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Local effect of compression stockings on skin microcirculatory activity through the measurement of skin effective thermal conductivity

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***Abstract*— This paper presents a preliminary study to demonstrate the instantaneous local effect of compression stocking (Class 2) on skin microcirculatory activity. The measurement needs to be carefully performed as the sensor is placed under the garment. To assess the local effect of compression stockings, we use the ambulatory device Hematron located on the calf under the garment. Skin microcirculatory activity is assessed through the skin's effective thermal conductivity measurement. A specific housing for the sensor has been designed to avoid excessive pressure induced by the sensor when squeezed by stockings. The experiment, conducted on ten healthy subjects, comprised two stages : without and with compression stockings. Skin effective thermal conductivity was recorded at three successive positions (supine, sitting and standing). Significant improvement in skin microcirculatory activity was recorded by the Hematron device for the three positions. We have also demonstrated that Hematron sensor can be used under compression stockings.**

I. INTRODUCTION

There is evidence for the beneficial use of compression in some clinical indications but there is much still to be explained. Indeed, medical compression stockings (MCS) are recognized as an essential component in the treatment of chronic venous insufficiency. They improve venous hemodynamics which reduce venous reflux, increase deep venous flow velocity, improve lymphatic flow and microcirculation and decrease ambulatory venous pressures [1]. Even if benefits have been established, little is known regarding the level of compression to be applied and the duration of treatment [2].

As regards the microcirculation, effects of compression on venous and arterial microcirculation have been largely investigated. Compression can play an important role in preventing transient ischaemic reperfusion injury to the endothelium and therefore in the development of venous ulceration [3] [4]. However, few studies deal with the effect of compression on skin microcirculation. Most investigations on skin microcirculation concern studies where intermittent pneumatic compression was applied to the extremities. Thanks to video-capillaroscopy, after 4 weeks of compression (2 weeks bandages and 2 weeks MCS), an increase of capillary density and a decrease of capillary diameter and pericapillary halo diameter have been reported [5]. It showed that compression treatment (bandaging or stockings) improved skin microcirculation.

The present experiment is a continuation of the study presented in [6] conducted on 8 healthy subjects wearing compression stockings (Class 1, Class 2 and Class3). A global increase in skin microcirculatory activity was reported for all investigated postures (lying, sitting, standing and walking) and the benefit increased with Class number. For these experiments, the sensor was located above the stocking at the top of the leg, next to the internal saphenous vein and consequently was not squeezed by the MCS. Local effects of compressive wearing cannot be explained through such a global study. Therefore, the influence of compression on skin microcirculation of the calf has now been studied. A sensor housing has been designed in order to limit the pressure that the sensor can induce when squeezed by the stocking.

II. MATERIALS AND METHODS

A. Hematron device

Hematron is a miniaturized device designed to enable the monitoring of skin effective thermal conductivity under ambulatory conditions [7]. This measurement is performed using the thermal clearance technique, in which a constant thermal field is created under the heater (isothermal method). Therefore, the volume explored by the probe is hardly dependent of the thermal conductivity of tissues. Heat supplied by the heater element is dissipated by the smallest vessels of the circulatory system. The probe consists of a disc 25 mm in diameter and 4 mm thick. It is placed on the epidermis, its centre is heated to establish an increment of 2°C between the centre of the sensor and its periphery. Hematron is an active sensor, based on a Proportional Integral regulator which controls the heating power of the central heater so that the increment of 2°C is maintained between the measuring and reference components, and thus, ensures that the volume explored by the thermal field is constant. As a consequence, the electrical power required to maintain the probe's temperature increment is proportional to the effective thermal conductivity of the tissues [8].

B. Hematron housing

Due to the geometry of the sensor, the calf has been chosen for the measurement of skin effective thermal conductivity (see fig 1). Housing of the sensor is a key factor in this experiment as the sensor is placed under the compression stocking. Indeed, the thickness of the sensor alone induces local

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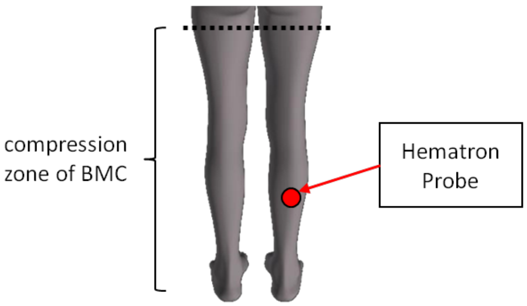

Fig. 1. Hematron sensor located on the posterior region of the calf

protuberance, which stretches stocking materials, resulting in a high pressure (P1) at the edge of the sensor (see fig 2 A). An excessive pressure could disturb and dramatically reduce the skin microcirculatory activity. This has been verified on 7 subjects where a decrease in skin effective thermal conductivity was recorded for three positions for all subjects (lying, sitting and standing). Hence, a specific housing has been designed so that the sensor located under the stocking minimally disturbs the phenomenon being measured.

