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Comparison of wearable and bedside laser Doppler flowmetry and fluorescence spectroscopy monitors

Elena V. Zharkikh[a], Yulia I. Loktionova[a], Viktor V. Dremin[a,b], Konstantin V. Podmasteryev[a], Victor V. Sidorov[c], Edik U. Rafailov[b], and Andrey V. Dunaev[a]

[a]Research Development Center of Biomedical Photonics, Orel State University named after I.S. Turgenev, 95 Komsomolskaya St, Orel, 302026, Russia
[b]College of Engineering and Physical Sciences, Aston University, Aston Triangle, Birmingham, B4 7ET, UK
[c]SPE "LAZMA", Moscow, 125252, Russia

ABSTRACT

Advances in the development of ultra-compact semiconductor lasers have opened up new possibilities for the development of wearable devices implementing biophotonic technologies, such as laser Doppler flowmetry (LDF) and fluorescence spectroscopy (FS). This work is aimed to evaluate the correlation between diagnostic parameters simultaneously registered by a newly developed wearable device and a standard bedside fiber-based technique. Experimental studies with healthy volunteers using the occlusion test showed a high correlation between the parameters recorded by the two devices.

Keywords: laser Doppler flowmetry, fluorescence spectroscopy, wearable sensors, occlusion test

1. INTRODUCTION

Recently, one of the main trends in modern health care has been its increasing digitalization. The development of various methods and tools to move away from discrete patient diagnosis at physician visits to continuous remote patient monitoring (telemedicine and remote diagnostic tools) improves the ability to make earlier and more accurate diagnoses and provide more targeted medical care. The intensive development of wearable electronics also plays a significant role in this process.

Recent advances in the development of ultra-compact semiconductor lasers have provided new opportunities for the development of the latest generation of wearable devices that implement biophotonic techniques.[1] These techniques include, in particular, laser Doppler flowmetry (LDF) and fluorescence spectroscopy.

LDF is a technology that has long proven itself in the study of microcirculation function both in healthy people and in various pathological conditions.[2] LDF has found wide application in assessing the function of microcirculation in a number of pathological disorders, including hypertension,[3] diabetes mellitus.[4] A recent study showed the effectiveness of LDF in assessing endothelial function in COVID-19 patients.[5] The method of fluorescence spectroscopy is also used in a wide range of research areas for *in vivo* diagnosis of pathological conditions.[6]

The first generation of wearable devices equipped with an LDF channel only has already undergone preliminary studies to assess microcirculation in healthy volunteers of different age groups[7] and smoking statuses,[8] as well as in studies of patients with diabetes mellitus.[9,10] However, at the moment, no studies have been conducted comparing the principle of operation and data recording by these devices with standard bedside monitors that implement the same diagnostic methods.

The aim of this work was to evaluate the correlation between measurements of cutaneous microcirculation and fluorescence intensity by two devices: a newly developed wearable device and a standard bedside fiber-based technique.

Send correspondence to Elena Zharkikh
E-mail: e.zharkikh@oreluniver.ru, Telephone: +7 953 474 06 86

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2. MATERIALS AND METHODS

The present study was conducted with the participation of 14 conditionally healthy volunteers (6 female, 8 male) with the approximate age of 22 ± 3 years. The study was approved by the local ethics committee, before the start of measurements each volunteer provided written consent to participate in the study. The study did not include individuals with any significant medical history or long-term smoking history. All measurements were carried out in the daytime not earlier than 2 hours after a meal.

The parameters of cutaneous microcirculation and fluorescence intensity were simultaneously recorded with two devices: newly developed wireless wearable LDF and fluorescence monitor "LAZMA-W2" (Aston Medical Technology Ltd., UK) and bedside monitor "LAZMA-D" ("LAZMA" Ltd., Russia). The device "LAZMA-D" implements LDF channel using a single-mode laser with a wavelength of 1064 nm as a radiation source. The delivery of optical radiation to the skin is carried out through an optical fiber.[11] The device "LAZMA-W2" uses a VCSEL chip with a wavelength of 850 nm as a single-mode laser source, delivering radiation directly to the skin.[1] Each instrument uses a 365 nm UV LED to excite endogenous fluorescence.

