The Modification of Beat to Beat Algorithm and its Application on the Assessment of Muscle Flexibility

Jian-Guo Bau* and Yung-Hui Li†

* Department of Biomedical Engineering, Hungkuang University, Taichung, Taiwan, R.O.C.
E-mail: baujg@sunrise.hk.edu.tw Tel: +886-4-26318652

† Department of Computer Science and Information Engineering, National Central University, Taoyuan, Taiwan, R.O.C.
E-mail: yunghui@csie.ncu.edu.tw Tel: +886-3-4227151 ext35204

Abstract—**Laser-Doppler Flowmetry (LDF) described by the theory related to the Doppler effect is one of the most convenient measurement techniques for routine tissue perfusion assessment. Although the LDF signal did not reveal a significant waveform in heart-beat frequency, its "waveform" could be obtained by beat to beat algorithm, in which the R peaks of electrocardiograph (ECG) were used as a reference. Nevertheless, because the period length of heart beat varies a little bit over time even for the same person, the segments of LDF signal divided according to the peaks of ECG definitely would not have exactly the same length. In this study, we modified the beat to beat algorithm by resampling the LDF segments and normalizing them into the same length. According to the modified beat to beat algorithm, the characteristics of LDF were compared between individuals with different flexibility of lower extremities. The LDF flux of the individuals with higher flexibility revealed higher stability underwent the muscle stretching, while the blood flux from the individuals with lower flexibility was interfered and became unstable during muscle stretching. We concluded that the modified beat to beat algorithm will be a useful tool for the analysis of LDF signals.**

I. INTRODUCTION

According to the recommendation from the American College of Sports Medicine, all adults should accumulate 30 minutes or more of moderate-intensity physical activity on five days each week to promote and maintain health [1]. Nevertheless, the surveys of exercise habits indicate that 41.9% (Taiwan), 48.3% (US), 78.4% (Hong Kong) and 77%-91% (European Union) of adults cannot meet the recommendation in modern sedentary lifestyle [2-5]. For the purpose of health promotion, not only the organizations should educate people with the advantages of physical activity and allocate more sources on promoting physical activity, individuals need adapt themselves to behavioral and environmental changes to facilitate physically active lifestyle.

Related investigations reveal that the major factor which prevents people from physical exercising is a shortage of time due to working or studying. The major motivation for people come to exercise is the consideration of health [3]. In other words, if the assessment of physical fitness is convenient, such as blood pressure monitoring in physical examination, the earlier alarm of the worse body condition could remind individuals to do exercise during working break or at home.

Physical health is typically assessed according to five health-related fitness components: the muscular component, the cardiorespiratory component, the motor component, the morphological component and the metabolic component [6]. Among these components, the assessment of muscular component provides the regional information of muscle or muscle group, which is the essential requirement of sports and occupational medicine for the diagnosis of musculoskeletal disorders [7]. The conventional muscular assessment includes muscle strength, muscular endurance and explosive strength. Flexibility is another important index in a variety of athletic performances, and also in the capacity to carry out the daily activities. Although flexibility is one of the factors belong to morphological component, it is affected not only by joint but also the physiology of muscle. The typical flexibility tests, including *side bending* and *sit and reach,* are assessed via the ability to move a joint through its complete range of motion. Little attention was paid in the assessment of flexibility according to the physiological condition of muscles.

A recent study found a compromised blood flow and oxygen during muscle stretching, and consequently muscle function is impaired [8, 9]. Otsuki compared changes in muscle blood flow during muscle stretching monitored by using near-infrared spectroscopy (NIRS) between ballet-trained and untrained subjects. He found the muscle blood flow and muscle oxygenation in ballet-trained subjects were less interfered by passive muscle stretching. In other words, the attenuation of microvascular perfusion during muscle stretching could be an index of flexibility. Muscles with better flexibility may be associated with a stable blood perfusion during exercise and posture changes.

Recently, the attention was paid in the assessment of muscle physiology using noninvasive Laser-Doppler Flowmetry (LDF). These studies reveal a significant association between the chronic musculoskeletal disorders and microcirculatory characteristics determined by using LDF [10, 11]. The vasodilative characteristic was shown to be more sensitive than the muscle activity from the records by electromyography. In these investigations, the intramuscular LDF with invasive optic-fiber probe was used. To apply LDF in non-invasive usage, a high power LDF with wide separation probe was developed to explore its potential for the non-invasive assessment of deeper tissues in humans [12].

The aim of this study was to develop a convenient index to evaluate the muscular flexibility in vivo. By analyzing the microcirculatory signal determined by using LDF and the beat-to-beat algorithm, participants with different levels of flexibility can be determined.

II. Materials and Methods

A. Study Population

Ten male and ten female participants, mean age 20 years (range 19–21 years) were recruited in this study. Each participant was asked to bend forward, and the distance from middle finger tip to ground was measured. Participants in high flexibility group (5 males, 5 females) can touch ground with their whole palm, while the distance from middle finger tip to ground was larger than 5 cm for the participants in control group (5 males, 5 females). The participants in both groups were matched for in age and body mass index. The study was approved by the Regional Ethical Committee with approval number 10132.

