Laser Doppler flowmetry based on spectrum decomposition for the diagnosis of skin vascular complications

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Aim of the research

Clinical functional diagnosis of blood microcirculation can be performed using non-invasive optical methods. Laser Doppler flowmetry (LDF) is one of these methods used in many branches of medicine, including endocrinology, dentistry, and dermatology. In this technique, blood perfusion is measured in the diagnostic volume in relation to the rate of blood flow and the concentration of red blood cells. In most modern LDF devices, however, useful information regarding Doppler frequency broadening cannot be accessed and used to solve diagnostic issues.

This work proposes a device and method for laser Doppler flowmetry that enhances the feature space based on the signal distribution by Doppler broadening frequencies.

Research protocol

1. Adaptation to experiment conditions – 10-15 min
2. Filling information consent and survey about health status – 5min
3. 10 min – Stage 1 – Baseline recording on 33 °C; 5 min – Stage 2 – Heating process with 1 °C/min; 25 min – Stage 3 – Heating test on 42 °C

Materials and Methods

Device:	Custom LDF device; 1064 nm wavelength of laser radiation; Coaxially combined with fibre local heating pad.
Area of interest:	Skin dorsal surface of the foot
Group of volunteers and patients:	11 patients with diabetes mellitus type 2 without necrosis and ulcers 17 volunteers without

Feature space for LDF analysis

$$PU(t)=\frac{\int_{f_1}^{f_2} f\cdot S\left[U_1(t)-U_2(t)\right]df}{i_{dc}^2}$$

Mean cumulative sum

$$C_n = C_{n-1}+\frac{f_n\cdot S(f_n)}{\sum_m f_i\cdot S(f_i)}$$

C_n – cumulative curve of perfusion distribution by Doppler shift frequency

$$AbC = C^1 \cap C^3$$

AbC – intersection area between two cumulative curves C^1 and C^3

C^1 – mean cumulative curve for stage 1.

C^3 – mean cumulative curve for stage 3.

Oscillation distribution

$$W_x(f_{osc},\tau)=\sqrt{f_{osc}}\times\int_{-\infty}^{\infty} PU(t)\cdot\psi^*\left[f_{osc}(t-\tau)\right]dt$$

$\psi(\tau)$ – mother wavelet function

$$M_{osc}(f_{osc})=\frac{1}{T}\int_0^T |W_x(f_{osc},\tau)|^2\,d\tau$$

$M_{osc}(f_{osc})$ – global wavelet spectrum

$$M(f_{osc},f_D)=\begin{bmatrix} a_{11} & \cdots & a_{1J}\\ \vdots & \ddots & \vdots \\ a_{I1} & \cdots & a_{IJ}\end{bmatrix}$$

$M(f_{osc},f_D)$ – distribution by Doppler broadening frequency and oscillation frequency

Results

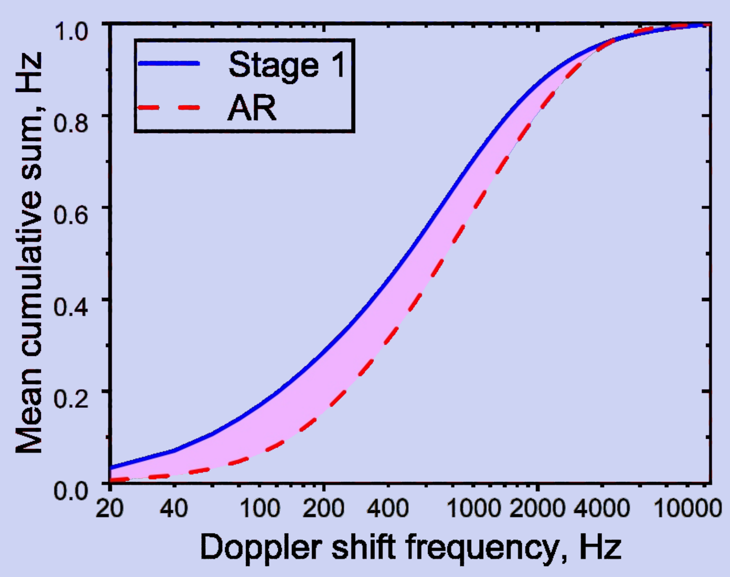

Figure 1 – Example of mean cumulative sums for Stage 1 and axon-reflex period (AR)

