Investigation of Doppler spectra of laser radiation scattered inside hand skin during occlusion test

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Abstract. Laser Doppler flowmetry (LDF) is a method widely used in diagnosis of microcirculation diseases. It is well known that information about frequency distribution of Doppler spectrum of the laser radiation scattered by moving red blood cells (RBC) usually disappears after signal processing procedure. Photocurrent's spectrum distribution contains valuable diagnostic information about velocity distribution of the RBC. In this research it is proposed to compute the indexes of microcirculation in the sub-ranges of the Doppler spectrum as well as investigate the frequency distribution of the computed indexes.

1. Introduction

The LDF-method allows to assess the dynamics of a tissue structures blood perfusion by index of microcirculation [1, 2]. This is an integrated assessment which characterizes the general functional state of a local microcirculation system:

$$I_m(\omega) = \int_0^\infty \frac{P(\omega) \cdot d\omega}{i_{dc}}, \quad (1)$$

where $I_m(\omega)$ – index of microcirculation; ω – frequency of Doppler shift; $P(\omega)$ – amplitude value of power spectrum; i_{dc} – DC component of the photocurrent. According to its physical meaning, index of microcirculation is proportional to the average velocity and concentration of the red blood cells. The time based changes of the registered LDF device perfusion signal contain two main components: constant and variable. The constant component is the average blood perfusion of the selected time interval. The variable component of the signal is caused by physiological factors regulating blood volume and reflects the frequency rhythms of blood flow regulation. Both components are important for the diagnostics of quite a number of diseases. In LDF devices, Doppler shift spectrum is registered in the range of 20 – 24,000 Hz arising after the reflection of radiation from an ensemble of red blood cells moving at different speeds in the range 0.1 – 10 mm/s in small vessels – arterioles, capillaries, and venules in diagnostic volume [3, 4]. Signals from microvessels with different blood flow velocity are mixed in one output time domain signal of perfusion. Consequently, perfusion distribution by Doppler shift frequency is commonly lost during traditional signal processing. Whereas, direct digital processing of received photocurrent is more informative. It was suggested that utilizing occlusion test, cold test and orthostatic test leads to redistribution of perfusion by Doppler shift frequency ranges and

this effect may vary in groups of healthy people and people with microcirculatory dysfunction. Thus, redistribution of signal during provocative factors can give significant diagnostic information.

2. Experimental method and equipment

For the designed experimental study appropriate hardware and software were developed. As a laser source, one-mode laser with 1064 nm wavelength was utilized. Si-photodiodes were used to convert detected radiation into photocurrent. Optical fibers were used to deliver radiation to the skin and to collect backscattering light. In the next step, the signal is amplified in a custom electronic board. Analog-to-digital conversion was performed by data acquisition board NI USB 6211. Finally, NI LabVIEW environment installed on PC was implemented for signal processing [5] (Fig. 1). Power spectrum of the signals is computed by classic algorithm based on Fast Fourier Transform.

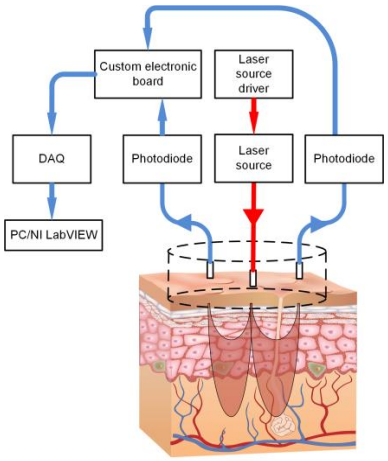

Figure 1 – Scheme of laser Doppler flowmetry device

Applying standard physiological functional tests to a limb results in changing RBC velocity distribution inside the skin. Fourteen experiment of shoulder occlusion were performed in order to record such alternations during the occlusion test [6]. Experiments involved only healthy volunteers. During the experiments simultaneously obtained parts of power spectra from fingers in consecutive frequency ranges 60 – 400 Hz, 400 – 800 Hz, 800 – 1600 Hz, 1600 – 3200 Hz, 3200 – 6400 Hz were also processed. Every experiment was conducted following the protocol: recording of the background level of perfusion (3 min); occlusion test (3 min); post-occlusion recording (5 min). Example of the LDF-gram with integrating in range of Doppler shift 60 – 6400 Hz is presented at Fig. 2. Examples of the LDF-grams with integrating in subranges are presented at Fig. 3.

