The Effects of Below-Knee Medical Compression Stockings on Pulse Wave Velocity of Young Healthy Volunteers

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Abstract

Szolnoky, G, Gavallér, H, Gönczy, A, Bihari, I, Kemény, L, Forster, T, and Nemes, A. The effects of below-knee medical compression stockings on pulse wave velocity of young healthy volunteers. *J Strength Cond Res* XX(X): 000–000, 2018—The effects of graduated medical compression stockings (MCS) on cardiovascular responses are poorly investigated. A simple study was undertaken to investigate whether the application of below-knee leg MCSs with different pressures could influence aortic pulse wave velocity (PWV) as the gold standard for aortic stiffness measurement evaluated by arteriography. Ten volunteers underwent PWV measurement at baseline, then in below-knee compression class (ccl) 1 (18–21 mm Hg), 2 (23–32 mm Hg) and 3 (34–46 mm Hg) MCSs in a consecutive manner. Baseline PWV (mean value: 7.86 $\pm$ 1.70 $m \cdot s^{-1}$) was significantly reduced by ccl 1 MCSs (mean value: 6.55 $\pm$ 0.88 $m \cdot s^{-1}$, $p = 0.04$). ccl 2 and ccl 3 stockings also notably decreased baseline PWV (mean values: 6.63 $\pm$ 0.65 $m \cdot s^{-1}$, $p = 0.058$ and 6.62 $\pm$ 1.00 $m \cdot s^{-1}$, $p = 0.067$; respectively). The application of low compression MCSs (ccl 1) leads to a significant decrease in PWV indicating a beneficial cardiovascular influence.

Key Words arteriography, pulse wave velocity, medical compression stocking

Introduction

Below-knee compression-associated beneficial perceptions of athletes have been described in several studies; however, these effects have not been confirmed undoubtedly (12). Compression therapy-directed research predominantly focuses on the improvement of venous and lymph return (19); however, studies on local arterial and microcirculation responses have also been available (7,8). There have been relatively limited investigations on the effects of compression stockings on cardiovascular responses (13,16,22) and so far no clearly significant influences have been verified. The systemic effects of limb compression are yet to be fully clarified.

There are bodies of evidence that external compression increases local arterial blood flow in healthy human probands (7,8). Accordingly, external mechanical compression has been proven to decrease arterial stiffness of the treated limb (7). Stiffness is considered one of the most prominent features of arterial and aortic functions (18). In general, cardiovascular practice stiffer arteries are known to be related to a higher risk of the development of atherosclerosis and cardiovascular diseases; thus, arterial stiffness is an independent predictor of cardiovascular morbidity, causing notable hemodynamic consequences such as pulse pressure and pressure waveform alterations (4). In terms of sports medicine, less stiff arteries are related to better cardiovascular and vasodilatory capacities (11). Pulse wave velocity (PWV) is a popular and uncomplicated measure of aortic stiffness comprising such distinct techniques as piezoelectric, oscillometric, and tonometric measurements (2). Stiffness and PWV are negatively associated with cardiorespiratory fitness and capacity (6,14,21). In this view, the reduction of stiffness and PWV leads to the improvement of cardiovascular efficacy.

This study desired to examine whether the application of below-knee medical compression stockings (MCSs) with different pressures could decrease PWV evaluated by an oscillometric method.

Methods

Experimental Approach to the Problem

Sports socks have gained popularity among professional and amateur athletes. Beneficial influences are attributed to their use, and the improvement of several biochemical markers (lactic acid, lactate dehydrogenase [LDH]), creatinine kinase (CK), fitness (heart rate, fatigue, performance power, aerobic

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capacity, effect size, perceived muscle soreness, time to fatigue, maximal oxygen consumption, rating of perceived exertion, pain pressure threshold, time to exhaustion) and quality of life (visual analogue scale on the assessment of comfortability of wear) parameters have been demonstrated; however, scant evidence exists on their systemic cardiovascular effects (1,10,12,13,16,17,22). In terms of cardiovascular fitness, the gold standard for the measurement of aortic elastic properties is pulse wave velocity determination using arteriography (2,4,6,11,14,21).

