Heterogeneity of cutaneous blood flow respiratory–related oscillations quantified via LSCI wavelet decomposition

Irina Mizeva[1,2] and Elena Potapova, Igor Kozlov, Viktor Dremin, Andrey Dunaev[2], Gennadii Krasnikov [3]

***Abstract*— We study respiratory–related oscillations of blood flow in microvessels of the human skin. The reasons for generation of peripheral blood flow oscillations in the frequency band 0.14-0.6 Hz are as follows: cardio-respiratory interactions, pressure variations in the venous part of the circulatory system caused by respiratory excursions of the chest and the effect of the sympathetic nervous system on the vascular tone. In [1], we described the spatial heterogeneity of 0.3 Hz oscillations. This work presents a pilot study in which a number of physiological tests, an appropriate measurement system and data processing algorithms were developed. At spontaneous respiration, the 0.3 Hz oscillations turned out to be stochastic, whereas in controlled respiratory tests the spatial coherence of oscillations increases twice. The protocols and methods proposed here can help to clarify whether the heterogeneity of respiratory-related blood flow oscillations exists on the skin surface.**

I. INTRODUCTION

The study of vascular tone oscillations provides more complete understanding of mechanisms and factors affecting microvascular physiology. Such oscillations can be quantified by laser Doppler flowmetry (LDF), temperature measurements, plethysmography, as well as by laser speckle contrast imaging (LSCI). A high correlation between the LSCI and LDF methods, predicted by Fredriksson in [2], was confirmed experimentally in [1]. It was also shown that respiratory-related oscillations are significantly different in phase and amplitude in the ROI (2×2 mm^2) on the skin surface.

There are several possible reasons for generation of peripheral blood flow oscillations in the frequency band 0.14-0.6 Hz: cardio-respiratory interactions, pressure variations in the venous part of the circulatory system caused by respiratory excursions of the chest and the effect of the sympathetic nervous system on the vascular tone.

The aim of this work is to develop a measurement and data processing procedure that holds promise for elucidating whether the heterogeneity of respiratory-related blood flow oscillations can be observed on the skin surface.

II. MATERIALS AND METHODS

The scheme of the experimental setup is presented in Fig. 1. The area under study was illuminated by a 10 mW laser source operating at 785 nm wavelength (Thorlabs Inc, USA). A CMOS-camera DCC3260M (Thorlabs, Inc., USA) with 1936×1216 pixels and 5.86 μm pixel size, camera lens MVL25TM23 (Thorlabs, Inc., USA) and a diffuser for uniform illumination of the area of interest were used to record raw speckle images. The data was acquired at the sampling frequency of 80 Hz and exposure time of 9 ms. The distance between the camera lens and the examined area was 25 cm. The typical raw speckle map is shown in Fig. 1. We attempted to avoid all movements and external vibrations. The hand was placed on the Pneumatic Vibration Isolation Workstation (1VIS10W, Standa, Lithuania) with th the optic setup. The hand was thermally isolated from the table and additionally fixed with bandages "Peha-haft" (Hartmann, Germany) to prevent involuntary movements.

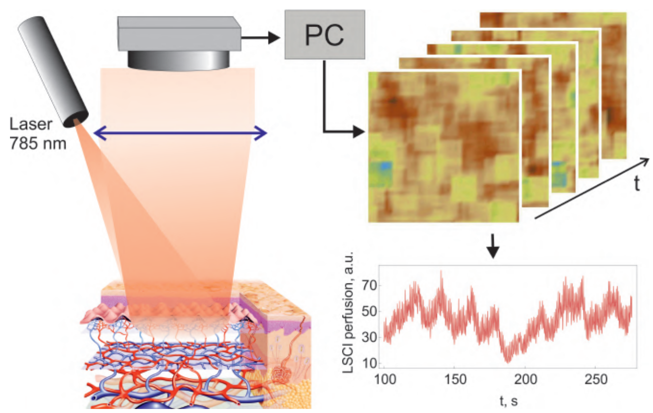

Fig. 1. Scheme of the experimental setup and the LSCI pattern plotted using the results averaged over the whole image.

III. MATERIALS AND METHODS

Our preliminary study included only one subject (female, 37 years old without cardiovascular diseases, nonsmoker). Three different protocols were applied:

1. Spontaneous respiration – 3 minute duration, data collected from palmar (protocol **1p**) and dorsal (protocol **1d**) surfaces of the right palm; 2. Controlled respiration – 3 minute duration, data collected from both parts of the palm (data **2p** and **2d**); 3. Deep inspiratory gasp (DIG) test – 3 minutes in basal conditions, then 15 second DIG and finally 3 minutes of spontaneous respiration (**3p** and **3d**)).

Data processing includes reconstruction of the temporal dynamics of speckle contrast ($LSCI(i, j, t)$, $i = 1..8$, $j = 1..8$) in each of 64 regions. Further, wavelet decomposition

*Supported by the Russian Science Foundation (Project No.18-15-00201).