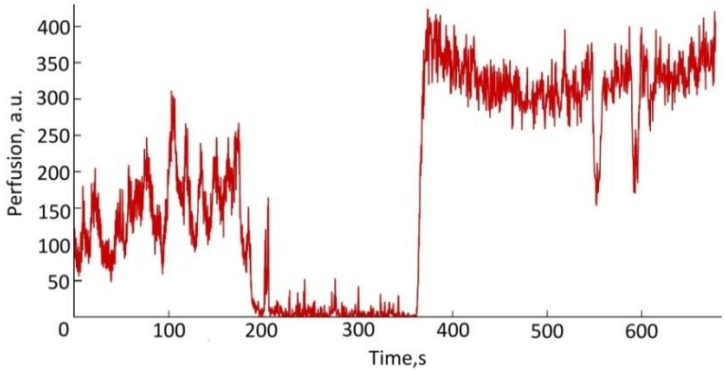

Figure 2 – Example of LDF-gram computed during occlusion test in frequency range 60 – 6400 Hz

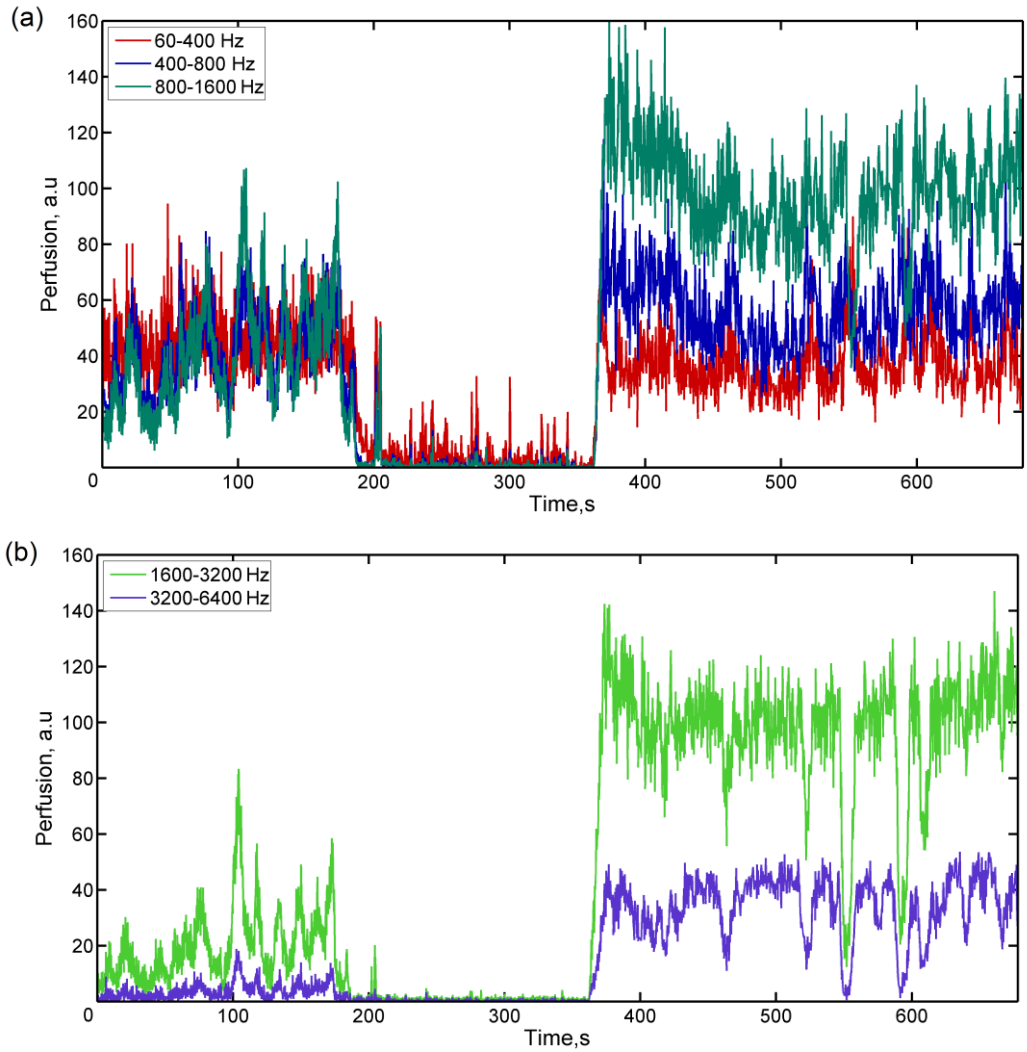

Figure 3 – Example of LDF-grams computed during occlusion test in frequency ranges 60 – 400 Hz, 400 – 800 Hz, 800 – 1600 Hz (a), 1600 – 3200 Hz, 3200 – 6400 Hz (b)

3. Results and discussion

Processing of the obtained experimental data has shown that at the moment of the post-occlusion reactive hyperemia (PORH) Doppler power spectrum undergoes broadening and the spectrum maximum shifts to the high-frequency ranges [7]. This effect can be explained by increasing number of ensembles of RBC with higher velocity in the optical sampling volume of the skin and increasing RBC concentration in low frequency ranges [8, 9]. The main statistical parameters (mean and standard deviation) of perfusion alteration during the occlusion tests were calculated in the selected spectral ranges of power spectrum integration (Fig. 4).

