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The Use of Compression Stockings During a Marathon Competition to Reduce Exercise-Induced Muscle Damage: Are They Really Useful?

Graduated compression garments are one of the most popular items of clothing in various endurance sports, such as running,[7] triathlon,[8] and cycling.[22] Compression garments were initially designed to be used in the clinical setting to improve venous blood return and to reduce leg swelling and the formation of blood clots in patients with chronic venous insufficiency.[1] However, the use of graduated compression garments—especially compression stockings—by endurance runners is especially encouraged by the manufacturers' claims of improved running performance mediated by increased venous blood return.[20] According to the manufacturers, compression stockings apply graduated compression around the calves, resulting in stimulation of the calf muscle pump and improved venous hemodynamics. The improved venous return caused by the application of mechanical pressure, in turn, increases end-diastolic volume and cardiac output during exercise, allowing athletes to perform at a higher intensity. However, scientific data do not support this theory. Wearing graduated compression stockings during a 10-km running trial ameliorated the increase in lower-leg volume just after the exercise, but this effect disappeared only 5 minutes after the end of running.[6] In addition, heart rate (an indirect measure to estimate the efficacy of compression garments to improve cardiac output and systolic volume during exercise) is not significantly modified with the use of compression stockings.[3,20,24]

STUDY DESIGN: Case-control study; ecological study.

OBJECTIVES: To examine the efficacy of wearing compression stockings to prevent muscle damage and to maintain running performance during a marathon competition.

BACKGROUND: Exercise-induced muscle damage has been identified as one of the main causes of the progressive decrease in running and muscular performance found during marathon races.

METHODS: Thirty-four experienced runners were pair-matched for age, anthropometric data, and best race time in the marathon, and randomly assigned to a control group (n = 17) of runners who wore conventional socks or to a group of runners who wore foot-to-knee graduated compression stockings (n = 17). Before and after the race, a sample of venous blood was obtained, and jump height and leg muscle power were measured during a countermovement jump. Serum myoglobin and creatine kinase concentrations were determined as blood markers of muscle fiber damage.

RESULTS: Total race time was not different between the control group and the compression stockings group (210 ± 23 and 214 ± 22 minutes, respectively; $P = .58$). Between the control group and the compression stockings group, postrace reductions in leg muscle power (–19.8% ± 17.7% versus –24.8% ± 18.4%, respectively; $P = .37$) and jump height (–25.3% ± 14.1% versus –32.5% ± 20.4%, respectively; $P = .27$) were similar. At the end of the race, there were no differences between the control group and the compression stockings group in serum myoglobin (568 ± 347 $ng \cdot mL^{-1}$ versus 573 ± 270 $ng \cdot mL^{-1}$, respectively; $P = .97$) and creatine kinase concentration (390 ± 166 $U \cdot L^{-1}$ versus 487 ± 227 $U \cdot L^{-1}$, respectively; $P = .16$).

CONCLUSION: The use of compression stockings did not improve running pace and did not prevent exercise-induced muscle damage during the marathon. Wearing compression stockings during long-distance running events is an ineffective strategy to avoid the deleterious effects of muscle damage on running performance.

LEVEL OF EVIDENCE: Therapy, level 2b.

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KEY WORDS: *compression stockings, marathon, muscle damage, myoglobin, performance*

During endurance running, the lower limbs absorb from 1.5 to 3 times the runner's body mass at every step,[16] and

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runners need more than 30 000 foot strikes to complete a marathon race (42.2 km). In fact, the distance covered during marathon trainings is one of the most important factors for developing muscle injuries in marathoners.[17] The continuous muscular work necessary to complete a marathon race leads to leg muscle fiber damage and local inflammation that ultimately affect the capacity to generate force during each strike.[12] In fact, muscle damage, as measured by blood markers such as myoglobin and creatine kinase concentrations, has been identified as one of the key variables for the reduced muscular performance[12] and reduced running pace during a marathon.[9]

Compression stockings may reduce the muscular vibrations triggered by the contact of the feet with the ground, and they may help to reduce the muscle oscillations in the calf during prolonged running,[6,18] which could help to prevent the degree of muscle damage sustained during a marathon. Although the use of compression garments may reduce subjective feelings of pain[14] and enhance the recovery of muscle strength and power[5,13] in the days following an exercise bout that induces muscle damage, the use of compression garments to improve running performance is controversial. Several investigations have found that wearing compression garments did not change running performance,[2,3,20,24] although other studies have found this not to be the case.[15,23] These previous investigations have included different tests (running time until fatigue, maximal treadmill test, 10-km running trials, etc), and all have used running distances shorter than 15.6 km. Thus, in these investigations, it is likely that the muscle damage level induced by the running bout was low, and their outcomes are difficult to apply to the population of marathoners.

To our knowledge, only 1 investigation has determined the effectiveness of compression stockings during a real competition.[8] Following a half-IRONMAN, triathletes who wore compression stockings had levels of muscle damage and reductions in leg muscle performance similar to those of individuals who completed the race with conventional socks.[8] This outcome may be related to the particularities of the triathlon: while swimming and cycling minimally induce muscle damage because of the low impact of these activities,[10] the value of wearing compression stockings in the triathlon is mainly related to the running sector (21.1 km of running in a half-IRONMAN). On the contrary, the use of compression stockings can produce a physiological benefit during the entire distance of a marathon race (42.2 km), and thus this strategy could be effective for marathoners.

Thus, even with the growing trend for runners to use compression stockings during endurance running events, their effectiveness to improve running performance is controversial. The purpose of this study was to investigate the possible benefits of wearing graduated compression stockings for running pace, prevention of muscle damage, and maintenance of muscle performance during a real marathon race.

