Effect of External Pressure on Skin Blood Flow at Lower Limb in Different Postures

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Abstract: The influence of garment pressure on human physiological activities has attracted researchers from many areas. In this study, to investigate the effect of external pressure on skin blood flow (SBF) at lower limb in different postures, external pressure was exerted on lower limb in supine and sitting postures using sphygmomanometer. Five undergraduate male students volunteered to participate in the study. An alternating pressure loading protocol between non-pressure and pressure of 20mmHg or 40mmHg was employed. The SBF undergoing pressure was observed with Laser Doppler Flowmeter. It was found that the SBF increased under low pressure and began to decrease as the pressure exceeded a certain level (around 35mmHg). It was speculated that the change in SBF due to external pressure was the result of balance between the neural effect and mechanical effect. The blood pressure in supine posture was lower than that in sitting posture, thus the blood pressure in metarterioles was lower in supine posture and thereby the SBF began to decrease under lower pressure in supine posture than that in the sitting posture. In the case of microcirculation, high pressure can be an obstacle, particularly in supine posture. These findings will be helpful in the design and application of tight-fit garments.

Keywords: Skin blood flow, external pressure, laser doppler flowmeter, posture change, lower limb, supine.

1. Introduction

Tight-fit garments, like foundation wear, hosiery, tights and jeans produce overall or local pressure on body skin, which might have complicated the influence on human physiological activities. It has been reported that garment pressure could have positive or negative influence on body type, heart rate, blood pressure, respiration, autonomic nervous system activity, digestion, sweating and other physiological activities [1-2]. To treat various venous diseases of lower limb, compression stockings and bandages were used to exert pressure on lower limbs, to enhance venous return, reduce venous distension and prevent stasis [3]. Pressure garments were used for rehabilitation of the burn injury of patients. In sports area, it has been reported that tight-fit sportswear helps to enhance blood circulation, improve endurance during exercise and post-exercise recovery etc. [4].

Since skin is soft and flexible, and is the first layer under garments pressure, the embedded microcirculation system will be affected. It was found that pressure exerted at lower limb resulted in obvious decrease of skin blood flow (SBF) at distal [5]. Some researchers found that the SBF at palm, sacrum and other body parts decreased under high external pressure [6]. Formy et al. investigated the SBF in finger response to applied incremental pressure and found that SBF increased under low pressure, and turned to decrease as the pressure exceeded a certain level [7]. In an earlier study, Mayrovtiz et al. exerted pressure of about 40mmHg with compression bandage at lower limb and found that the SBF at calf of some subjects increased, while that of other subjects decreased in supine posture, but when the subjects were seated, the SBF increased [8]. In our previous study, when subjects were in supine posture, the SBF at lower limb increased under lower pressure and decreased under higher pressure [9].

How does external pressure affect the SBF? Through spectrum analysis on SBF signals, it has been found that human SBF is influenced by metabolic, neurogenic, myogenic, respiratory and cardiac activities respectively [10]. In the spectrum analysis of sacral SBF response to alternating pressure, Jan et al. found that the myogenic activity enhanced under low pressure [11]. Brienza et al. also found the enhancement of myogenic activity through their spectrum analysis on sacrum SBF response to incremental pressure [12]. However, there is still only a few reports about SBF's response to garment pressure and the mechanism is still unclear.

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Since human body is of complicated shape, a tight-fit garment can result in uneven pressure distribution on skin. The garment pressure dynamically changes with body posture and its effect on SBF will be more complicated. In this study, the effect of garment pressure on SBF was investigated in terms of pressure magnitude, posture and body parts.

2. Methods

2.1 Subjects

Five healthy male undergraduate students marked as S1-S5 volunteered to take part in this study. Their physical data (mean±standard deviation) were as follows: age 23±1yrs, height 167±3cm, and weight 60±3kg. The subjects had refrained from heavy exercise for 24h and hadn't consumed salty food, alcohol or caffeine for 24h before measurement. To avoid the influence of climate change on SBF, the experiments were carried out in a climatic chamber of constant temperature (20±2°C), relative humidity (45±5%) and air velocity less than 0.1m/s. The subjects were required to wear loose trousers, sit in a chair or lie on a cushion for measurements. They were asked to rest for at least 30 minutes to reach a stable resting state before the tests were started and kept sitting or lying still during measurements.

