Laser Doppler flowmetry: multifractal spectra of signals recorded in hand of young healthy subjects before and after local heating

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Abstract— **Laser Doppler flowmetry (LDF) signals give a peripheral view of the cardiovascular system. We herein propose to analyze the complexity of LDF signals recorded in the palm side of the hand and to compare the results with those obtained in the forearm. Moreover, we also study the possible impact of local heating (40°C) on the width of the multifractal spectra for the hand. For this purpose, LDF signals are recorded simultaneously in the hand and forearm. A local heating of 40°C is performed in the hand palm, leading to an increase of the local skin blood flow via, among others, the production of nitric oxide. LDF data recorded before and during the local heating are processed in order to obtain their multifractal spectra. The latter are computed, without normalization of the signals amplitude, by first estimating the discrete partition function of the data, then by determining their Renyi exponents with a linear regression, and finally by computing their Legendre transform. The results show that, at rest, the average multifractal spectrum of signals recorded in the hand palm is larger and more asymmetric than the one of data from the forearm. Furthermore, without normalization of the signals amplitude, local heating in the hand palm leads to a slightly narrower and more symmetric average multifractal spectrum for this site. This study brings information on the multifractal spectra of LDF signals and is a first step in order to have more knowledge on the potential implication of the endothelium in the complexity of LDF signals in the hand palm.**

Keywords— **Laser Doppler flowmetry, multifractality, local heating, spatial variations, biomedical engineering.**

I. INTRODUCTION

Laser Doppler flowmetry (LDF) is an established technique for the real-time monitoring of microvascular perfusion in tissue [1-4]. It is commonly used in clinical research and gives a peripheral view of the cardiovascular system. LDF can be used in many purviews and on many organs, such as skin, brain, liver and intestines [5,6]. LDF signals are generated by the interaction between photons of a laser light and moving scatterers, mainly red blood cells. Both concentration and velocity of the moving scatterers affect the LDF perfusion estimate [7].

We herein propose to study the complexity of LDF signals recorded in the palm side of the hand and to compare the results with those obtained in the forearm. Complexity of LDF signals from glabrous and non glabrous skins is therefore analyzed. Recent works have shown that LDF signals recorded in the forearm, in young healthy subjects at rest, are weakly multifractal [8], but that aging can lead to a reduced multifractality [9]. However, to our knowledge, no work has been carried out for the hand palm. Moreover, we also propose to study the possible impact of local heating on the width of the multifractal spectra for the hand. For this purpose, LDF signals recorded simultaneously in the hand and forearm, at rest and during a local heating (local heating in the hand palm), are processed in order to obtain their multifractal spectra.

In response to the skin local temperature increase, cutaneous blood vessels dilate via local temperature-dependent mechanisms. Local skin heating involves local generation of nitric oxide (NO) [10], and is therefore commonly used as a functional marker of endothelial microvascular functions [11]. The observation of its effects is important as the endothelium is the main regulator of vascular wall homeostasis. Abnormal production of NO can affect blood flow and other vascular functions.

In what follows we first introduce the LDF technique and the measurement procedure used. Then the multifractal analysis is presented. Afterwards, we apply the signal processing analysis on experimental LDF data and present the results. Finally we end with a discussion and conclusion.

II. LDF TECHNIQUE

LDF allows a continuous monitoring of microcirculatory blood flow. The technique relies on the Doppler shift. When