The Hematron sensor surrounded by its housing is located on the posterior region of the calf, where the radius of curvature is largest. Interface pressure (P2) between the sensor and the skin induced by the compression of the MCS, is reduced thanks to the geometry of the support (see fig 2 B). The support has a hole at its center which is located directly above the sensor. Foam is inserted between the sensor and the MCS in order to transmit the pressure due to the stocking tension. The support's convex shape reduces the radius of curvature generated by the MCS on the sensor, as modelled by the Laplace's law (see Eq 1).

$$P = T/r \quad (1)$$

where P is the pressure exerted by the stocking (N.m^{-2}), T is the tension of the stocking (N.m^{-1}) and r, the radius of curvature related to the MCS on the sensor (m).

Additionally, as the bearing surface area of the sensor surrounded by the housing is increased, the pressure applied is decreased. Thus the microcirculatory activity is minimally disturbed by the insertion of the Hematron sensor under compression stocking.

C. Experimental protocol

The study was carried out on 10 volunteer subjects, 6 female and 4 male (see Table I), without severe venous pathology as verified by a phlebologist (evaluation by echo-Doppler). All subjects were informed of the experimental protocol. One class of compression stockings was tested, Class 2, which corresponds to a pressure exerted at the ankle region of about 15-20 mmHg. The limb is compressed with graduated compression, strongest at the ankle and decreasing going up the leg.

The experiment was carried out in a room of approximately 8m^2 with an average ambient temperature of 22°C

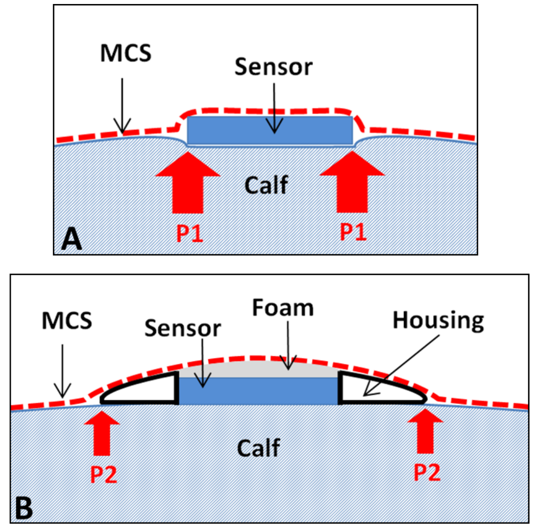

Fig. 2. A : Sensor under the MCS (dash line) without support; B : Sensor surrounded by its support under the MCS

and the subjects were in a normal state of vigilance at the time of their arrival. The experiment lasted 40 minutes and proceeded in two phases. The first phase was dedicated to the measurement of skin effective thermal conductivity of the calf of the subject without compression stockings. These values were used as reference values. The second set of experiment aimed at measuring skin effective thermal conductivity of the calf with MCS Class 2. Measurements were performed on one leg, but MCS were worn on the two legs. Relative differences were calculated for each of the investigated positions, considering values with and without compression. Thus, improvement or reduction in the skin microcirculatory activity of the calf induced by wearing MCS Class 2, could be evaluated.

The recording of microcirculatory activity was started once the Hematron sensor was fixed on the investigated area. Each subject followed the same sequence of postures, first without compression stockings then with MCS:

1) The subject was in a standing posture for 5 minutes to stabilize the signal of the effective thermal conductivity (required time for the digital regulation to reach a steady state). Data were recorded but not analyzed.
2) The subject was in supine posture for 4 minutes on a matress. A hole had been realized in the matress to allow the subject to be in a supine position without squeezing the sensor.