Young healthy volunteers have been recruited and assigned to our short clinical study procedure, which aimed to measure PWV, the gold standard parameter of aortic stiffness with and without below-knee compression stockings. Each proband served as its own control. Arterial PWV detections comprised baseline (without compression stockings), final (in stockings with high pressure), and 2 interim measurements (in low and medium pressure stockings). Besides PWV measurements, 10-minute breaks also included the change of MCSs. Between the 4 arteriography procedures, probands wore 3 different compression stockings with increasing pressures for 30-minute intervals in a consecutive fashion. This was a time-consuming approach in which each measurement of the same subject was performed under the same circumstances (nutrition, hydration, date, timing, room temperature, and humidity).

Subjects

The study comprised 10 volunteers in the range of 19–26 years (mean age: 22.9±1.96 [mean ± *SD*]) with an equal gender ratio and body mass indices in the range of 18.96–23.51 (mean value: 21.05±1.49 [mean ± *SD*]) $kg \cdot m^{-2}$. All volunteers underwent physical examination and systolic and diastolic blood pressure, transthoracic echocardiography and electrocardiography measurements. Exclusion criteria included hypertension, coronary or valvular heart disease, atrial fibrillation and other arrhythmias, heart failure, and unstable angina pectoris. Acute myocardial infarction was also excluded. Informed consent was obtained from each person, and the study protocol adhered to the ethical guidelines of the 1975 Declaration of Helsinki, as reflected in a prior approval by the Institutional Review Board of the Albert Szent-GyÖrgyi Medical Center, University Of Szeged.

Procedures

Stocking Selection. Before the clinical trial, both legs of each participant were measured with a centimeter tape to select the appropriate size of the fitting ready-made Mediven Plus (Medi, Bayreuth, Germany) knee-length (AD) compression class (ccl) 1 (composition: 25% elastane, 75% polyamide; pressure range: 18–21 mm Hg), 2 (composition: 31% elastane, 69% polyamide; pressure range: 23–32 mm Hg) and 3 (composition: 37% elastane, 63% polyamide; pressure range: 34–46 mm Hg) stockings.

Interface Pressure Measurement. Interface pressures were measured by a Kikuhime device (Medi Trade, Soro, Denmark) using a small pressure probe placed to point B1 in a standing position (20) underneath compression stocking so as to determine if stocking selection was appropriate.

Pulse Wave Velocity Measurement. TensioMed Arteriograph (Tensiomed Ltd., Budapest, Hungary) was applied for the measurement of PWV. This is a small-sized device having 2 major components: an inflatable cuff which is as well a pressure sensitive sensor and very high-fidelity oscillometric tonometer receiving and identifying the weak suprasystolic signals from the cuff. The test also requires the preprocedural measurement of the distance between the jugulum and symphysis that corresponds to the length of aorta. This instrument measures the blood pressure in the upper arm by oscillometry and then produces a cuff pressure over the brachial artery (systolic blood pressure measured plus 35 mm Hg). Fluctuations in pulsatile pressure in the artery beneath the inflated cuff produce periodic pressure changes in the inflated cuff, and these oscillations are indirect measures of the pulsatile changes in the artery. The cuff detects pressure oscillations in the brachial artery, which are recorded and analyzed as pulse waves by the computer. The difference in time between the beginning of the first and the second (reflected) waves is related to the distance between the jugulum and the symphysis, resulting in the PWV given in $m \cdot s^{-1}$. The early, late systolic and diastolic waves are separated by the Arteriograph software. The onset and the peaks of the waves are also detected. The onset of the waves is determined by using first and second derivatives for PWV analysis. To intensify the signal and differentiate the initial wave from the reflective wave, the Arteriograph evaluates the pulse waves only when a suprasystolic pressure of 35 mm Hg has been attained.

