest. The patient sat in such a way that the forearm of his right hand was 20 cm below the level of the heart. The total duration of the experiment was not more than 40 min.

3. RESULTS AND DISCUSSION

The changes revealed in the temperature response on the occlusion test indicate the formation of pronounced changes in the microcirculation of patients with rheumatologic diseases profiles. Studies have revealed at least three types of response to a sequentially conducted stress tests according to the protocol of the study. The typical view LDF- and thermograms for the 3 types of the microvascular response to the occlusion test in the thermally stabilized environment are shown in Fig. 3.

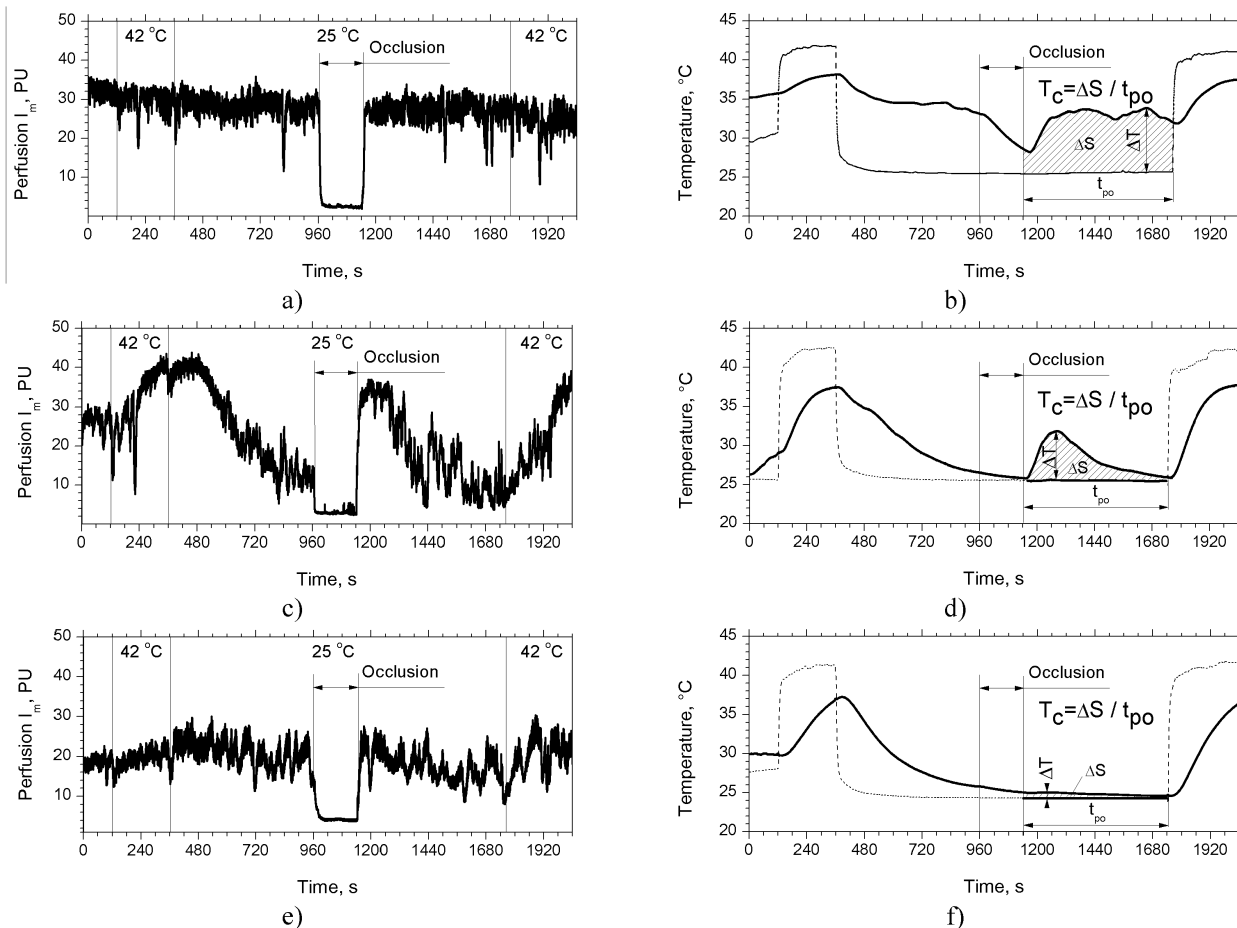


Figure 3. Typical view LDF- (a, c, e) and thermograms (b, d, f) for the 3 types of the microvascular response to the occlusion test in the thermally stabilized environment.

Table 2 presents a summary of data for each proposed response type, with characteristic distinguishing features and their interpretation.

Table 2. The interpretation of the obtained data in group of patients with rheumatologic diseases.