The devices were positioned on the midline of the dorsum of the wrist without exerting any pressure on the measurement area. The location of the devices on the subject's hand during the study is shown in Fig. 1. Experimental studies were carried out in the sitting position of the subjects with their hands placed on the table at the heart level.

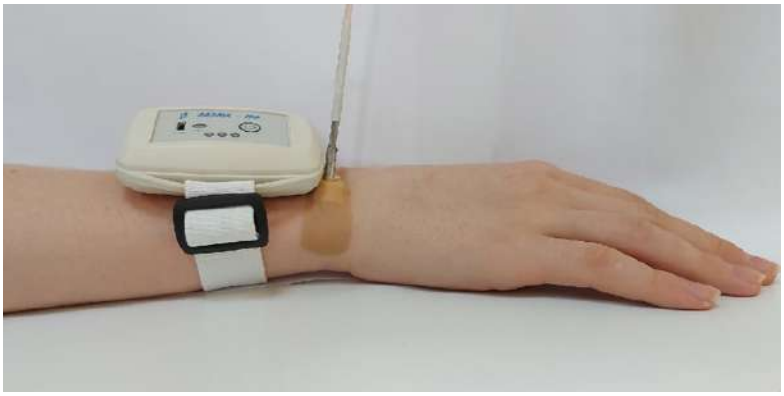


Figure 1. Location of the wearable device (left) and the optical fiber of the bedside monitor (right) on the subject's arm.

LDF signals were recorded simultaneously by 2 devices for 20 minutes. To compare the reproducibility of LDF data, a functional test, brachial artery occlusion, was used in this study. The protocol of LDF signal registration included 10 min of recording the baseline signal level, 3 min of occlusion test, and 7 min of subsequent recording of signal recovery to the baseline level. A diagram of the LDF signal registration protocol is shown in Fig. 2. At the end of each measurement, the value of the fluorescence intensity excited with 365 nm light was also recorded.

During the study, the index of microcirculation (I_m) and the fluorescence amplitudes registered at wavelengths of 460 nm ($I_F^{4\,60}$) were recorded and normalized to the back-scattered radiation. Based on the results of the occlusion test, the blood flow reserve ($BFR, \%$) parameter was also calculated according to the following formula:

$$BFR = I_m^{max} / I_m^{baseline} \cdot 100\% \tag{1}$$

The relationship between LDF and fluorescence data recorded by the two devices was evaluated by means of Person's linear fitting.

3. RESULTS AND DISCUSSION

The results of calculating the Pearson correlation for the microcirculation index recorded by the LDF method and the fluorescence intensity are shown in Fig. 3. We received high correlation values of the fluorescence parameter for the two compared devices ($r = 0.81, p < 0.05$). Since the LDF channels of the devices used in