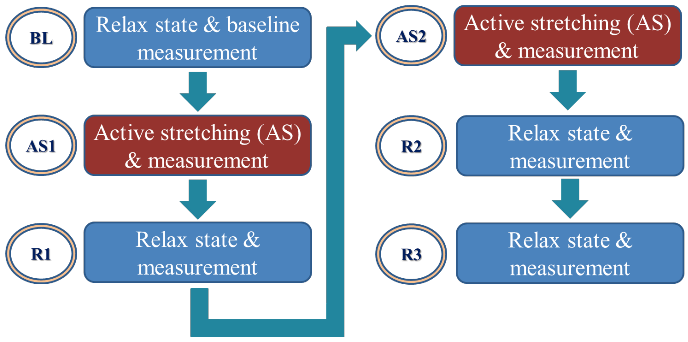
B. Experimental Procedures

Experimental procedures are shown in Figure 1(a). Before conducting trials, the participants stayed in the experimental environment with the temperature maintained at 26±1 °C for at least 20 minutes, then were supine on a comfortable coach during whole trail. There were six 1-minute measurements of microcirculation with 1 minute interval between measurements in each trial. The measurement site was located on the belly of gastrocnemius muscle. After the first 1-minute measurement of baseline (BL), participants stretched their gastrocnemius muscle with ankle dorsiflexion, as shown in Figure 1(b), and the measurement with active stretching (AS1) was taken simultaneously for 1 minute. After AS1, one measurement with relax state (R1) was conducted, which was followed by forth measurement with active stretching (AS2). Finally, two measurements with relax state was taken. The angle of ankle dorsiflexion was measured for each participant was measured after the trial.

In this investigation, both microcirculatory flux and electrocardiograph (ECG) signals from participants were simultaneously, synchronously detected and sampled via an analog-to-digital converter (ADLINK, PCI-9111DG, Taiwan) at a sampling rate of 1024 Hz, then sent to a personal computer for further analysis. The microcirculatory flux was measured using a high power LDF (VMS-LDF1-HP, Moor Instruments, UK) with a 785 nm, 20 mW laser (Class 3R per IEC 60825-1:2007) and a 4 mm separation non-invasive skin probe (VP1-V2-HP), and a sampling frequency of 40Hz. All of the measurements were conducted according to the manufacture's safety requirements.

C. Signal Processing

Figure 2 shows the electrocardiograph (ECG) signals and microcirculatory flux measured simultaneously. The ECG signal shows a periodic pattern, in which the R peaks exhibited the periodicity of the heartbeats, while the LDF signal did not reveal a visually apparent waveform in heart-beat frequency. After the signal processing with beat-to-beat algorithm, figure 3 shows the mean LDF waveform with the peak located about 0.2 second after R-peak.



(a)

(b)

Fig. 1: (a) The experimental protocol and schedule (b) The Location of the measurement site and active gastrocnemius muscle stretching with ankle dorsiflexion

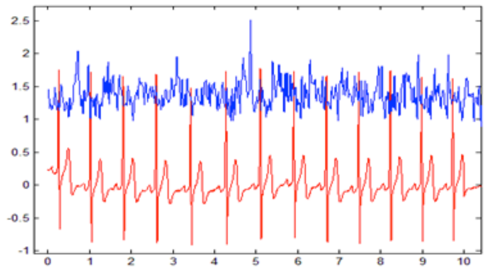


Fig. 2: LDF signal (blue), plotted together with ECG signal (red).

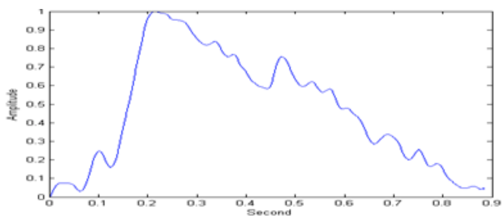


Fig. 3: Mean LDF signal waveform derived from segments of blood flow waveforms. The zero of x-axis represents the time of R-peak.

D. Statistical Analyses

A paired-sample t test was used to check whether stretching produced changes of blood perfusion (changes between two measurements). An independent *t*-test was used to compare the outcomes between high flexibility group and control group. Differences were considered as significant when two-tailed significance level $P<0.05$. The data are expressed as the mean ± 1 SE unless stated otherwise.

III. RESULTS

Figure 4 shows the mean blood perfusion of gastrocnemius muscle in both high flexibility group (N=10) and control group (N=10). There are six sequential measurements (BL, AS1, R1, AS2, R2, R3) along each trial. As the muscle was stretched, blood perfusion decreased (AS1 and AS2) and then recovered during the muscle relaxed (R1 and R2). The reduction and recovery between adjacent measurement were statistically significant ($p<0.05$) in control group, while the interference was milder in high flexibility group. After the stretching intervention, the blood perfusion in relax state (R3) is decreased relative to that in the beginning (BL) by 9% (from 59.6 PU to 54.4 PU) in control group; in contrast, the perfusion is stable in high flexibility group (from 56.8 PU to 57.1 PU).