2.2 Measurement of skin blood flow

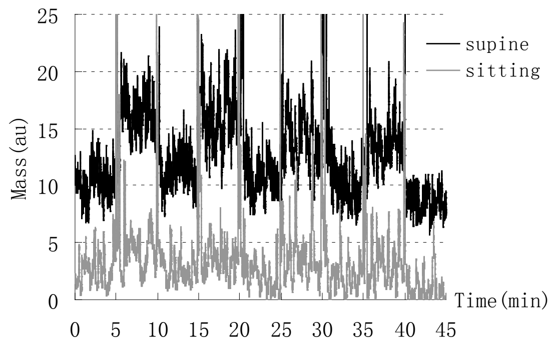
The SBF under pressure at lower limb were observed using Advance Laser Blood Flowmeter, ALF21R (Advance Co. Ltd., Japan). Three parameters of skin blood flow can be obtained simultaneously: "mass", "velocity" and "flow". "Mass" corresponds to the mass of blood in the measured area at a time and can be obtained directly; "velocity" is the equivalent velocity of all the capillary flows within the measured skin region and can also be obtained directly; "flow" denotes the total blood volume entering the skin soft tissue of 100g per minute, which is expressed as the product of the first two parameters. In this study, the signal of "mass" was analyzed. A time constant of 0.1s was selected for SBF signal sampling.

2.3 Pressure loading protocol

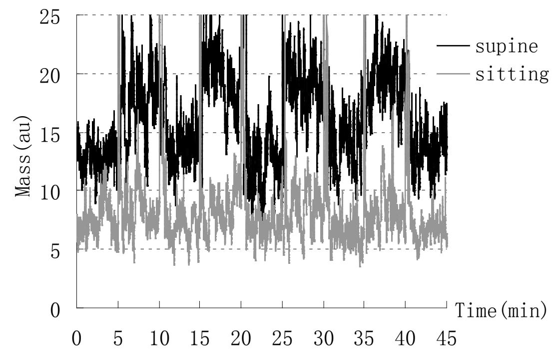
To control the pressure magnitude easily, a sphygmomanometer was used to exert pressure on ankle or calf respectively. Pressure magnitudes of 20mmHg and 40mmHg were employed in sitting or supine posture respectively. An alternating loading protocol was applied: 5mins without pressure and 5mins under pressure, totally for 45 minutes.

3. Results and discussion

3.1 Skin blood flow change under a pressure of 20mmHg



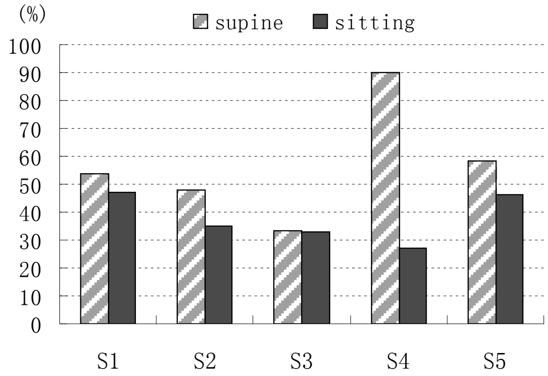
(a) SBF change at ankle



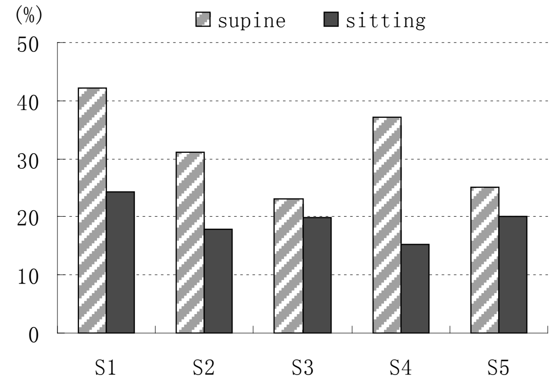
(b) SBF change at calf

Figure 1 SBF change of S1 under a pressure of 20mmHg in different postures.

Figure 1 shows the SBF change of S1 at ankle and calf respectively under a pressure of 20mmHg in different postures. It was clear that the initial level of SBF at ankle or calf in supine posture was much higher than that in the sitting posture respectively. The difference could be because while sitting the SBF at lower limb which is far from the heart becomes less due to the effect of hydrostatic pressure. In Figure 1(a), in supine posture, the SBF greatly increased as pressure was exerted at ankle, and it returned to the initial level as pressure was removed; in sitting posture, the SBF also increased but not very much with pressure loaded and it returned when pressure was removed. When the pressure was loaded at calf, the same change trend was found, as shown in Figure 1(b).