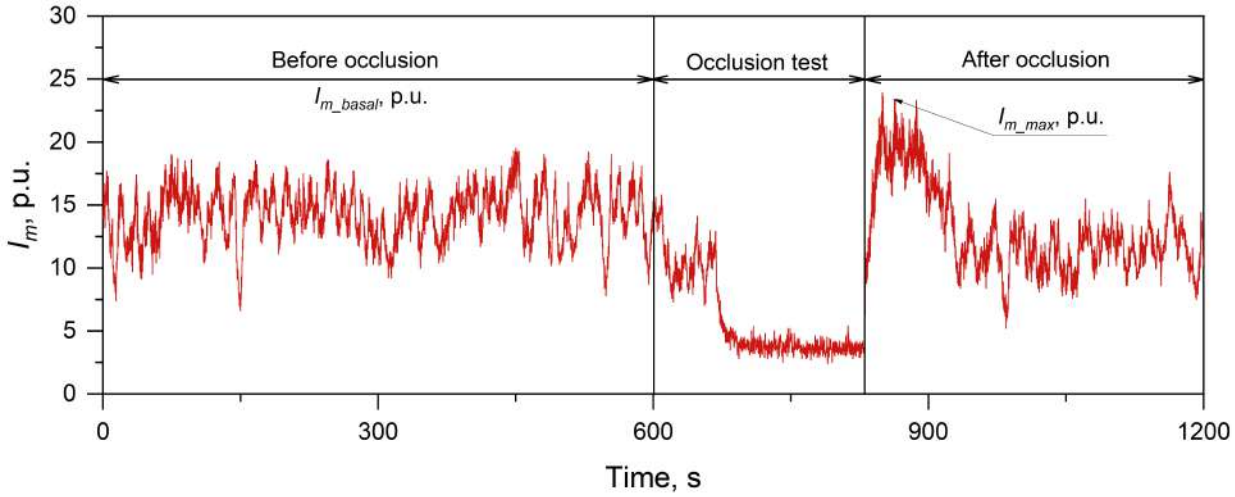
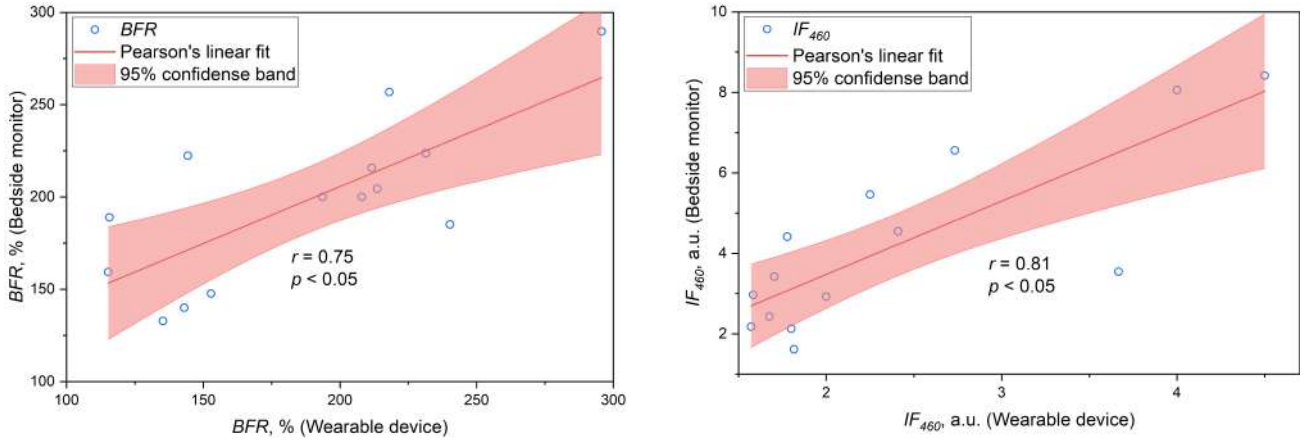


Figure 2. LDF signal registration process during the experiment.

this study operate at different wavelengths and have different probing depth and diagnostic volume, our study focused more on comparing the dynamic changes in microcirculation during the occlusion test. The blood flow reserve (BFR, %) parameter was found to be highly correlated ($r = 0.75, p < 0.05$) when measured by the two devices.



(a) **(b)**

Figure 3. Pearson linear approximation plots for measurement results: (a) for blood flow reserve measurements by LDF and (b) for measurements of the skin fluorescence intensity normalized to back-scattered radiation.

Measurements of baseline blood microcirculation index (I_m) by the two devices also showed a high correlation ($r = 0.60, p < 0.05$), which is although less compared to BFR. It should be pointed out that the devices used in this study operate at different wavelengths and have different probing depths and diagnostic volume. In addition, in this study for simultaneous measurements, the devices were placed at some distance from each other. Thus, it can be assumed that the measurements in these devices do not necessarily reflect the state of the same skin layer and the microvasculature.

4. CONCLUSION

In this work, we have shown that the compared bedside and wearable monitors exhibit a high correlation of recorded data. This work represents the first stage of testing new wearable monitors for laser Doppler flowmetry and fluorescence spectroscopy. Additional studies to analyze the inter-day reproducibility of both baseline signals

and various functional tests are required. It is also necessary to take into account the inter-site variability of the LDF signal and conduct experiments in different areas of interest.

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