Wavelet-Based Analysis of Skin Blood Flow at Lower Limb Under External Pressure

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Abstract: In this study, to investigate the effect of external pressure on skin blood flow (SBF) of lower limb, external pressure was exerted on ankles and calves respectively by using sphygmomanometer. Alternating loading protocol was used: 5mins without pressure and 5mins under pressure of 40mmHg. The change of SBF was observed, wavelet analysis on the SBF signal was also performed. The results showed that SBF increased with pressure no matter it was loaded on ankle or calf. Wavelet analysis results showed that the peak spectrum amplitude in the frequency band of intrinsic myogenic activity increased (p<0.01) while its corresponding frequency decreased significantly (p<0.01) due to pressure loading. The mechanism of SBF’s response to external pressure was also discussed.

Key Words: wavelet analysis, skin blood flow, external pressure, lower limb

INTRODUCTION

It has been reported by many researchers that garment pressure has complicated influence on heart rate, respiration, blood pressure, digestion, sweat and other physiological activity (Okada, 1995; Hirata and Yoshida, 1995). Garment pressure has been utilized effectively in many ways. Nowadays, pressure garments are widely used in rehabilitation for burn injury patients. Sports socks, which exert certain pressure on lower limb, have been reported helpful to accelerate blood circulation during doing exercises and thus improve sports performance.

The pressure exerted on human body may have complicated influence on micro-circulation in the underlying compressed soft tissue. In our previous study, it was found: the distal SBF decreased when pressure was exerted on the lower limb; SBF of regions under pressure increased when the pressure was low, and it turned to decrease as the pressure increasing to certain value (Wang et al, 2007; Zhou et al, 2008).

Spectrum analysis has been widely used to understand skin microcirculatory response to various stimul (Stefanovska et al, 1999; Kvandal et al, 2006; Bernjak et al, 2008). Jan et al. even applied this method to analyse sacral skin blood flow response to alternating pressure. An increase in power of endothelium-related metabolic frequency and a decrease in power of the myogenic frequency during alternating pressure were found (Jan et al, 2008).

There are still few reports available to understand well the pressure-induced SBF response. In this paper, skin blood flow at lower limb under external pressure was investigated. Spectrum analysis was carried out on the SBF signals and the mechanism of SBF change was also discussed.

METHODS
Two healthy male undergraduate students denoted as S1-S2 volunteered to take part in this study. The subjects had refrained from heavy exercise for 24h and hadn’t consumed salty food, alcohol or caffeine for 17h before entering the laboratory. The experiments were carried out in a climate chamber of constant temperature (20 ± 2°C), humidity (40 ± 5%) and air velocity less than 0.2m/s. The subjects were required to wear loose trousers and sit on a bench. They were asked to rest for at least 30 minutes to achieve a steady baseline blood flow before the tests got started.

The SBF was observed by using Advance Laser Blood Flowmeter, ALF21R(Advance Co. Ltd. Japan). Pressure was measured simultaneously by using air-pack pressure sensors (AMI Co. Ltd, Japan). To control the pressure magnitude easily, a sphygmomanometer was used to exert pressure on ankle and calf respectively. Alternating loading protocol was employed: 5mins without pressure and 5mins under pressure of 40mmHg, totally 45 minutes. The change of skin blood flow along with time was recorded per 0.1s.

Wavelet analysis was carried out by using the math software package MATLAB 7.1. The ranges of five characteristic frequency bands of SBF signals were previously divided as follows: (I) endothelium related metabolic activity (0.005 ~0.021Hz); (II) neurogenic activity (0.021 ~ 0.052 Hz); (III) intrinsic myogenic activity (0.052 ~ 0.145 Hz); (IV) respiratory activity (0.145 ~ 0.6 Hz); (V) cardiac activity (0.6 ~ 2 Hz) (Bernjak et al, 2008). The measured SBF signal was normalized before wavelet transform, as shown in Fig. 1(a). Fig. 1 (b) shows the obtained spectrum of SBF signal in the five characteristic frequency bands, in which the vertical axis is the spectral averaged along the time period. From the spectrum, the peak amplitude in each frequency band was picked out.

![Wavelet analysis on SBF signal](image)

RESULTS

Change of Skin Blood Flow

Fig. 2 showed skin blood flow change of S1-S2 along with time both on ankle and calf, respectively. It was clear that SBF increased obviously when pressure was exerted on ankle or calf and returned to the initial level rapidly as pressure was removed. The amounts of SBF increase for ankle in Fig. 2 (a) and (c), were obviously larger than the respective ones for calf shown in Fig. 2(c) and (d). It indicates that it is more effective to exert pressure at ankle than at calf to accelerate blood flow. Maybe that is why sports socks exert certain pressure at lower limb, especially at ankle, and thus improve sports performance.
Wavelet Analysis Results

To understand SBF’s response to external pressure, spectrum analysis was carried out on each 5mins period SBF signal and the peak spectrum amplitudes in the five frequency bands together with the corresponding frequencies were picked out. There were no obvious change trends found in neurogenic, respiratory and cardiac frequency intervals. The spectrum amplitude of endothelium related metabolic activity was found to increase due to pressure. This is consistent with Jan’s finding (Jan et al, 2008). Moreover, no matter the pressure was loaded on ankle or calf, the spectrum amplitude in myogenic frequency band increased (p<0.01) with pressure loading and decreased with pressure removing, as shown in Fig. 3(a). It indicated that external pressure enhanced myogenic activity. Moreover, it was also clear in Fig. 3 (b) that the frequency corresponding to the peak amplitude in the myogenic frequency band declined (p<0.01) as external pressure was loaded.

Precapillary sphincter are rings of smooth muscles that rhythmically switch between the dilatation and constriction condition (Stefanovska and Bracic, 1999), resulting in the opening and closing of capillary network. Spontaneous activity in microvascular smooth muscle cells was 4~10 events a minute (0.066~0.166 Hz) (Golenhofen, 1970), lying in the third frequency interval of intrinsic myogenic activity(0.052~0.145Hz). Therefore, the intrinsic myogenic activity could be considered as closing and opening of capillaries. The decrease of the frequency of the intrinsic myogenic activity then meant that the cycle of the opening and closing of capillary network took longer time, in which the time period of the opening, closing, or both opening and closing could be prolonged. Referring to Fig. 2, the increase of SBF due to pressure
indicated that the opening time period increased, thus more blood flow perfused into the capillaries. It was thus speculated that external pressure may have some influence on the action of the precapillary sphincter.

![Graph](image)

(a) Change of peak spectrum amplitude

(b) Change of frequency

Figure 3 Change of peak spectrum amplitude and its corresponding frequency in myogenic frequency band

CONCLUSIONS

In this study, the pressure effect on SBF of lower limb was investigated and wavelet analysis was carried out on the SBF signals. The SBF was found to increase no matter the pressure was loaded on ankle or calf. Wavelet analysis results revealed that the spectrum amplitude of the intrinsic myogenic activity increased while its corresponding frequency decreased. It implicated that external pressure could not only enhance the myogenic activity but also affect on the action of the precapillary sphincters.

REFERENCES


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