Lower limb volume in healthy individuals after walking with compression stockings

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ABSTRACT

Objective: Despite the modern appeal of wearing compressive garments during physical activities, the literature is lacking in quality data and controversial in the investigations dealing with the pathophysiologic mechanism by which graduated compression stockings (GCS) affect the calf pump activation in healthy individuals. The aim of the investigation was to provide insight into the clinical effects of GCS use during a standardized walking exercise.

Methods: Twenty physically active healthy volunteers (mean age, 34 ± 5 years; body mass index, 22 ± 2 kg/m^2) underwent lower limb ultrasound scanning to exclude vascular impairment. All individuals performed continuous aerobic exercise, walking for 30 minutes on a treadmill, under cardiac monitoring, at 70% of individual estimated maximal heart rate according to the Tanaka equation. The study population performed the standardized walk without GCS (baseline) and at 1 week performed the same standardized walk wearing knee-length 20 to 30 mm Hg GCS (compression). All individuals underwent a lower limb volume assessment by truncated cone formula before and after the walk and a perceived exertion assessment by means of the validated Borg scale at the end of the exercise protocol.

Results: All individuals had normal venous and arterial ultrasound examination findings. No significant postural defects were reported. Both legs were assessed in all 20 individuals for a total of 40 cases with and 40 cases without GCS. In the baseline group, the median (interquartile range) lower limb volume changed from 2496 (770) mL before exercise to 2512 (805) mL ($P = .2597$) after exercise. The compression group reported a significant lower limb volume change from 2466 (670) mL before exercise to 2276 (567) mL ($P = .0001$) after exercise. Mean perceived exertion was 13 (11) and 11 (1) in the baseline and compression groups, respectively ($P = .0001$). The interface pressure exerted by the GCS was 24 (2) mm Hg. No complaints in terms of discomfort were reported after use of GCS.

Conclusions: In healthy individuals, GCS (24 [2] mm Hg) use during a continuous standardized walk of 30 minutes is associated with a significant decrease in lower limb volume and a decrease in perceived exertion. The mechanism by which GCS impart their effect during physical activity may involve improved muscle pump function and reductions in inflammatory pathways. Further study will need to validate the mechanisms of the function of GCS used during physical exercise. (J Vasc Surg: Venous and Lym Dis 2019;7:557-61.)

Keywords: Stockings; Compression; Volume; Exertion; Aerobic exercise

A recent review of the literature has underlined that graduated compression stockings (GCS) have scientific validity in the management of lower limb venous and lymphatic drainage impairment.[1] The benefits of GCS use have also been reported in healthy individuals involved in occupational activities that require prolonged standing,[2,3] in physiologic conditions such as pregnancy,[4,5] and in individuals subjected to prolonged flights.[6] Of significant interest, the use of stockings in the sports world is rapidly increasing. However, there is a lack of evidence-based validity regarding the related impact on physical performance and variations in lower limb parameters. Moreover, there is a disparity in performance between commercially developed, certified graduated compression products and stockings generally used during physical exercise or sport.[7]

The available literature is showing a positive effect of compression garments mainly on the delayed onset of

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muscle soreness, without reporting significant data about the required compression features in terms of pressure and stiffness.[8,9] Importantly, studies published >70 years ago reported a significant decrease in ambulatory venous pressure by walking, suggesting the activation of the muscle pump, improving lower limb drainage. With many decades spent in the use of GCS, no study reported the ideal duration and speed of a walk aimed to improve lower limb drainage, making the current indication of walking for an unspecified time based more on empirical observation rather than on scientific evidence.[10]

In a previous investigation of our group, we analyzed the lower limb volume and perceived exertion variations in healthy individuals undergoing an intermittent walk without and with below-knee GCS of different pressure levels. The results showed that at least 23 mm Hg is needed to significantly decrease lower limb volume. On the contrary, 18 mm Hg was associated with no significant variation of the lower limb volume, whereas individuals wearing sham stockings experienced a leg volume increase. Interestingly, only the group wearing 23 mm Hg GCS reported a significant decrease in perceived exertion.[11]

The purpose of this study was to evaluate the effects of GCS on limb volume and perceived exertion during standardized exercise. We hypothesized that the use of GCS will reduce limb volume and perceived exertion during a controlled standardized walking exercise. The aim of the investigation was to assess lower limb volume variation and perceived exertion after a standardized continuous walk of 30 minutes with and without below-knee GCS.

ARTICLE HIGHLIGHTS

- **Type of Research:** Single-center prospective crossover study
- **Key Findings:** Continuous aerobic exercise wearing below-knee 20 to 30 mm Hg graduated compression stockings (GCS) leads to a significant lower limb volume decrease from 2466 (670) mL to 2276 (567) mL ($P = .0001$) and a significantly lower perceived exertion, whereas no significant volume change occurs without GCS.
- **Take Home Message:** A standardized continuous walk of 30 minutes in healthy individuals is associated with significant lower limb volume reduction when GCS of 24 (2) mm Hg are applied. Wearing this type of compression is also associated with a significant decrease in perceived exertion, potentially facilitating an even longer walking activity.