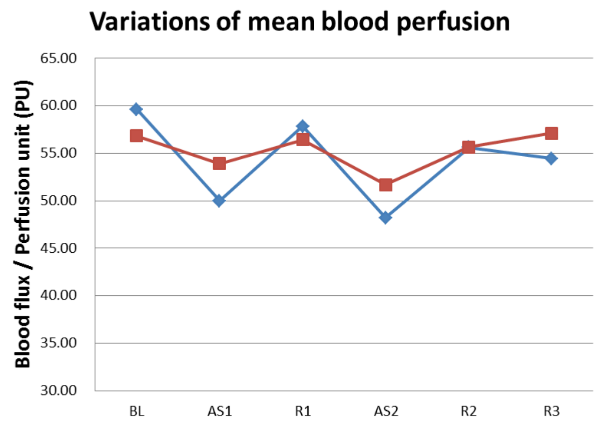


Fig. 4 Blood perfusion of six measurements on the gastrocnemius muscle along each trial in high flexibility group (■) and control (◆) (N=10).

IV. DISCUSSIONS AND CONCLUSION

The primary finding of the present study reveal the microcirculatory characteristics determined by using noninvasive LDF could be developed as an indicator of the assessment of muscle flexibility. These results underscore the higher stability of muscle perfusion in high flexibility group, while the perfusion was affected by muscle stretching in normal control subjects. These results could be associated with the regulatory of microcirculation.

According to Poole's study on spinotrapezius [9], capillary tortuosity decreased systematically with increases of sarcomere length. While the sarcomere length increased up to 2.6 microns, most capillaries appeared to be highly oriented along the fiber longitudinal axis. Further increases in sarcomere length above this value will reduce the capillary diameter, and therefore blood perfusion decrease. Our finding suggested that the microcirculatory perfusion could be activated under the intervention of muscle stretching to provide a stable blood perfusion for subjects with high flexibility. In contrast, the regulatory function in normal subjects is worse. Our results are consistent with Otsuki's finding in the tibialis anterior muscle with passive muscle stretching by using NIRS technique. Similar to the ballet-trained subjects, the blood flow did not decrease (or even be enhance) for subjects with high muscle flexibility.

V. CONCLUSION

The muscle flexibility is associated with the stability of microcirculatory perfusion under the stretching intervention. By analyzing the perfusion signal determined by using the Laser Doppler Flowmeter, this technique could be developed for the assessment of flexibility in sports and rehabilitation medicines.

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REFERENCES

[1] Haskell, W.L., et al., *Physical Activity and Public Health.* Medicine & Science in Sports & Exercise, 2007. **39**(8): p. 1423-1434.

[2] Centers for Disease Control and Prevention, 2011.

[3] Directorate General for Education and Culture, E.C., *Sport and Physical Activity.* 2010.

[4] Region, T.G.o.t.H.K.S.A., Public Opinion Survey on Physical Exercise Participation in Hong Kong. 2006.

[5] Bureau of Health Promotion, D.o.H., R.O.C. (Taiwan). 2009; Available from: http://www.bhp.doh.gov.tw/BHPNet/Web/Index/Index.aspx.

[6] Vanhees, L., et al., How to assess physical activity? How to assess physical fitness? European Journal of Cardiovascular Prevention & Rehabilitation, 2005. 12(2): p. 102-114.

[7] d'Errico, A., et al., Risk Factors for Upper Extremity Musculoskeletal Symptoms among Call Center Employees. Journal of Occupational Health, 2010. 52(2): p. 115-124.

[8] Otsuki, A., et al., Muscle Oxygenation and Fascicle Length During Passive Muscle Stretching in Ballet-Trained Subjects. International Journal of Sports Medicine, 2011. 32(7): p. 496-502.

[9] Poole, D.C., T.I. Musch, and C.A. Kindig, In vivo microvascular structural and functional consequences of muscle length changes. American Journal of Physiology - Heart and Circulatory Physiology, 1997. 272(5): p. H2107-H2114.

[10] Strøm, V., et al., Pain induced by a single simulated office-work session: Time course and association with muscle blood flux and muscle activity. European Journal of Pain, 2009. 13(8): p. 843-852.

[11] 21. Strøm, V., C. Røe, and S. Knardahl, Work-induced pain, trapezius blood flux, and muscle activity in workers with chronic shoulder and neck pain. Pain, 2009. 144(1-2): p. 147-155.

[12] Clough, G., et al., Evaluation of a new high power, wide separation laser Doppler probe: Potential measurement of deeper tissue blood flow. Microvascular Research, 2009. 78(2): p. 155-161.