Briefly, the instrument unifies the rapid measurement (cca. 2 minutes) of the most important parameters (PWV, systolic and diastolic blood pressures, heart rate and miscellaneous hemodynamic measures). From the practical point of view, the procedure is easy and there is no need for highly specific personnel as the measurement is fully automatic except the placement of the upper arm-cuff and the launch of the test which is highly reproducible and associated with low variance. The blood pressure measurement combined with pulse wave registration begins automatically under influence of the command issued by the software running in the computer adjusted to Arteriograph. Data regarding pulse wave and momentary pressure samples are transferred to the computer and the real-time change of pulse is visible.

Study Protocol. Volunteers without MCSs underwent baseline arteriography measurements in supine position. Subsequently, they put on a pair of ccl 1 AD (low pressure) stockings on both legs, worn for 30 minutes in a standing position, after which arteriography was repeated in supine position. Then, volunteers removed ccl 1 stockings and reapplied MCS with one class higher pressure (medium

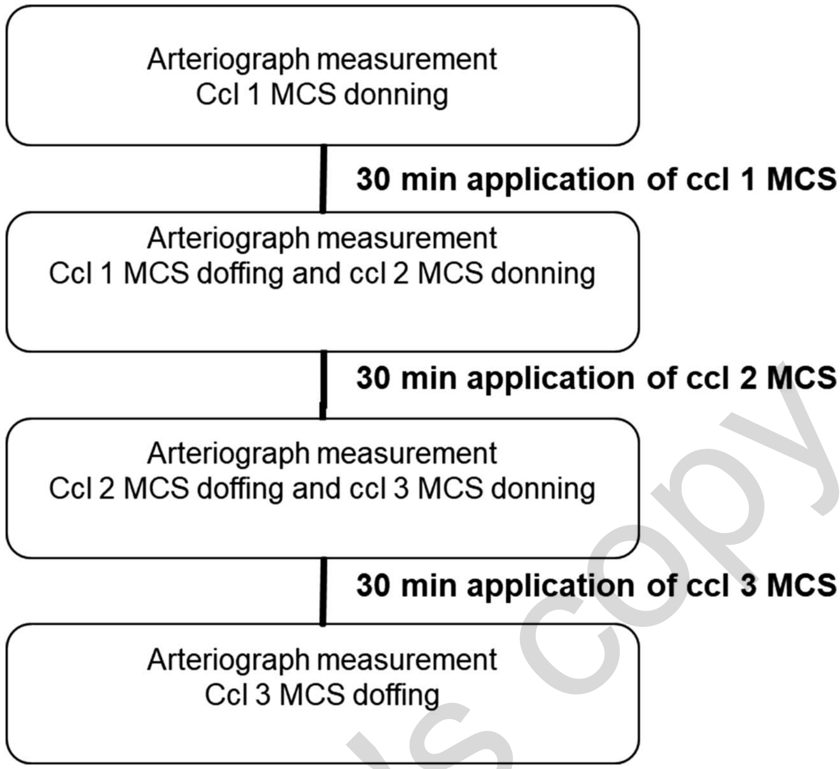

Figure 1. Flow chart of study protocol. PWV detections comprised baseline (without below-knee compression stockings), 2 interim (in low and medium pressure stockings) tests and a final (in high pressure stockings) measurement. First interim test was undertaken in low pressure stockings (ccl 1) worn in the preceding 30-minute period, then the proband took off this pair of garments and donned the new pair with medium pressure, and the same procedure was repeated twice (second interim and the final tests). PWV = pulse wave velocity.

pressure, ccl 2 AD stockings) and after 30 minutes underwent PWV measurement with Arteriograph again in supine position. Finally, the participants changed ccl 2 stockings to ccl 3 (high pressure) garments and a 30-minute application was followed by the final arteriography (Figure 1).

Tests were held in November and each proband had only a light breakfast between 6.45 and 7.00 AM according to our instructions. Tests started at 9.00 AM and subjects were not allowed to do any kind of physical exercise and to consume any meal or during the study period. Room temperature and relative humidity were stable at 21–22° C and 45–50%, respectively. Each garment was used firstly and our physiotherapist colleagues assisted donning and doffing if needed.