METHODS

Population. Twenty healthy volunteers underwent lower limb ultrasound scanning to exclude arterial and venous vascular impairment and weight-bearing analysis to rule out postural defects potentially altering venous return.[12] The cohort was composed of 10 women and 10 men with a mean age of 34 ± 5 years and body mass index of 22 ± 2 kg/m^2; all the individuals were defined as physically active because they performed regular (not sport professional) physical activity at least three times per week and were familiar with walking on a treadmill.

Inclusion criteria were age from 18 to 75 years and body mass index <35 kg/m^2. Exclusion criteria were cardiac comorbidity, chronic venous disease, lower limb arterial disease, use of drugs affecting venous volume, lymphedema, previous varicose vein treatments, moderate or severe biochemical alterations, and postural defects.

Study protocol. In a room with controlled temperature ranging from 21°C to 22°C and always between 3 PM and 5 PM, all the individuals walked continuously on a treadmill for 30 minutes, under heart frequency monitoring, at 70% of individual estimated maximal heart rate (208 − 0.7 × age) according to the Tanaka equation.[13]

The study population performed the standardized walk without GCS (baseline group), and at 1 week, at the same time of day, the same individuals performed the same standardized walk wearing below-knee 20 to 30 mm Hg GCS (compression group). Because we did not use custom-sized garments, to determine the correct GCS size, all the individuals were measured with a centimeter tape at the ankle and calf level and per the manufacturer's specification were assigned the most appropriate size (Mediven Plus 20-30 mm Hg; MEDI GmbH & Co KG, Bayreuth, Germany). All individuals were instructed to wear comfortable athletic shoes for the examination and standardized walk and to wear the same shoe as a participant in the baseline group and the compression group. All the individuals were asked to report eventual discomfort associated with the use of GCS.

The protocol has been approved by the Institutional Review Board at the University of Ferrara, and all the individuals signed the informed consent (approval No. 170476).

Outcome parameters. Before and after the walk, all individuals underwent a lower limb volume assessment by measuring the leg circumference with a centimeter tape starting immediately above the malleolar level and continuing measurements every 4 cm for eight leg segments.[14] Using an Excel database (Microsoft, Redmond, Wash), the leg volume was calculated by the mathematical truncated cone formula[15] (Kuhnke formula: $V_{limb} = \Sigma\, X^2/\pi$)[16] (Fig 1).

At the end of the exercise protocol, a perceived exertion assessment by means of the original Borg scale was performed. The Rating of Perceived Exertion (RPE) scale

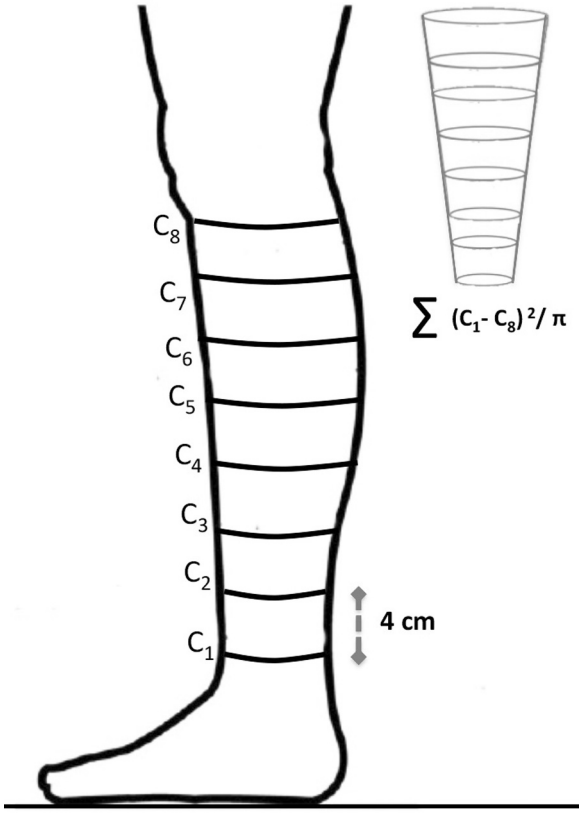

Fig 1. Calculation of limb volume by circumference measure. Measures are taken every 4 cm, and the volume of a truncated cone is calculated according to the Kuhnke formula, summing the eight neighboring circumference measures.