(a) Increment of SBF at ankle



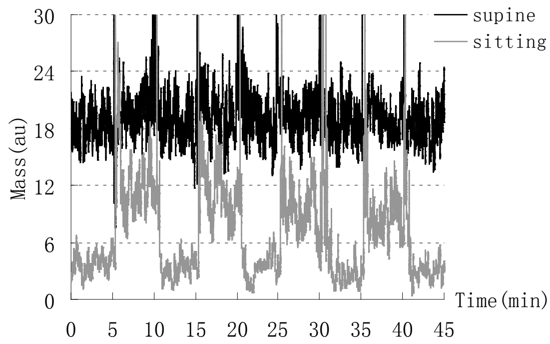
(b) Increment of SBF at calf

Figure 2 Increment of SBF under a pressure of 20mmHg in different postures.

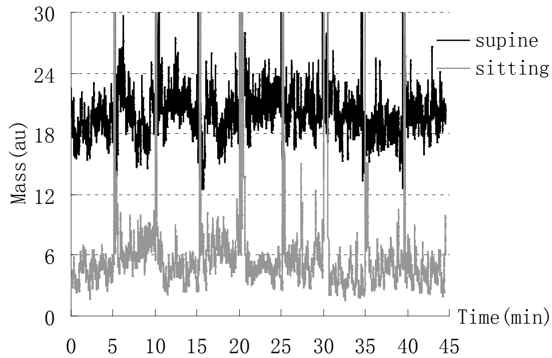
To well understand the different effects of external pressure on SBF in different postures, the increment between the SBF mean during the first 5mins of non-pressure and that of the following 5mins under pressure was calculated, and was compared between supine posture and sitting posture among 5 subjects as plotted in Figure 2. It was clear from Figure 2(a) that the increments of SBF at ankles in supine posture were obviously much higher than those in sitting posture respectively and all the five subjects show the same trend. In Figure 2(b), the increments of SBF at calves of all the five subjects show a similar change trend.

3.2 Skin blood flow change under a pressure of 40mmHg

Figure 3 shows the SBF change of S1 at ankle or calf respectively under a pressure of 40mmHg. Consistent with Figure 1, SBF in supine posture was much higher than that in the sitting posture. In Figure 3(a), in sitting posture, the SBF greatly increased when pressure was loaded at ankle and returned to initial level when pressure was removed, showing a similar change trend with that under pressure of 20mmHg, moreover, the SBF increment was much higher; in supine posture, the SBF increased a little when pressure was exerted and returned to the initial level when pressure was removed. However, when the pressure was loaded at calf, the SBF change in different postures seemed more complicated. As shown in Figure 3(b), in sitting posture, the SBF increased obviously when pressure was loaded and returned to initial level; in supine posture, the SBF decreased to some extent when pressure was exerted and returned when pressure was removed.



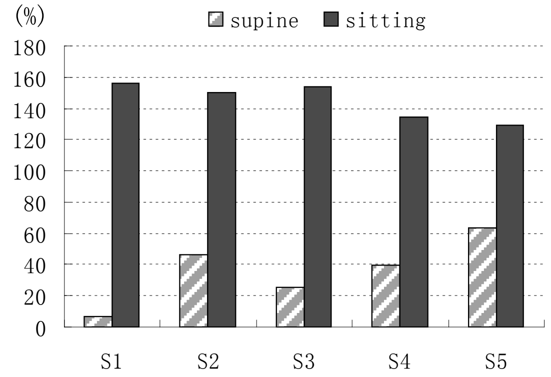
(a) SBF at ankle



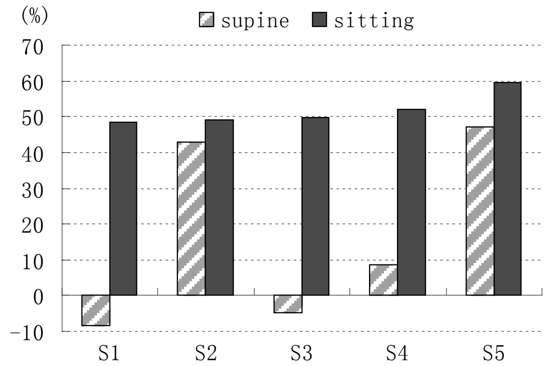
(b) SBF at calf

Figure 3 SBF change of S1 under a pressure of 40mmHg in different postures.