[1]Irina Mizeva is with Institute of Continuous Media Mechanics UrB RAS Perm, Russia &Research & Development Center of Biomedical Photonics Orel State University Orel, Russia mizeva@icmm.ru

[2]Elena Potapova, Igor Kozlov, Viktor Dremin, Andrey Dunaev are with Research & Development Center of Biomedical Photonics Orel State University Orel, Russia potapova_ev_ogu@mail.ru

978-1-7281-5751-1/20/$31.00 ©2020 IEEE

was applied to each (i,j) using the original algorithms developed based on the wavelet Morlet with the decay factor 1.7 [3], [1]. The wavelet cross-correlation coefficients, the averaged phase shift and the wavelet coherence were calculated in the frequency range of 0.07-2 Hz. At the last stage, the spectral energy of oscillations was evaluated and the coherence estimates were obtained for randomly chosen 40 pairs (i,j) [4] :

$$C(i,j) = \sqrt{< \cos\phi(\nu,t) >^2 + < \sin\phi(\nu,t) >^2}. \quad (1)$$

IV. Results

Wavelet spectra and wavelet phase coherence are presented in Fig. 2, 3. We compared spontaneous respiration (**1p**) and controlled respiration (**2p**) records (Fig.2. In order that the DIG results could be analyzed properly, we considered two 15 second fragments, which were taken at spontaneous respiration and during the gasp (**3p** test). During controlled respiration, the activity of 0.3 Hz oscillations increased and concurrently they became more coherent. Our preliminary surrogate data analysis has provided evidence of the significance of the results which were obtained in the test **2p**.

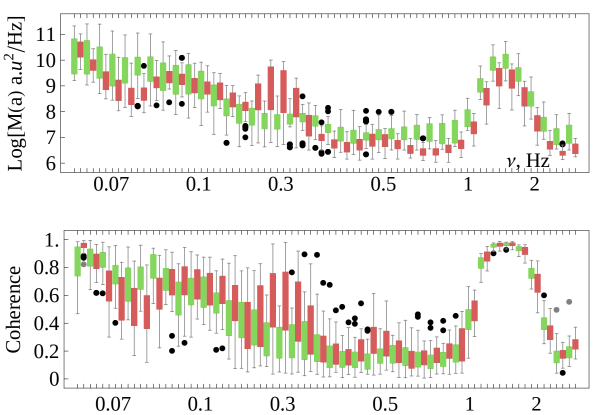

Fig. 2. Wavelet spectra and coherence averaged over the ROI, green boxes – spontaneous respiration test **1p**, red boxes – controlled respiration test **2p**.

In the DIG test, the spectral energy of respiratory-related oscillations changes only slightly, but the coherence increases significantly. We suppose that this phenomenon is due to the decreased influence of the distributed source of oscillations in the microvessels associated with respiratory activity. Note that this tendency is pronounced on both sides of the palm.

V. Discussion

LSCI provides images of blood perfusion and allows one to evaluate the spatial distribution of perfusion oscillations. We developed an experimental setup, data processing algorithms, and a set of physiological tests to support our idea of heterogeneity of respiratory-related oscillations. At the moment, we have very preliminary results saying for this hypothesis. To avoid calculation errors, all data processing tools must be properly tested and updated. We intend to use the Gaussian sliding filter for a sequential determination of both spatial and temporal parts of the speckle contrast [5].

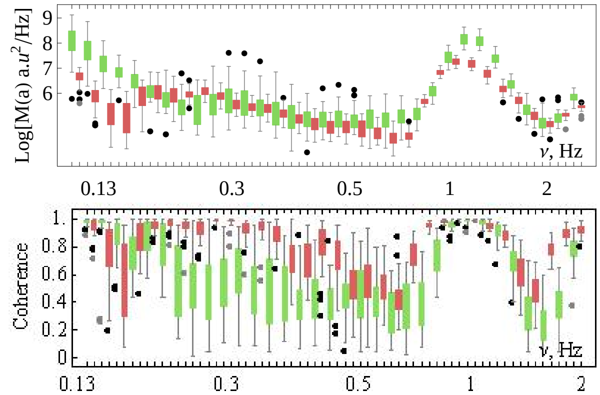

Fig. 3. Wavelet spectra and coherence averaged over the ROI, green boxes – spontaneous respiration test **1p**, red boxes – DIG test **3p**.

Particular attention will be focused on evaluation of statistcal significance of the obtained results [6]. If the blood flow spatial heterogenity effect is detected by LSCI, then other physical methods, such as imaging LDF, videocapillaroscopy [7] and imaging photoplethismography, will be applied.

References

[1] I. Mizeva, V. Dremin, E. Potapova, E. Zherebtsov, I. Kozlov, and A. Dunaev, “Wavelet analysis of the temporal dynamics of the laser speckle contrast in human skin,” *IEEE Transactions on Biomedical Engineering*, 2019.

[2] I. Fredriksson and M. Larsson, “On the equivalence and differences between laser doppler flowmetry and laser speckle contrast analysis,” *Journal of Biomedical Optics*, vol. 21, no. 12, p. 126018, 2016.

[3] *Wavelets: an analysis tool*, ser. Oxford mathematical monographs. Clarendon Press, 1995.

[4] A. Bandrivskyy, A. Bernjak, P. McClintock, and A. Stefanovska, “Wavelet phase coherence analysis: Application to skin temperature and blood flow,” *Cardiovascular Engineering: An International Journal*, vol. 4, no. 1, pp. 89–93, Mar 2004.

[5] E. B. Postnikov, M. O. Tsoy, P. A. Timoshina, and D. E. Postnov, “Gaussian sliding window for robust processing laser speckle contrast images,” *International Journal for Numerical Methods in Biomedical Engineering*, vol. 35, no. 4, p. e3186, 2019.

[6] G. Lancaster, D. Iatsenko, A. Pidde, V. Ticcinelli, and A. Stefanovska, “Surrogate data for hypothesis testing of physical systems,” *Physics Reports*, vol. 748, pp. 1 – 60, 2018.

[7] N. B. Margaryants, I. S. Sidorov, M. V. Volkov, I. P. Gurov, O. V. Mamontov, and A. A. Kamshilin, “Visualization of skin capillaries with moving red blood cells in arbitrary area of the body,” *Biomedical optics express*, vol. 10, no. 9, pp. 4896–4906, 2019.