Alterations of Skin Microcirculatory Rhythmic Oscillations in Different Positions of the Lower Extremity

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Microcirculatory vasomotion is considered to be an important mechanism promoting and facilitating the transfer of blood cells through skin capillaries. Since skin vulnerability of the leg is closely associated with gravitational factors and skin microcirculation, we investigated by a laser Doppler apparatus influence of postural changes on skin blood flow oscillations in lower limbs of healthy volunteers. Our data show a marked decrease in microcirculatory oscillation amplitudes at a frequency 7.6 (± 0.6) min $^{-1}$ after lowering the leg. This could be reversed by the application of compressive bandage. Our study points toward a potentially important mechanism of microcirculatory impairment during orthostasis. ***Key words: Skin blood flow; Laser Doppler flowmetry.***

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The microcirculatory blood flow in the lower extremity skin is easily disturbed by various pathological conditions, such as obstructions of venous outflow, increased blood viscosity states (e.g. dysproteinemias, sickle cell anaemia) and vasculitis (1). This in turn leads to local skin necrosis and ulcer formation. As it is widely accepted that gravitational factors play a major role in skin microcirculation impairment. One of the most effective ways of prevention and treatment is leg elevation and various forms of external compressive therapy. As it recently became apparent that proper blood vessel vasomotion can improve nutritive tissue perfusion (2,3), we investigated by laser Doppler flowmetry the alterations in skin microcirculatory oscillations during limb postural changes. We report that cutaneous blood flow in the perimalleolar region of the resting limb undergoes local periodical oscillations that are severely supressed as the leg is lowered. This phenomenon may be reversed by applying a compressive bandage.

MATERIALS AND METHODS

Nineteen healthy volunteers (8 men, 11 women; median age 28 years, range 19–55 years) participated in the study. Determinations were carried out in a room kept at 22-23°C following acclimatization of the subjects at rest in supine position for approximately 10 min. Skin blood flow was assessed using a laser Doppler flowmeter (PF2 Perimed, Stockholm, Sweden) and plotted by a pen-recorder. An unheated probe in a standard round plastic probeholder was placed 10 cm above the medial malleolus of the left leg and held in this position with double-sided adhesive rings (3-M). The processing unit filter was set at 4 kHz, the time constant at the output amplifier at 0.2 s and the gain at 10× or 30×. The frequency of rhythmic oscillations in the frequency region from 6 to 12 cycles per minute (cpm) was counted directly from the recordings. The graphs of skin blood flow were subsequently digitalized, fed into the computer and analysed by the fast Fourier transform algorithm. The result was a set of amplitudes of the input data harmonic components (power spectra). Each spectrum was analysed in the frequency band 6–12 cpm, where maximal (peak) amplitude and corresponding frequency (peak frequency) were recognized. Two sets of experiments were performed on each subject. First, skin blood flow traces were recorded and peak amplitudes and frequencies calculated when leg was: *a*) placed horizontally at heart level (control amplitude 1), *b*) lowered 50 cm below heart level (test amplitude), *c*) moved back to the horizontal position (control amplitude, 2). Second, skin blood flow patterns were recorded again in the same leg positions after application of compression on left foot and calf. A single layer of Granuflex bandage ™ (ConvaTec, UK) with which we repeatedly exerted an ankle pressure of 25 mmHg was applied 5 min before starting the experiments and was maintained throughout the recording period. The LD probe, together with its holder, remained under the layer of the bandage directly facing the skin. In each subject the amplitude index was calculated as follows:

$$\frac{\text{test amplitude}}{0.5\,(\text{control amplitude } 1 + \text{control amplitude } 2)}$$

All experiments were run in duplicate. For statistical analysis, Student's *t*-test and Wilcoxon's rank test for paired samples were used. As a level of significance, a *p*-value of 0.01 was chosen.

RESULTS

Fig. 1 presents traces illustrating typical patterns of leg cutaneous blood flow in horizontal (*a*) and lowered position (*b*), respectively. The mean value of the laser Doppler signal recorded from the leg placed in the horizontal position was 250 ± 70 mV (± SD), whereas after lowering the leg it dropped to 75 ± 20 mV (significant, $p<0.01$, Wilcoxon's rank test). After applying the bandage, laser Doppler waveform patterns taken in both positions resembled traces shown on Fig. 1*a*) (mean flux values: 270 ± 90: horozontal position; 240 ± 70: dependent position; not significant, Wilcoxon's rank test). In all instances the frequencies of oscillations counted directly from laser Doppler charts varied between 6.5 and 9.5 cpm (mean 7.6 ± 0.6 cpm) (±SD)) and they did not differ from mean peak frequencies obtained from Fourier transform spectra ($p<0.01$, Student's *t*-test). In several instances (8 subjects) the amplitudes of the oscillations taken from the unbandaged legs in the dangling position were so low that the assessment of the frequencies was impossible. In unbandaged limbs the amplitudes of oscillation harmonic components were decreased after leg lowering, as compared with the horizontal position (expressed as amplitude indexes) (Fig. 2). In contrast, after application of compressive bandage, the values of amplitude indexes were significantly higher ($p<0.01$, Wilcoxon's rank test, Fig. 2).