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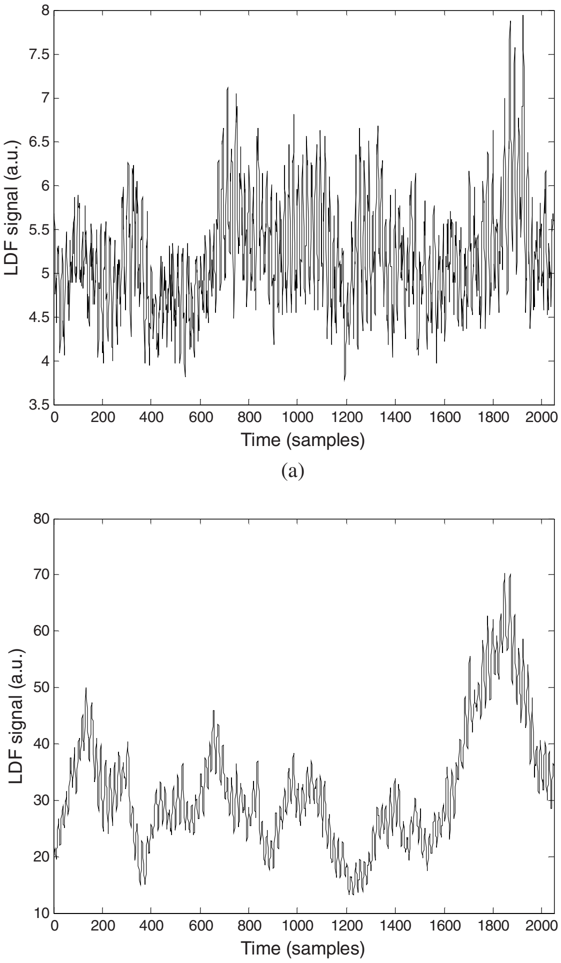
a coherent light is steered towards a tissue, photons are backscattered by static or in-movement structures. The Doppler effect appears when photons meet moving particles, mainly red blood cells. Their frequency is then modified. The backscattered light is brought towards an optical fiber to a photoreceptor. The LDF signal obtained is connected to the properties of the blood cells in the floodlighted volume.

III. MEASUREMENT PROCEDURE

The measurement procedure for the LDF signal acquisition was the following: five young healthy subjects were studied in the supine position. Their mean age was 28.2 ± 5.8 years. The measurements were performed in a quiet room with an ambient temperature set at 24 ± 1°C.



(a)

(b)

Fig 1: LDF signal of a young healthy subject recorded (a) in the left forearm, (b) in the left hand palm

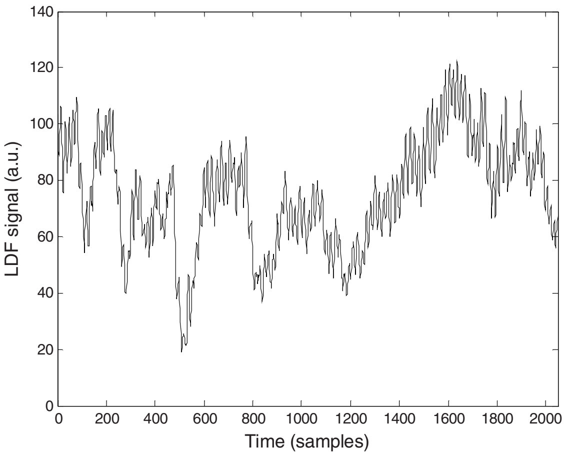


Fig 2: LDF signal of a young healthy subject recorded in the left hand palm 17 minutes after the beginning of the local heating (40°C).

After at least 10 minutes of acclimatization, skin blood flow measurements started. Skin blood flow was assessed in arbitrary units (a.u.) and recorded on a computer via an analog-to-digital converter (Biopac System) with a sample frequency of 20 Hz.

For the recordings, a LDF probe connected to a laser-Doppler flowmeter (Periflux PF4001, Perimed, Stockholm, Sweden), was positioned on the left hand palm of the subjects. Local warming devices (PeriTemp 4005 Heater, Perimed, Stockholm, Sweden) coupled to the LDF hand probe were also fixed onto the hand palm. Another probe was positioned on the left forearm (ventral face). Two LDF signals were thus recorded simultaneously for each subject. The local heating in the hand, chosen to 40°C, began after twenty minutes of recording.

LDF signals recorded after ten minutes of recording (thus before local heating) are shown in Fig. 1. Moreover, a signal recorded in the hand palm seventeen minutes after the beginning of the local heating is shown in Fig. 2. In what follows, we analyze 2048 samples from each LDF signal.

IV. MULTIFRACTAL ANALYSIS

The rapid changes in a time series X are called singularities and a characterization of their strength can be obtained with the Hölder exponents [12]. The Hölder exponent $\alpha(t_0)$ characterizes the strength of the singularity at $t = t_0$ [12]. When a "broad" range of exponents is found, signals are considered as multifractal. A "narrow" range implies monofractality. Multifractality in a process is a mark of a higher complexity compared to monofractal processes. The fractal behavior of a signal can be studied statistically by the multifractal spectrum *f*(*α*), using the multifractal formalism, which is defined as the fractal dimension of the subset of points with Hölder exponent *α*.