Statistical Analyses

Sample size calculation using Power & Sample Size Calculator (Statistical Solutions LLC., Cottage Grow, WI, USA) revealed a minimum group size of 8 probands at a power of 80%.

Data are reported as mean ± *SD*; 95% confidence limits are also included and a probability value $p < 0.05$ was accepted as statistically significant. Kolmogorov–Smirnov test was undertaken to assess distributions of the groups. Differences between variances were studied with Mauchly's Test of Sphericity. Then, data were analyzed with repeated measures analysis of variance (ANOVA). The result of repeated measures ANOVA was considered by Greenhouse-Geisser correction. Fisher's least significant difference post hoc analysis was used to determine pairwise differences. We applied SPSS version 24 (IBM Corp., Chicago, IL, USA).

Results

Interface Pressure Measurement

The following mean pressures were detected along the application of MCSs with distinct compression classes: ccl 1 (20.2 ± 1.35 mm Hg), ccl 2 (29.0 ± 2.2 mm Hg), and ccl 3 (37.6 ± 4.25 mm Hg) in standing positions, which confirmed appropriate stocking ordering.

Pulse Wave Velocity Measurement

Baseline PWV (mean value: 7.86 ± 1.70 $m \cdot s^{-1}$) was significantly reduced by ccl 1 knee-high MCSs (mean value: 6.55 ± 0.88 $m \cdot s^{-1}$, $p = 0.04$). Application of ccl 2 and ccl 3 stockings also strongly decreased baseline PWV (mean values: 6.63 ± 0.65 $m \cdot s^{-1}$, $p = 0.058$ and 6.62 ± 1.00 $m \cdot s^{-1}$, $p = 0.067$; respectively) (Figure 2).

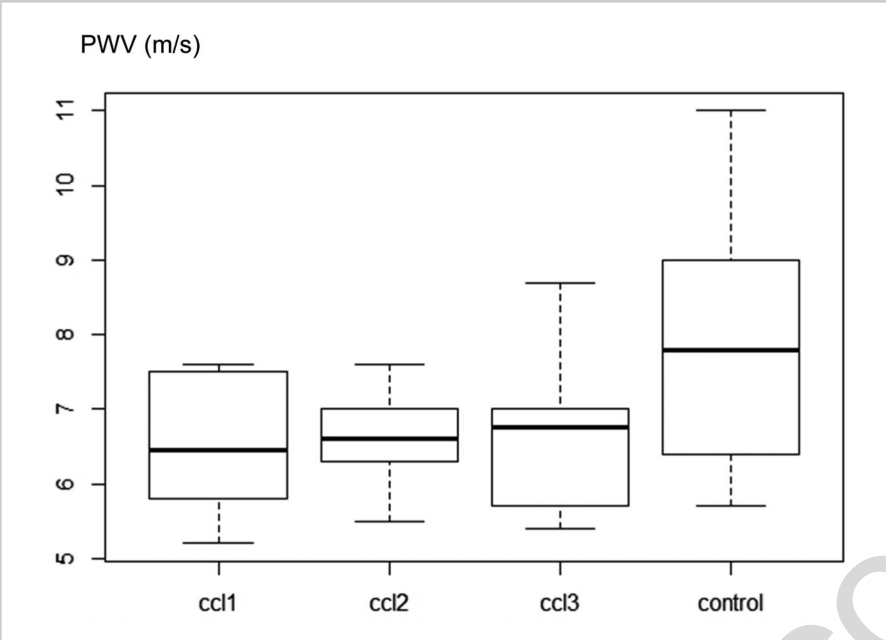

Figure 2. PWV values at baseline (control) and with the 30-minute application of 18–21 mm Hg (ccl 1), 23–32 mm Hg (ccl 2) or 34–46 mm Hg (ccl 3) below-knee stockings. *Denotes significant difference ($p < 0.05$) from control. PWV = pulse wave velocity.