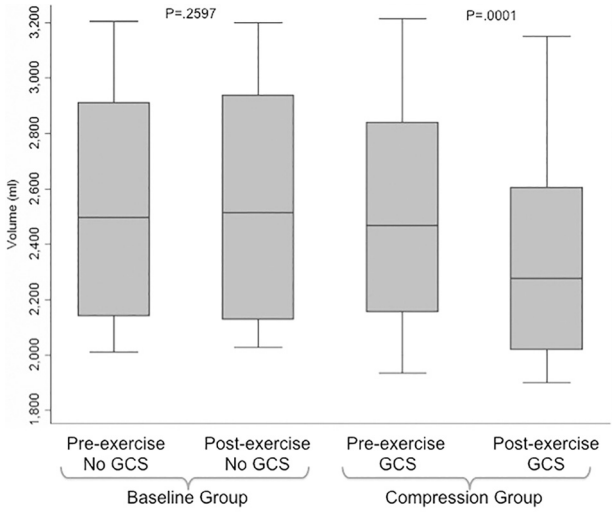

Fig 2. The first quartile (*bottom of box*) and third quartile (*top of box*) volume value; the *band inside the box* is the median. The *lines extending vertically* from the boxes (whiskers) represent the lowest and the highest volume values. The first two boxes indicate the volume values measured before and after exercise without graduated compression stockings (*GCS*; baseline group), showing no significant differences. The last two boxes represent the volume values with a significant decrease assessed before and after exercise wearing GCS (compression group).

is a validated assessment tool used in clinical practice to measure perceived exertion. RPE is a widely used and reliable indicator to monitor and to guide exercise intensity. The scale allows individuals to subjectively rate their level of exertion during exercise, and it can be used as an indicator of impending fatigue.[17]

On the RPE scale, the verbal expressions are anchored to the correct positions on a visual scale. The original Borg scale starts at number 6, where the individual has no difficulty at all (perceived exertion: very, very light) and progresses through to number 20, where the effort is maximal (perceived exertion: very, very hard).[17-19] All the individuals were invited to give their personal score. The interface pressure values between the compression devices and the skin were measured in standing position right before and right after the exercise.

A pneumatic pressure transducer (PicoPress Microlab Italia, Padua, Italy) connected to a pressure probe of 5 cm in diameter and <1 mm in thickness filled with 2 mL of air during measurement was attached on the ankle skin minimum girth point (B). The sensor was never positioned on a bone prominence.[20] This device has been shown to provide accurate, linear, and reproducible measurements.[21]

Statistical analysis. InStat GraphPad (GraphPad Software, Inc, La Jolla, Calif) was used for statistical analysis. The data were expressed as median (interquartile range). The Kolmogorov-Smirnov test was used to assess the data distribution. The differences between volume values, Borg scale score, and interface pressure were tested using nonparametric Wilcoxon matched pairs test. Statistical significance was defined as $P < .05$.

RESULTS

All individuals had normal venous and arterial ultrasound examination findings. No significant postural defects were reported. Both legs were assessed in all 20 individuals for a total of 40 cases with and 40 cases without GCS. The starting leg volume (measured before exercise) was 2496 (770) mL and 2466 (670) mL for baseline and compression groups, respectively, showing no statistically significant difference ($P = .7829$). In the baseline group, the lower limb volume changed from 2496 (770) mL before exercise to 2512 (805) mL ($P = .2597$) after exercise. The compression group reported a significant lower limb volume change from 2466 (670) mL before exercise to 2276 (567) mL ($P = .0001$) after exercise (Fig 2).

Mean perceived exertion was 13 (1) and 11 (1) in the baseline and compression groups, respectively ($P = .0001$; Fig 3). The interface pressure exerted by the GCS before walking was 24 (2) mm Hg; after exercise, the interface pressure measured at the same point was 24 (1) mm Hg ($P = .0831$). No complaints in terms of discomfort were reported after the use of GCS.

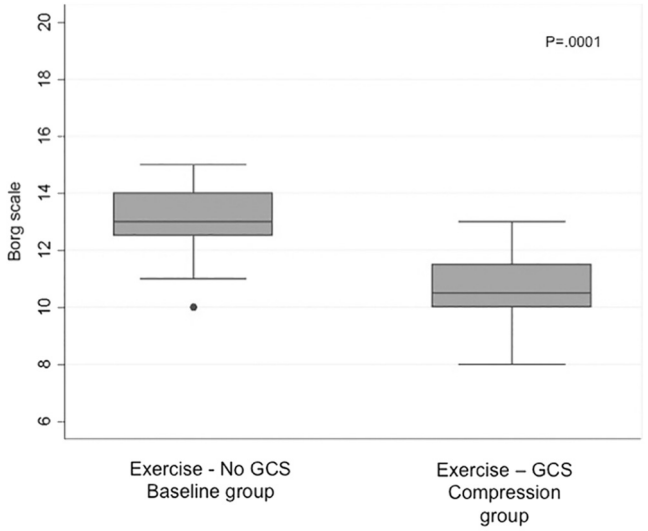

Fig 3. Box and whiskers plots of the perceived fatigue exertion registered at the end of 30 minutes of walking exercise without and with graduated compression stockings (*GCS*). The Borg scale score significantly decreased in the group that performed the exercise wearing GCS.