In what follows, no normalization amplitude of LDF data was performed before the analysis. The multifractal spectra were determined by first estimating the discrete partition function of the signals with non-overlapping boxes of increasing size (use of the so-called box method), which is defined as [13]:

$$Z(q,\varepsilon)=\sum_{i=1}^{N_{boxes}(\varepsilon)}\mu_i(\varepsilon)^q \tag{1}$$

where q is a real parameter that indicates the order of the moment of the measure $\mu_i(\varepsilon)$ and ε is the size of the boxes used to cover the signal. The boxes are labeled by the index i and $N_{boxes}(\varepsilon)$ indicates the number of boxes of size ε needed to cover the signal.

We then determine their Renyi exponents by a linear regression:

$$\tau(q)=\lim_{\varepsilon\to 0}\frac{\log(Z(q,\varepsilon))}{\log(\varepsilon)}. \tag{2}$$

Finally we obtain *α* and *f(α)* by computing their Legendre transform [13]:

$$\alpha(q)=\frac{\partial\tau(q)}{\partial q},\quad f(\alpha)=\alpha(q)q-\tau(q) \tag{3}$$

The computation of the Legendre transform was performed with the Reyni exponents between scales 2^9 and 2^{12}.

V. MULTIFRACTAL SPECTRA OF LDF SIGNALS

With the above mentioned considerations, the results of the average multifractal spectra for the two anatomical sites before local heating are shown in Figs. 3. The results obtained on the hand palm before and during local heating are shown in Fig. 4. From these figures we observe that the average multifractal spectrum of the LDF signals recorded in the hand palm is larger and more asymmetric than the average multifractal spectrum recorded in the forearm. Thus, without local heating, when *f*(*α*) = 0.5, the average width is 0.0584 for the forearm and 0.2599 for the hand palm. Blood flow from the hand palm (glabrous skin) seems therefore more complex than blood flow from the forearm (non glabrous skin).

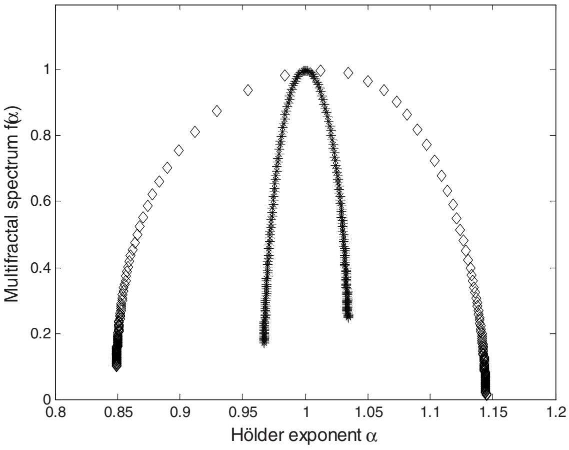


Fig 3: Average multifractal spectra of LDF signals recorded in the left forearm (star curve) and the left hand palm (diamond curve) at rest.

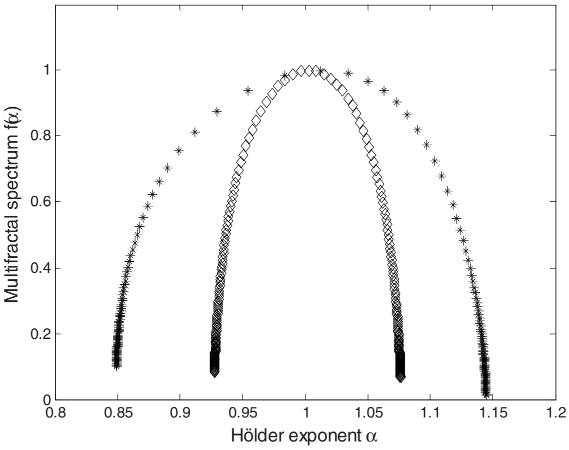


Fig 4: Average multifractal spectra of LDF signals recorded in the left hand palm at rest (star curve) and 17 minutes after the beginning of a local heating of 40°C (diamond curve).