DISCUSSION

This study demonstrates the postural alterations in the pattern of ankle skin blood flow oscillations. The data were recorded by laser Doppler flowmetry and further processed using fast Fourier transform algorithm to express quantitatively the

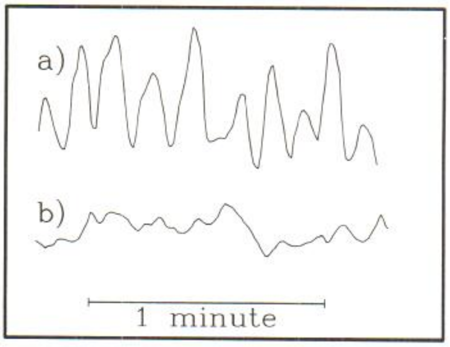

Fig. 1. The typical laser Doppler waveform patterns of skin blood flow recorded from the leg: *a*) kept in the horizontal position, *b*) lowered 50 cm below heart level.

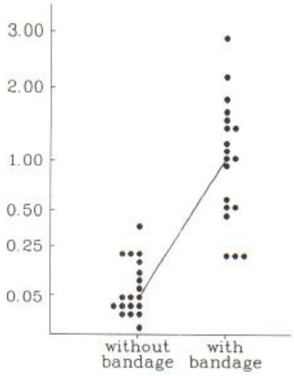

Fig. 2. The amplitude indexes of skin blood flow oscillations recorded from unbandaged and bandaged legs. The solid line joins median values.

power of amplitude of a set of harmonic components at an arbitrarily chosen frequency. These values describe the shape of the flow pattern because they show the relative contribution of the waves in the frequency band 6–12 cpm to the total power carried by the microcirculatory oscillations. Data presented here show unequivocally that leg lowering below heart level causes a significant decrease in maximal amplitude of skin blood flow periodic oscillations at the steady peak frequency (7.5 ± 0.6 cpm). This means that the waves at this frequency were less prominent in the spectrum of harmonic components of the microcirculatory oscillations. Our laser Doppler waveform patterns obtained from resting subjects resemble variations in skin blood flow recently shown by Salerud et al. (4) and Kastrup et al. (5). As these waves have a dominant frequency similar to the rhytmic changes in blood motion in single human nailfold capillaries (6,7) it is conceivable that they reflect the collective behaviour of a group of microvessels in about 1 mm^3 covered by a laser Doppler probe (2).

We concentrated particularly on the oscillations in the frequency band 6–12 cpm. It was suggested previously that the periodic flow in this range may enhance the transport of blood cells by microcirculation (2,8). One can derive from Poiseuille's law that the flow of a liquid through a vessel is proportional to the fourth power of its radius and the resistance of a vessel of constant diameter is greater than that of a pulsating vessel of the same average diameter in which the cross-section area changes sinusoidally (9). Secondly, in oscillatory flow, high shear stresses attained near the peak of the cycle may deform red cells and facilitate their passage through capillaries (2). Similarly, it was suggested that the spontaneous vasomotor activity in microcirculation may help to maintain blood fluidity (3). Periodic vasomotion may also promote displacement of cells adhering to the endothelium (2). The augmentation of flow oscillations in the presence of circulatory disturbance (sickle cell disease, myocardial hypoperfusion, inital post-ischaemic phase in arm skin) suggests that it may be a common process to compensate for impaired tissue perfusion by means of encouragement of blood cells transfer (2,8,10). Thus the decrease in the amplitudes of such oscillations after leg lowering, as proven here, may be related to the development of gravitational stasis and attenuation of nutritive perfusion. Therefore this finding suggests an additional mechanism of increased predilection of various diseases to the skin over the ankle. Furthermore, our data show the preservation of sufficiently high amplitudes of rhytmic oscillations under the external compression. In theory it might have been influenced by the fact that the bandage caused skin flattening so that the laser light would penetrate more readily to the deeper strata. However, from skin ultrasound studies (unpublished) we know that one single compressive procedure does not change skin thickness. Therefore the optical transmission of the laser light in the skin was probably unchanged during the course of the experiment. Thus it is conceivable that compression may considerably improve skin perfusion and counteract the gravitational stasis in papillary vessels. Elastic bandage application is effective in various leg diseases such as skin ulcers of venous and hematogenic origin. We conclude that the contribution of sufficient vasomotion to the pherapeutic action of compression and leg elevation seems to be a matter of importance and needs further clarification.

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