

# RELATIONSHIP BETWEEN SACRAL SKIN BLOOD FLOW OSCILLATIONS AND VASODILATORY FUNCTIONS IN PEOPLE AT RISK FOR PRESSURE ULCERS

Yih-Kuen Jan, Fuyuan Liao, David W. Garrison, and Mark A. Anderson  
University of Oklahoma Health Sciences Center, Oklahoma City, OK, USA  
email: [yjan@ouhsc.edu](mailto:yjan@ouhsc.edu) (Dr. Jan), web: [http://www.ah.ouhsc.edu/rehab/yih\\_kuen.asp](http://www.ah.ouhsc.edu/rehab/yih_kuen.asp)

## INTRODUCTION

The role of microvascular function in the risk for pressure ulcers can be assessed by studying the changes of skin blood flow oscillations (BFO) in response to causative factors of pressure ulcers such as local heating [1]. Previous studies, using either Fourier- or wavelet-based spectral analysis, provide essential contributions to the understanding of the control mechanisms of BFO [2]. Wavelet analysis of skin BFO reveals five characteristic frequencies, associated with endothelial metabolic activities, sympathovagal neurogenic activities, vascular myogenic activities, breathing movements, and heart beats. This method allows clinicians and researchers to non-invasively assess microvascular dysfunction in various pathological populations. However, wavelet analysis is a linear method and cannot characterize the nonlinear properties embedded in BFO of the cardiovascular system. The cardiovascular system is a complex, nonlinear dynamical system, and skin blood flow regulation is therefore a nonlinear process [3].

Nonlinear analyses are currently widely used to evaluate variability and rhythms in physiological signals (e.g. heart rate variability and gait variability) in order to understand the underlying structure of these variations [4]. To date, a decrease of nonlinear behavior of physiological rhythms is considered to be associated with diseases and aging. At this stage, these few studies using some nonlinear analysis of BFO have not established a guideline indicating which analysis methods are appropriate to analyze nonlinear properties of BFO. The purposes of this study were to systemically quantify the nonlinear properties of sacral skin BFO and to explore their relationships with impaired vasodilatory function in people at risk for pressure ulcers.

## METHODS

A total of 25 participants were studied. The participants were divided into 3 groups: ten people aged 65-75 years with normal vasodilation (Biphasic Thermal Index (BTI) (5.5, 4.5, 10.1)), ten people aged 75-85 years with slight impaired vasodilation (BTI (3.7, 3.2, 6.7)), and five people with impaired vasodilation (BTI (2.4, 1.7, 4.5)). The degree of microvascular impairment was quantified by the Biphasic Thermal Index (BTI) [2]. The Biphasic Thermal Index is defined as ratios of first peak, nadir, and second peak to baseline blood flow during the biphasic vasodilation.

The laser Doppler flowmetry (LDF) (BMP main unit and P-435 probe, Vasamedics, Eden Prairie, MN) was used to measure sacral skin blood flow oscillations. Skin blood flow was recorded on a computer via an analog-to-digital converter with a sample frequency of 20Hz. The temperature of the heater probe (TCO, Vasamedics, Eden Prairie, MN) was set to 42°C to heat the sacral skin. This heating protocol was designed to differentiate between axon reflex mediated vasodilation and nitric oxide mediated vasodilation [5].

Nonlinear indexes were calculated during the pre-heating (1-10 min) and maximal vasodilation (51-60 min) periods. We chose the most commonly used nonlinear indexes that have proven useful in the quantification of nonlinear properties of heart rate variability (HRV), to include Hurst exponent (HE), detrended fluctuation analysis (DFA), sample entropy (SampEn), correlation dimension (CD), and largest Lyapunov exponent (LLE) [6]. The Wilcoxon signed rank tests were used for between-subject comparisons. The level of significance was set at 0.05. Matlab (R2008b, MathWorks, Natick, MA) were used to implement nonlinear analysis and statistical testing.