Discussion

The aim of this study was to determine the cardiovascular effects of various degrees of below-knee elastic compression among young healthy volunteers. No previous studies have investigated the same or even similar effects of MCS within this population. Instead of local mechanisms or formerly scoped systemic parameters, an alternative assessment was designed and undertaken to measure compression-derived systemic effects. Pulse wave velocity, a direct measure of arterial stiffness, is a widely approved and standard method to assess current vascular status. We used arteriography for the measurement of PWV, which requires little technical expertise and has robust epidemiological evidence. Higher aortic stiffness assessed by PWV is associated with increased risk of a first cardiovascular event and may also be a prognostic factor in heart failure. Decrease in PWV is one of the primary objectives to improve cardiovascular function (3). On the other hand, arteriography is a reliable tool for noninvasive calculation of PWV using oscillometric measurements and has been validated against tonometric and piezoelectric methods (15).

In our experimental setting, ccl 1, 2 and 3 stockings were able to ameliorate PWV measured by arteriography; however, only low compression was able to cause a significant reduction ($p = 0.04$). The exact mechanism is yet to be elucidated; however, external compression generated local arterial vasodilation-driven influence on aortic function cannot be excluded. Besides the therapeutic potential in preventing venous and lymphatic insufficiencies, low compression with leg stockings may have a positive effect on aortic function among healthy individuals, so their medical properties could be enriched accordingly after further investigation. Furthermore, our small study is a novel explanation to the perceived beneficial effects of below-knee compression by anecdotal reports of amateur, semi- or full-professional athletes.

Compression therapy is considered the gold standard for the conservative treatment of venous and lymphatic insufficiencies (19). Recent proofs support the idea that external compression, especially short-stretch bandage application, is also capable of arterial blood flow stimulation among healthy individuals (7,8). Among local blood flow alterations, the reduction of local arterial stiffness was one of the most prominent features (7), which was attributed to the changes in smooth muscle tension, vessel wall geometry and the mechanical properties of the vessel wall. External compression through increasing muscular compression causes vessel distortion and a subsequent reduction in vessel transmural pressure leading to smooth muscle relaxation. Local vasodilators may also be triggered by venous shear-stress and veno-arterial reflex following venous emptying might also be a regulator in arterial stiffness (5,9).

A pioneer study focusing on the influence of compression stockings on cardiac functions found no changes in supine position. However, in a standing position, MCSs enhance cardiac output and stroke volumes while reducing heart rate. Elevated cardiac output could be attributed to increased venous return, whereas decreased heart rate is driven by a compensatory mechanism to avoid a sudden dramatic increase in blood pressure (23). Studies looking at running performances among athletes wearing compression stockings were able to identify decrease in some biochemical markers (lactic acid, LDH, CK) and improvement in other physiological and pathophysiological outcome measures (heart rate, fatigue, performance power, aerobic capacity, effect size, perceived muscle soreness, time to fatigue, maximal oxygen consumption, rating of perceived exertion, pain pressure threshold, time to exhaustion) (1,10,12,13,16,17,22), but heart rate was the only parameter having a true relationship with cardiovascular function.

In conclusion, this simple, nonexpensive, and validated method using Arteriograph was able to demonstrate the efficacy of bilateral, below-knee low compression on the reduction of PWV. The applied protocol was sufficient to detect at least one significant difference against the baseline condition.

Small proband group size and relatively low level of significance demand a more extensive examination recruiting larger number of volunteers.

Practical Applications

Low compression with below-knee MCSs was able to improve PWV measured by arteriography. The reduction of PWV is a beneficial effect, which can ameliorate vascular functions and cardiovascular risk. Improved cardiovascular fitness could result in better adaptation to condition changes and benefits athletes and nonsportsmen. On the other hand, upgrading cardiovascular fitness using below-knee stockings is a rather simple and nonexpensive way that requires neither specific training nor medical assistance.

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