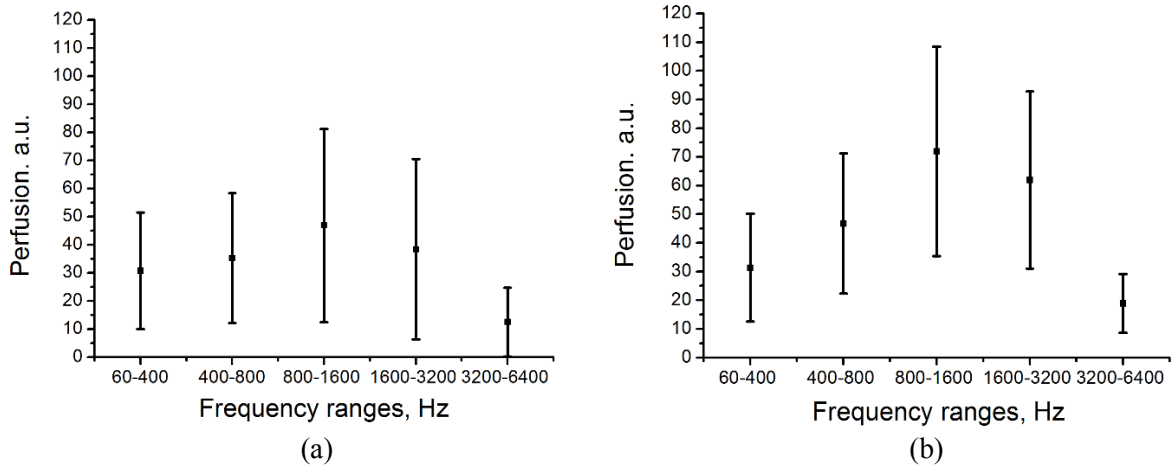

Figure 4 – Means and standard deviations of perfusion calculated in frequency sub-ranges: (a) pre-occlusion period; (b) post occlusion reactive hyperaemia

In addition, method of visualization of perfusion distribution by frequency of Doppler shift was offered (Fig. 5). These graphs represent values of multiplication of power spectrum and corresponding frequency in color scale according to the following equation:

$$I_m(\omega) = \frac{P(\omega) \cdot \omega}{i_{dc}} \quad . \tag{2}$$

Then, all processed perfusion values are colored and presented in time domain.

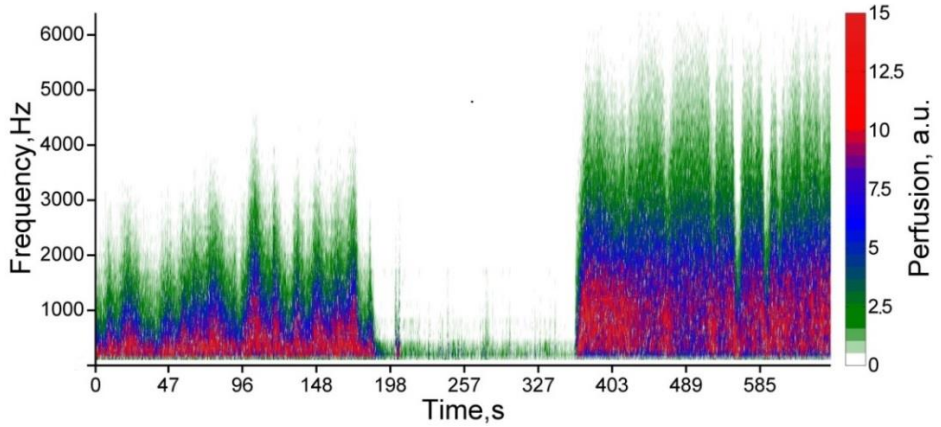

Figure 5 – Visualization of perfusion distribution by frequency of Doppler shift during experiment represented in Fig. 2

This approach can demonstrate registered effect of perfusion redistribution after occlusion. As it presented on the graph, perfusion distribution shifts up to 6000 Hz during post-occlusion reactive hyperemia.

4. Conclusion

As the result of the study we have obtained transient dynamics of perfusion distribution from frequency during such provocative factor as occlusion test. Proposed approach of perfusion distribution visualization can indicate information about concentration and velocity characteristics of blood flow. Further experimental studies in the group of patients with microcirculation diseases are planned. Moreover, identification of microcirculation components such as capillary, arteriole and

venule blood flows by analyzing of frequency distribution of Doppler shift is planned. The comparison of the data from the patients with the data from healthy volunteers will allow to substantiate new diagnostic criteria.

Acknowledgements
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