## RESULTS AND DISCUSSION

Hurst exponent (short-term self similarity) showed a decrease in nonlinear properties of BFO under local heating as compared with baseline BFO in both the 65-75 years group ( $p < 0.01$ ) and the 75-85 years group ( $p < 0.05$ ). People with impaired vasodilatory function did not show a significant decrease in Hurst exponent in response to local heating ( $p > 0.05$ ).

The scaling exponents obtained from the detrended fluctuation analysis (long-term self-similarity) were calculated in terms of three scaling regions: short-term  $\alpha_1$ , intermediate-term  $\alpha_2$ , and long-term  $\alpha_3$ . For the three groups, the intermediate-term scaling exponent  $\alpha_2$  changed significantly in response to local heating ( $p < 0.01$ ), but the short-term and long-term scaling exponents did not have a significant difference ( $p > 0.05$ ). Moreover, compared with the 75-85 years group, the changes in  $\alpha_2$  for the 65-75 years group were more prominent ( $p = 0.076$ ). The short-term scaling exponent  $\alpha_1$  and long-term scaling exponent  $\alpha_3$  didn't show significant changes in response to local heating in all three groups.

The sample entropy index did not show any significant difference in three groups during pre-heating and maximal vasodilation periods.

Similar findings were observed in the correlation dimension index with the Hurst exponent. Correlation dimension (complexity of the dynamic system) showed a decrease in nonlinear properties of BFO under local heating as compared with baseline BFO in both the 65-75 years group ( $p < 0.01$ ) and the 75-85 years group ( $p < 0.05$ ), but not in the impaired group ( $p > 0.05$ ).

The largest Lyapunov exponent (chaotic behavior) showed a decrease in nonlinear properties of BFO under local heating as compared with baseline BFO in all three groups ( $p < 0.05$ ).

## CONCLUSIONS

Our results indicate that nonlinear properties of BFO can be used to predict impaired vasodilatory

function based on laser Doppler time series. Laser Doppler flowmetry has been established as a useful tool to assess microvascular function; however, the variations of blood flow limit its use as a direct measurement. Analysis of nonlinear properties embedded in BFO can overcome temporal variations of laser Doppler measurements. Further, nonlinear analysis of BFO can complement current linear spectral (wavelet) analysis used to characterize blood flow control mechanisms. With a better understanding of linear and nonlinear properties of microvascular function, the role of microvascular dysfunction in pressure ulcer development can be better defined.

## REFERENCES

1. Geyer, M.J., et al., *Using wavelet analysis to characterize the thermoregulatory mechanisms of sacral skin blood flow*. Journal of Rehabilitation Research & Development, 2004. **41**(6): p. 797-806.
2. Jan, Y.K., et al., *Wavelet analysis of sacral skin blood flow oscillations to assess soft tissue viability in older adults*. Microvascular Research, 2009. **78**(2): p. 162-168.
3. Stefanovska, A. and Bracic, M., *Physics of the human cardiovascular system*. Contemporary Physics, 1999. **40**(1): p. 31-55.
4. Harbourne, R.T. and Stergiou, N., *Movement Variability and the Use of Nonlinear Tools: Principles to Guide Physical Therapist Practice*. Physical Therapy, 2009. **89**(3): p. 267-282.
5. Minson, C.T., et al., *Nitric oxide and neurally mediated regulation of skin blood flow during local heating*. Journal of Applied Physiology, 2001. **91**(4): p. 1619-26.
6. Beckers, F., et al., *Aging and nonlinear heart rate control in a healthy population*. American Journal of Physiology-Heart and Circulatory Physiology, 2006. **290**(6): p. H2560-H2570.

## ACKNOWLEDGEMENTS

This work was supported by the Christopher and Dana Reeve Foundation (JA2-0701-2) and Switzer Fellowship, National Institute on Disability and Rehabilitation Research (H133F060025).