The SBF increments were also compared between supine posture and sitting posture among all the five subjects, as shown in Figure 4. It was clear from Figure 4(a) that the SBF increment at ankle in sitting posture was much higher than that in the supine posture. All the five subjects show a similar same trend, contrary to the results obtained under the pressure of 20mmHg plotted in Figure 2(a). In Figure 4(b), the increment of SBF at calf in sitting posture was also much higher than that in supine posture, which was consistent with the result obtained at ankle as shown in Figure 4(a). Moreover, in supine posture, the increment of SBF at calf of subjects S1 and S3 became negative, SBF decreased under pressure.



(a) Increment of SBF at ankle



(b) Increment of SBF at calf

Figure 4 Increment of SBF under a pressure of 40mmHg in different postures.

Comparing the results obtained from supine posture with those of sitting posture, it is clear that under a pressure of 20mmHg, the increment of SBF in supine posture was much higher than that in the sitting posture; however, under a pressure of 40mmHg, the increment of SBF in sitting posture was much higher than that in supine posture, irrespective of whether the pressure was exerted at ankles or calves. The SBF decreased under lower pressure in supine posture than that in the sitting posture.

3.3 Discussion about skin blood flow change

Irrespective of supine or sitting posture, the SBF at lower limb increased under a pressure of 20mmHg. The increase of SBF under pressure was consistent with Formy et al.'s finding. Why did the SBF increase under low pressure seem difficult to understand. Since the subjects kept sitting or lying still, there should be no significant change in metabolic, respiratory and cardiac activities. The external pressure produces mechanical stimuli to vessels embedded in skin and the underlying soft tissue, and may affect blood microcirculation through autonomous nervous system. In the spectrum analysis of sacrum SBF response to pressure, the myogenic activity was found enhanced under low pressure [11-12]. It can be speculated that the SBF change under pressure is induced through neurogenic and myogenic activities.

Since the small vessels connecting to capillaries embedded in skin are soft and flexible, they are easy to be squashed. Under higher pressure than the blood pressure in metarterioles, they could be mandatorily deformed or squashed, and the blood perfumed into the connecting capillaries would be blocked, consequently, the SBF decreased. This can be conceived with our common sense. It was reported that the blood pressure in metarterioles is around 35mmHg [13]. As shown in Figure 4(b), the SBF at calf of subjects S1 and S3 decreased under the pressure of 40mmHg in supine posture.

Under a pressure of 20mmHg (lower than 35mmHg), the capillaries hadn't been squashed, the SBF was mainly affected through neurogenic and myogenic activities, thereby the SBF increased with pressure. However, in supine posture, when the exerted pressure increased to 40mmHg, parts of the capillaries were squashed, the SBF decreased. The SBF change was the result of balance between the effect of neurogenic and myogenic activity and mechnical squashing effect. Consequently, the SBF increment at ankle under pressure of 40mmHg was lower than that under the pressure of 20mmHg; the SBF at calf even began to decrease. Since human blood pressure is higher while sitting than lying due to hydrostatic pressure, the blood pressure in metarterioles is also higher. Thereby, in sitting posture, under a pressure of 40mmHg, the capillaries might not have been squashed, thus the SBF increment was much higher than that under the pressure of 20mmHg.

Through this study, it was confirmed that the SBF increased under low pressure, and decreased as the pressure exceeded certain level (around 35mmHg). This certain level in the case of supine posture was lower than that in sitting posture. The pressure influence on SBF also varied with body parts. The SBF at calf decreased under lower pressure than that of ankle. In view of blood microcirculation, high pressure could be an obstacle to skin blood flow, especially in supine posture. Therefore, pressure around 35mmHg seems to be critical for tight-fit garments, and it's not good for people to wear tight-fit garments while sleeping. Since various body parts seemed to bear pressure of different levels, the design of pressure distribution for tight-fit garments is very necessary. For example, the pressure exerted by compression stockings decreased gradually from ankle to knee or thigh, the pressure at ankle is usually less than 40mmHg. It is a safe design of pressure distribution.

4. Conclusion

In this study, the effect of external pressure on SBF at lower limb in different postures was investigated. It was found that the SBF increased under low pressure and began to decrease as the pressure exceeded a certain level (around 35mmHg). It was speculated that the SBF change due to external pressure was the result of balance between the neural effect (neurogenic and myogenic activity) and mechanical effect (parts of the capillaries were squashed). The blood pressure in supine posture was lower than that in the sitting posture, thus the blood pressure in metarterioles was also lower in supine posture, and thereby the SBF began to decrease under lower pressure in supine posture than that in sitting posture. These findings will be helpful in the design and application of tight-fit garments.

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