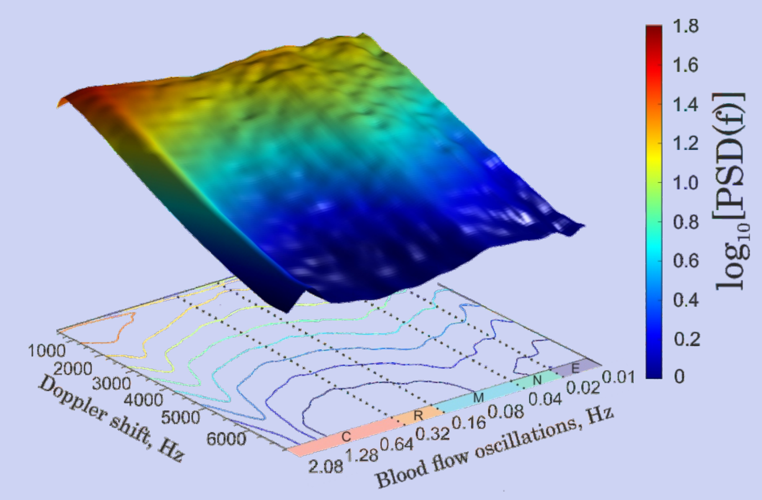

Figure 2 – Example of blood perfusion oscillation distribution by frequency of Doppler shift

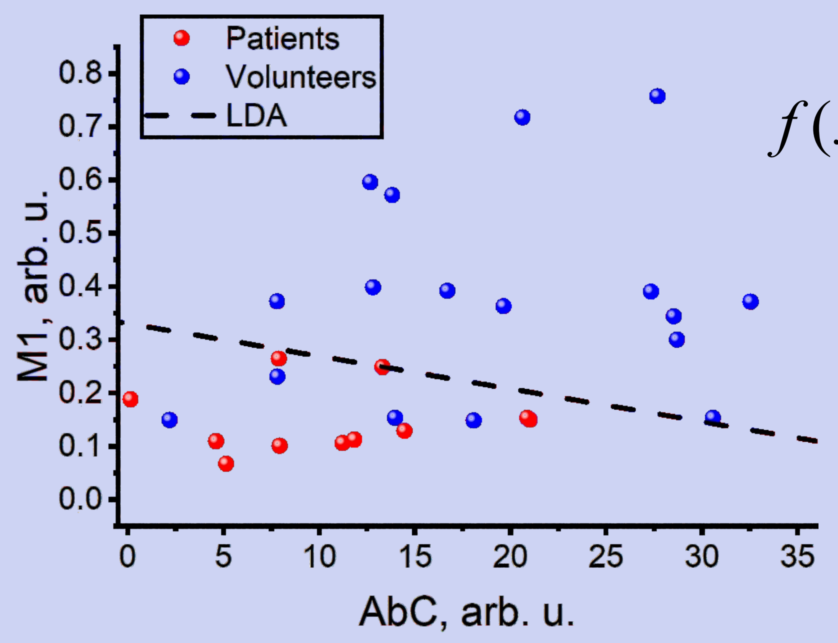

Figure 3 – Scatter diagram and linear discriminant function

$$f(x)=3.36+0.06AbC+10.1M_1$$

M_1 – mean blood perfusion oscillation amplitude where

$f_{osc}\in(0.08, 0.8)$ Hz

$f_D\in(800, 7000)$ Hz

Table 1 – Accuracy characteristics of LDA

Specificity	Sensitivity	AU ROC
0.73	1	0.89

Conclusion

It is demonstrated that the implemented technique for establishing diagnostics criteria show a high AU ROC and other accuracy characteristics. As the result, a novel system for microcirculation disorders diagnosing in patients with diabetes type 2 has been developed and new feature space has been proposed.

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