A new signal processing in laser Doppler flowmetry

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Abstract

Due to simplicity and ease of use, the laser Doppler flowmetry (LDF) has found applications in various areas of research related to non-invasive diagnosis of blood microcirculation. In fact, LDF still has a number of unsolved problems that limit its day-to-day use in clinical practice. Current report discusses the new approach for the LDF signal processing, that allows to receive a new diagnostic information. The proposed algorithm provides information on the quantitative distribution of the red blood cells velocities in the probing volume of biological tissue when applying different provocative effects.

Keywords: laser Doppler flowmetry, Doppler spectrum decomposition, blood microcirculation, signal processing, frequency of Doppler shift

I Introduction

Laser Doppler flowmetry (LDF), for the first time used in 1972 for the analysis of blood microcirculation[1], is currently one of the most common technologies for assessing the perfusion of biological tissues[2]. The method is based on probing tissue with laser radiation and recording a stochastic photocurrent resulting from optical mixing on photodetector a frequency-shifted (scattered from moving components) and non-shifted (scattered from static components) light[3]. LDF has found its application in a wide variety of studies[2,4,5], which is facilitated by the non-invasiveness of the method, ease of use, and the ability to record the signal in real time.

However, despite all the advantages of this technology, there are unresolved issues preventing its wider introduction into clinical practice. The main challenge of the technology that limits its use is the overcoming the large inter- and intra-individual variability of the LDF signal[6,7] due to differences in the optical properties of tissues, the structure of the vascular bed and physiological factors, which makes it impossible to measure perfusion in absolute units. The resulting signal (index of microcirculation) is recorded in the so-called perfusion (arbitrary) units. This results in poor reproducibility of the signal dimension, which significantly complicates the calibration of LDF devices during their manufacture, as well as their further metrological control[8].

In the traditional processing of the LDF signal, the power spectrum is weighted by frequency, and as a result, the output signal is proportional to the concentration of red blood cells in the probing volume and their mean velocity[9]. In this case, integration over the wide frequency range is usually applied (20-24000 Hz). Previous studies have shown that the frequency range of Doppler spectrum integration has a significant effect on the recorded signal[10], and in some cases, a narrower integration range is preferable[11].

In this paper, a new approach to the processing of the LDF signal, which allows for the evaluation of the contribution of various frequency components to the total resulting perfusion signal, is considered and tested.

II Materials and Methods

An in-house laser Doppler flowmetry setup was developed. The system includes one-mode laser of 1064 nm wavelength, two photodiodes, an analog amplifier with current-to-voltage converter, data acquisition card and PC with installed visual programming environment NI LabVIEW. Delivery of radiation to the skin and

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collecting of the backscattered light were performed by optical fibers. The scattered radiation was transformed in photocurrent on a photoconverter and then received signal was amplified by use of custom electronic board and digitized on data acquisition card NI USB 6211[12,13].

Signal processing was carried out in PC with NI LabVIEW environment, and the result was displayed on the screen and recorded in a data file. The power spectrum of the signals was evaluated by a classic algorithm based on Fast Fourier Transform[14].

Two different functional tests were chosen as a provocative effect: an arterial occlusion test and an experiment with local tissue pressure loading. Volunteers were pre-adapted to the room temperature of 24-25°C and were in a state of physical and mental rest. All measurements were performed daily from 11:00 until 13:00 to avoid any influence of circadian rhythms on the blood circulation.

The first part of the study included the occlusion of the brachial artery, which was carried out by clamping the forearm with a tonometer cuff with a pressure of 220 mm Hg. Fourteen healthy young volunteers (mean age is 21 years) participated in the study. LDF signals were obtained and integrated by following sub-bands: 60-400 Hz; 400-800 Hz; 800-1600 Hz; 1600-3200 Hz; 3200-6400 Hz. The signal was recorded during three consecutive stages: baseline measurements of skin perfusion for 3 min, arterial occlusion – 3 min and postocclusive period recording for 5 min.

The second part of the experiment included the study of the effect of locally applied pressure[15,16] on the LDF signal and its distribution over the frequency sub-bands. Special tooling developed and manufactured using a 3D-printer was used in the study for loading tissue with weights[17]. The tooling was placed coaxially to optic fiber. At the beginning of the study, the signal was recorded without tissue loading with weights. The weights were then added evenly to the tooling until the pressure was 40 kPa. The next stage of the experiment was the sequential unloading of the tissue in the same order in which the loading occurred. The study was conducted on 7 young healthy volunteers and lasted about 50 min.

III Results and Discussion

During the occlusion test, an increase in the LDF signal was observed in the frequency ranges of 800–1600 Hz and 1600–3200 Hz.

The research results are presented on a time-resolved graph with corresponding calculated frequencies of the Doppler shift (Figure 1).

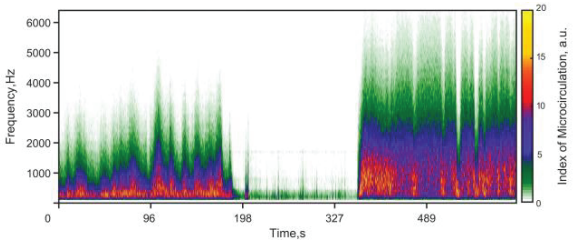

Figure 1. The distribution of the index of microcirculation in frequency and amplitude in time during the occlusion test.

The obtained measurement results after removal of the occlusion can be explained by post-occlusive reactive hyperemia, i.e. an increase in the number of fast moving red blood cells.

In the second part of the study with the local loading test, it was shown that the index of microcirculation starts to decrease with the pressure of 5 kPa. At the same time, in the low-frequency range (up to 1000 Hz), an increase in the signal amplitude is observed at small values of the applied pressure. The results of the experiment are presented in Figure 2.

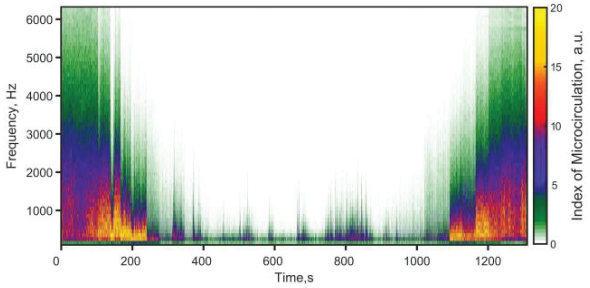

Figure 2. The distribution of the index of microcirculation in frequency and amplitude in time during the local pressure loading test.

The obtained result may be related to the fact that an increase in pressure applied to the skin slows down the

blood flow. Thus, more slowly moving red blood cells appear in the probed volume of biotissue.

IV Conclusions

Using the developed algorithm, the distribution of the red blood cells velocities during functional tests was evaluated. The proposed method allows for evaluation of the contribution of each frequency sub-band to the total LDF signal.

The performed experiments demonstrated the difference in the response of different frequency sub-bands of the Doppler shift to provocative effects. It was shown that the largest contribution to the increase in the LDF signal in the period of post-occlusive reactive hyperemia is made by the frequency ranges from 400 to 3200 Hz. During the test with local loading of the skin, an increase in the signal integrated over low-frequency range (up to 1000 Hz) was demonstrated, while the high-frequency components of the signal decreased.

The proposed approach to analyzing the LDF signal allows obtaining new data on microcirculatory blood flow. Investigation of the microcirculation index distribution over the frequency sub-bands could potentially have diagnostic value in conditions associated with microvascular disorders.

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