DISCUSSION

Calf muscle pump activation is considered so beneficial in lower limb drainage that it has been defined as a "peripheral heart."[22] The activity of walking has such potential in reducing venous pressure that in the past, a dedicated "walking venous pressure test" was used in lower limb drainage assessment. Nevertheless, despite some preliminary clinical data about the benefits for chronic venous disease patients of walking for 50 minutes with 20 to 30 mm Hg GCS,[23] to the best of our knowledge, no data are available in the literature about the effect of a standardized walk with and without GCS on healthy individuals' lower limb drainage and perceived exertion.

This investigation demonstrated that 30 minutes of a continuous standardized walk without GCS was unable to significantly reduce lower limb volume in healthy individuals. On the contrary, GCS exerting at least 24 (2) mm Hg were able to significantly decrease lower limb volume. The use of the same GCS was also associated with a significant improvement in fatigue control during the physical exercise by having decreased value of perceived exertion. These data related to a continuous walk are in accordance with the study previously published regarding the lower limb volume variation and the perceived exertion reduction with the use of at least 23 mm Hg below-knee GCS in an intermittent walk.[11]

Compliance with correctly prescribed GCS was demonstrated to be high, with no uncomfortable feeling being reported by the users. The interface pressure assessment in this study confirmed that the range of values stated by the GCS manufacturer corresponded to the in vivo measurement. Noteworthy is the fact that after the physical exercise, the GCS maintained their elastic properties and the interface pressure features; the compression group demonstrated a significant decrease in lower limb volume. Previous literature has shown that compression is usually not associated with causing a significant increase in the ejection fraction; 30.5 mm Hg GCS were associated with a moderate nonsignificant improvement of the ejection fraction of 17%.[24]

Considering that the data presented herein show that 24 mm Hg GCS were able to significantly reduce lower limb volume and perceived exertion, an open question remains about the driving force responsible for the improved venous drainage. If we exclude the possibility of an improved muscle pump function, we could assume that GCS are able to improve drainage by decreasing the deep veins' caliber and not the superficial ones, according to the so-called compression paradox described by Uhl et al.[25] According to this theory, GCS are acting on the muscular-fascial structure of the leg, directly in contact with the deep veins that are consequently reduced in caliber, different from the more superficial ones that are surrounded by loose subcutaneous tissue. Such a hypothesis is in accordance with our data, considering that the intramuscular pressure measured by Uhl et al significantly decreased with use of 22 mm Hg GCS.

A potential bias of the investigation is represented by the individuals' first having the baseline walk and, 1 week later, the walk with GCS, thus eventually perceiving less exertion because of more familiarity with the specific physical activity. On the other hand, the study population was composed of active individuals used to walking on a treadmill, thus limiting the same possible bias.

Another potential limit of this investigation is the lack of sham GCS use. At the same time, different from a previous investigation of our group[11] in which we compared different individuals with different garments, in this specific case, the same individual was tested in two different conditions (without and with compression). Adding a sham GCS in this scenario could have equally introduced a bias in the form of feeling the different compression level.

Further investigations should explore the biochemical impact of GCS during exercise and correlate the clinical findings with biochemical and pathophysiologic mechanisms in edema reduction and reduced exertion.

CONCLUSIONS

This investigation offers the evidence-based demonstration that in healthy individuals, a standardized continuous walk of 30 minutes while wearing 24 (2) mm Hg GCS is associated with a significant reduction in lower limb volume and a significant decrease in perceived exertion, potentially facilitating an even longer walking activity.

This study's clinical evidence provides a foundation to assess GCS in physical activity and sports. Current sports literature reports evidence showing a role for compressive garments in delaying muscle soreness after exercise. These data add the effect of a reduced perceived exertion after the use of certified GCS. Continued research into the mechanism of GCS effects on limb volume and exertion is needed to fully understand the beneficial effects of limb compression during activity.

AUTHOR CONTRIBUTIONS

Conception and design: SG
Analysis and interpretation: SG, GM, ElM, JD, JR, PZ, ErM
Data collection: SG, MS, ErM
Writing the article: SG, GM, ElM, JD, JR, ErM
Critical revision of the article: SG, GM, MS, JD, JR, PZ, ErM
Final approval of the article: SG, GM, MS, ElM, JD, JR, PZ, ErM
Statistical analysis: ElM
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Overall responsibility: SG

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