TABLE I
ANTHROPOMETRIC DATA

	Mean (SD)
Age (years)	33.2 (8.38)
Height (m)	1.69 (0.11)
Weight (kg)	65.5 (12.55)
BMI (kg/m^2)	22.83 (3.30)

3) The subject was in a sitting position for 4 minutes in a comfortable seat, his back against the backrest and the feet flat on the ground.
4) The subject was in standing position, the arms along the body and avoiding movements, for 4 minutes. This concluded the first experimental phase.
5) The subject wore the MCS Class 2 on the two lower limbs and started once again the above sequence (standing, supine, sitting and standing)

TABLE II
RELATIVE DIFFERENCES IN SKIN EFFECTIVE THERMAL CONDUCTIVITY(%)

	Mean (SD)	Median	P>χ^2
Supine	6.49 (9.06)	7.09	0.027
Sitting	7.14 (3.04)	7.63	0.002
Standing	4.12 (6.64)	3.81	0.058

III. RESULTS AND DISCUSSION

Results are reported in Table II. Looking at median values of the relative differences in skin thermal conductivity with compression stockings compared to those without stockings, positive values are reported for the three positions. Best results are obtained in the sitting position where an increase of around 8% was significantly highlighted ($p < 0.005$). An improvement of 7% was obtained for the supine position ($p < 0.05$) and finally, 4% for the standing position but this was not significant ($p > 0.05$).

Results of this study show that application of low pressures on the lower limbs has a direct positive influence on the skin microcirculatory activity measured using the skin's effective thermal conductivity. According to the literature and particularly from Fromy et al. [9], the change of cutaneous blood flow of the finger has been investigated when applied pressure was progressively increased in this area. In this work, microcirculatory variations were measured on the index thanks to a laser Doppler perfusion monitor (Periflux 4001). Cutaneous blood flow increased for low pressures ranging up to around 25 mmHg. Then, it reached a maximum around 30 mmHg. Above this value, microcirculatory activity decreased. This value is close to the pressure called "capillary closing pressure" that is the pressure needed to close the capillaries (around 32mmHg). Cutaneous blood flow started to be degraded until the total stop observed for a pressure of around 85 mmHg. According to additionnal studies [10] [11], Fromy and Garry observed that the local application of chemical substances (anaesthetic or capsaicin) on the investigated area under pressure, involved the disappearance of the vasodilatory action present in normal experimental conditions. The so called PIV, for Pressure Induced Vasolidation, has been described as a protective mechanism allowing to delay tissue ischaemia. Although these mechanisms are nowadays little known, the PIV would be related to a neurophysiological mechanism implying cutaneous nervous fibres. Our results are in agreement with the literature as we observe an increase in skin microcirculatory activity measured at the calf. At this location, the pressure exerted by the MCS is less than pressure at the ankle (15-20 mmHg for Class 2). The corresponding pressure at the calf should be around 7-12 mmHg, which is below the "capillary closing pressure". Our low pressure values are consistent with those highlighted by Fromy [9] where an increase of cutaneous blood flow has been reported for this pressure range.

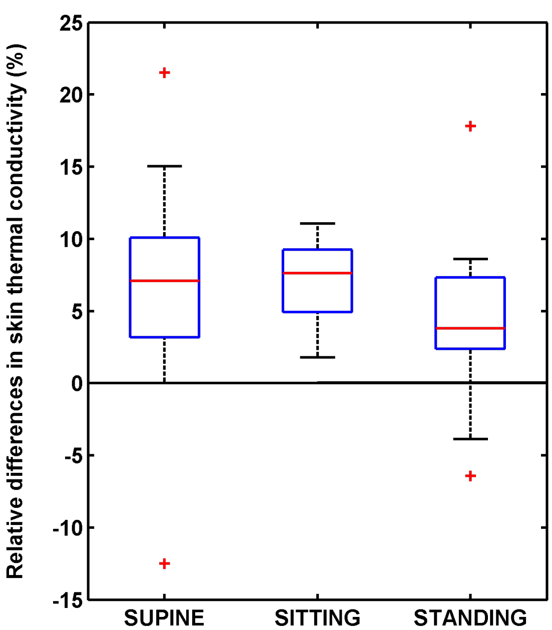

Fig. 3. Relative differences in skin thermal conductivity of the calf obtained without and with Class 2 compression stockings for Supine, Sitting and Standing positions

IV. CONCLUSIONS

This preliminary study demonstrates that medical compression stockings (Class 2) have positive effects on the skin microcirculatory activity, measured via the skin thermal effective conductivity. Indeed, positive relative differences in skin thermal conductivity with compression stockings compared to those without stockings, have been reported for three positions (supine, sitting and standing). This experiment has been possible thanks to the specific design of the sensor Hematron housing. We have demonstrated that Hematron is an exclusive device providing an ambulatory assessment of skin microcirculatory activity, that could be located under garment. A clinical study is now planned on non-healthy subjects (C0 and C1) to investigate the action of MCS Class 2 and confirm the results of this preliminary study.

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