№	The analyzed characteristics	Types of responses		
		Type 1	Type 2	Type 3
1	Proposed evaluation	Normal regulation		The tendency to angiospasm
2	Interpretation	Excellent blood supply to the fingers.	Good blood supply to the fingers. After removing the cooling stimulus, recovery of the initial skin temperature is observed.	Circulatory disorders of the fingers. The tendency to angiospasm. After removing the cooling stimulus, temperature of the skin is restored with difficulty.
3	The dominant process forming temperature during cooling in water	The inflow of hot blood of homoeothermic core. The inflow of heat from the blood comparable to the heat loss to the environment.	Cooling limb in water. The inflow of heat from the blood is less than the heat loss to the environment.	Cooling limb in water. The inflow of heat from the blood is much less than the heat loss to the environment.
4	Characteristics of the temperature graph	Nonexponential cooling. The presence of temperature change waves. Within 10 minutes the skin is not cooled to a temperature of the water (the difference between 3-8 °C). After removing the occlusion the moderately severe increases in temperature and microcirculation index is present.	Exponential cooling. The lack of temperature change waves. Within 10 minutes the skin is closer to the water temperature (the difference between 1-3 °C). After the occlusion a pronounced increase in skin temperature (2-4 °C) and the level of microcirculation index to the level before occlusion is present.	Same as in type II, but after the occlusion increasing the temperature of the skin to the level before occlusion is insignificant.
5	Qualitative characteristic of the LDF graph	High or average level of perfusion.	Average level of perfusion.	The level of perfusion is significantly reduced.
6	Normal state of hands in a survey of volunteers	Hot hands	Warm hands	Cold hands
7	Amplitude of hyperemic temperature rise $\Delta T, ^\circ\text{C}$	4.6 ± 1.8	3.1 ± 1.2	1.0 ± 0.9
8	Mean integral parameters of post-occlusion temperature increase $T_c, ^\circ\text{C}$	6.5 ± 1.7	3.5 ± 1.7	1.2 ± 0.8
9	The frequency of occurrence in the group of patients with rheumatologic diseases	34 %	17 %	49 %

Identified changes in the temperature response to occlusion test indicate the formation of pronounced changes in the blood microcirculation in patients with a rheumatologic diseases profile. These data indicate a violation of the blood supply regulation in the form of a pronounced tendency towards microvascular vasoconstriction in the fingers. Thus, the response displaying a tendency toward angiospasm (type 3) among patients in the rheumatological diseases profile group was observed mainly in the most severe cases (49 % of group).

High frequencies of participants meeting with response type 1 (34 % of group) can be explained by prescription by doctors of drugs which increase microcirculation (Trental®, Actovegin®). Low severity of the disease allowed for short time to compensate for the pathological condition by application of pharmacological preparations.

The distribution of types of microvascular response in patients according to week of treatment (Fig. 4) shows that patients with normal blood microcirculation (type 1) predominate among patients on the 2nd week of treatment.

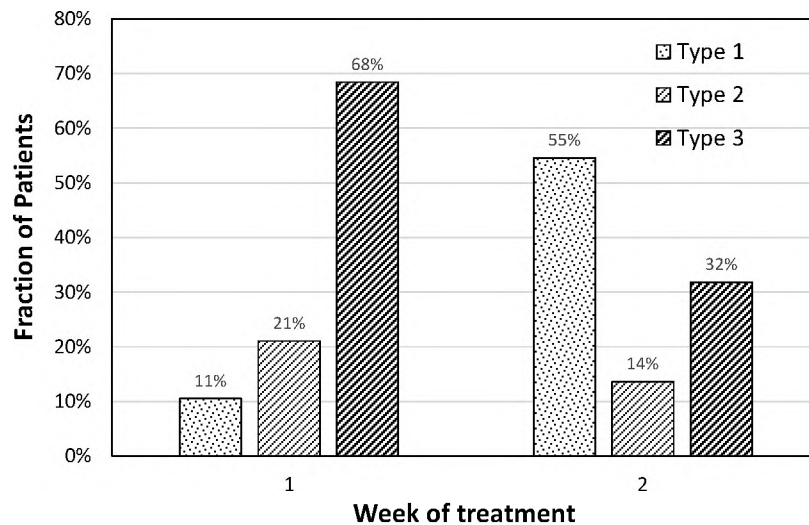


Figure 4. The distribution of types of microvascular response in patients according by week of treatment.

Taking into account the fact that the sharp breach state of peripheral blood flow and of its regulation in patients with rheumatological profile correlate with the severity of the clinical picture, it can be assumed that the proposed method not only finds application in part of the definition of the presence or absence of lesions in the blood microcirculation system during rheumatic diseases, but also serve as a tool of early diagnosis.

4. CONCLUSION

The proposed approach allows assessment of the tendency towards spasm of limb vessels as well as evaluating the thermal characteristics of biological tissues. Thus, cutaneous blood microcirculation and temperature measurements performed together can help in diagnosis of the functional state of peripheral vessels both in a healthy state and when expressing pathology. The theoretical possibility of diagnostics of the functional state of peripheral vessels, based on the combined use of the methods of LDF and contact thermometry during occlusion test was experimentally substantiated.

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