Moreover, we observe that the average multifractal spectra of data recorded seventeen minutes after the beginning of the local heating to 40°C is narrower and more symmetric than the one obtained at rest. Thus, the average width is 0.1301 for the hand palm seventeen minutes after local heating, while it is of 0.2599 at rest.

VI. SUMMARY AND CONCLUSION

Many biological signals were recently analyzed to evaluate their mono- or multifractality. Most of them were recorded from the central cardiovascular system. In this study we process LDF signals which correspond to data issued from the peripheral cardiovascular system.

Signals recorded simultaneously in two different anatomical sites are analyzed. Moreover, to study the possible impact of the endothelial microvascular function in the multifractal spectra width for the hand, a local heating to 40°C is performed.

From our results we confirm that LDF signals recorded in the forearm in healthy subjects at rest are weakly multifractal. This is in accordance with previous works [8,9]. In addition, our results show that, without amplitude normalization, the average multifractal spectrum of LDF signals recorded in the hand palm are broader than the one computed from data recorded in the forearm. Moreover, we show that, without amplitude normalization, the average multifractal spectrum of LDF data recorded during local warming, in the hand palm is narrower and more symmetric than the one of signals recorded at rest.

The underlying mechanisms leading to the width of the multifractal spectra for LDF signals are still unknown. However, our findings show that the breadth of the multifractal spectra could depend on the anatomical sites. Furthermore, in sight of our results, NO could also have an impact on the multifractal spectra. This study is a first step in order to have more knowledge on the potential implication of the endothelium in the complexity of LDF signals recorded in the hand palm.

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REFERENCES

[1] Nilsson G E, Tenland T, Oberg P A (1980) Evaluation of a laser Doppler flowmeter for measurement of tissue blood flow. IEEE Trans. Biomed. Eng. 27:597-604

[2] Bonner R F, Nossal R (1990) Principles of Laser-Doppler Flowmetry in *Laser-Doppler Blood Flowmetry*. Shepherd A P, Oberg P A, eds. Kluwer Academic, Boston, Mass., 17-45

[3] Leahy M J, de Muhl F F M, Nilsson G E, Maniewski R, (1999) Principles and practice of the laser-Doppler perfusion technique. Technol. Health Care 7:143-162

[4] Humeau A, Steenbergen W, Nilsson H, Strömberg T, (2007) Laser Doppler perfusion monitoring and imaging: novel approaches. Med. Biol. Eng. Comput. 45:421-435

[5] Perimed A (2001) Reference list, http://www.perimed.se Perimed AB

[6] Moor Instruments Ltd (2001) Reference list, http://www.moor.-co.uk Moor Instruments Ltd

[7] Nilsson G E (1984) Signal processor for laser Doppler tissue flowmeters. Med. Biol. Eng. Comput, 22:343-348.

[8] Humeau A, Chapeau-Blondeau F, Rousseau D, Tartas M, Fromy B, Abraham P (2007) Multifractality in the peripheral cardiovascular system from pointwise Hölder exponents of laser Doppler flowmetry signals. Biophys. J. 93:L59-L61

[9] Humeau A, Chapeau-Blondeau F, Rousseau D, Trzepizur W, Abraham P (2008) Multifractality, sample entropy, and wavelet analyses for age-related changes in the peripheral cardiovascular system: preliminary results. Med. Phys. 35:717-723

[10] Kellog D R Jr (2006) In vivo mechanisms of cutaneous vasodilation and vasoconstriction in humans during thermoregulatory challenges. J Appl Physiol . 100:1709-1718.

[11] Cracowski J-L., Minson C T, Salvat-Melis M, Halliwill J R (2006) Methodological issues in the assessment of skin microvascular endothelial function in humans. Trends. Pharmacol. Sci. 27:503–508.

[12] Struzik Z. R. (2000) Determining local singularity strengths and their spectra with the wavelet transform. Fractals 8 (2):163-179

[13] Halsey T. C., Jensen M. H., Kadanoff L. P., Procaccia I., Shraiman B. I. (1986) Fractal measures and their singularities – The characterization of strange sets. Phys. Rev. A 33:1141-51.

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