METHODS

Subjects

Initially, 40 healthy and experienced marathon runners volunteered to participate in this study. The participants were contacted by phone and e-mail from a group of runners who had participated in an investigation during the previous marathon edition.[4] Inclusion criteria were as follows: aged between 15 and 60 years; free of any history of muscle, cardiac, or kidney disorders; participating in the marathon at maximal intensity; and having a running experience of at least 5 years and of at least 3 completed marathons. Exclusion criteria were as follows: taking medications during the 2 weeks prior to competing, having suffered a musculoskeletal injury in the 3 months previous to the competition, and not completing the marathon. Before enrolling in the investigation, a questionnaire about previous training, running experience, and best race time in the marathon (within the last 5 years) was completed by each participant. Participants were encouraged to include accurate data in this questionnaire, and a number of queries were included with the same objective of ensuring the validity of this information. Six participants were excluded because they did not fulfill the inclusion criteria. Then, participants were matched in pairs by age, anthropometric data, training status, and best race time in the marathon. One participant from each pair was randomly assigned to the experimental group (wearing compression stockings during the race) or to the control group (wearing conventional athletic socks during the marathon). With the initial sample, we were able to match 17 pairs of individuals (n = 17 for each group) with very similar anthropometric characteristics, best marathon performance, and training experience (TABLE 1). The sample size was estimated by using data obtained in a previous investigation[9] carried out in the same marathon race and with participants of similar characteristics. To obtain a significant effect of wearing compression stockings on postrace serum myoglobin concentration (with 80% statistical power and an alpha value of 1.96), we estimated a minimal sample size of 19 individuals per group. This estimation was based on an expected reduction in serum myoglobin concentration (350 $ng \cdot mL^{-1}$) when comparing values of participants in the compression stockings group and participants in the control group.

Before the onset of the experiment, all participants were fully informed of the potential risks and discomforts associated with the experiments and signed written consent to participate. The study was approved by the Camilo José Cela Ethics Committee, in accordance with the latest version of the Declaration of Helsinki, and participants' rights were protected during the experiment.

Experimental Design

Participants in the experimental group completed the marathon race wearing commercially available compression stockings (NRG Energy; Medilast Sport, Lleida, Spain). The stockings were made of 77% polyamide, 13% elastane, and 10% polyester, and covered from the foot to the inferior pole of the knee cap with graduated pressure (the pressure was highest at the foot and malleolus and decreased proximally from 25 to 20 mmHg). The size of the compression stocking assigned to participants was based on their lower-leg maximal perimeter and ankle perimeter, according to the manufacturer's indications. Participants in the control group completed the marathon race wearing conventional athletic socks. The socks were made of cotton-nylon, covered the foot up to approximately 2 cm above the malleolus, and applied minimal pressure on the lower leg. These socks were chosen for control purposes, as the participants routinely wore this type of sock.

TABLE 1 Characteristics and Training Habits of the Participants*

Variable	Control (n = 17)	Compression Stockings (n = 17)	Mean Difference†	*P* Value
Men/women, n	15/2	15/2	...	...
Age, y	42.7 ± 7.8	41.2 ± 8.9	1.5 (–4.4, 7.3)	.61
Body mass, kg	69.9 ± 7.7	70.2 ± 9.4	–0.3 (–6.3, 5.7)	.92
Height, m	1.73 ± 0.09	1.70 ± 0.07	0.03 (–0.03, 0.09)	.38
Running experience, y	10.50 ± 3.79	11.61 ± 3.44	–1.11 (–5.63, 3.40)	.62
Completed marathons, n	7 ± 6	9 ± 9	–2 (–6, 4)	.58
Best marathon race time, min	211 ± 29	200 ± 23	11 (–7, 28)	.21
Average training distance/wk, km	59 ± 18	57 ± 22	2 (–12, 16)	.45
Training sessions/wk, n	4.3 ± 1.2	4.5 ± 1.1	–0.2 (–1.0, 0.6)	.69

**Values are mean ± SD for runners wearing compression stockings and conventional socks during a marathon race.*
†Values in parentheses are 95% confidence interval.

Experimental Protocol

Two weeks before the race, a pair of compression stockings was sent by postal mail to each participant to familiarize the participants with the use of this garment, and participants were encouraged to wear the compression stockings during at least 3 training sessions before the race. Forty-eight hours before the race, a 7-mL venous blood sample was obtained from an antecubital vein after 10 minutes of supine resting. During this period, blood oxygen saturation was measured by means of pulse oximetry (OXYM2001; Quirumed, Valencia, Spain). After this, lower-leg volume (including the foot, soleus, and gastrocnemius) was measured using water displacement while participants were in a standing position.[19] Lower-leg volume was measured twice in each extremity, and the average was used for statistical analysis. Then, participants underwent a standardized 10-minute warm-up, including a skipping exercise, stretching, and 5 submaximal countermovement jumps, and performed 2 maximal countermovement vertical jumps on a force platform (Quattro Jump; Kistler Holding AG, Winterthur, Switzerland). For this measurement, participants began stationary in an upright position, with their weight evenly distributed over both feet and their hands on their waist in order to remove the influence of the arms on the jump. On command, participants flexed their knees, jumped as high as possible while maintaining their hands on their waist, and landed with both feet. The prerace jumps were performed with the competition clothes and shoes, and the repetitions were separated by 1 minute of rest. In each jump, maximal height, maximal leg power output during the concentric phase of the jump, and drop of center of gravity during the landing phase (adjusted for the participant's body height) were determined from ground reaction forces, as previously described.[11] The highest jump was used for statistical analysis. All participants were previously familiarized with the jump test. During this prerace measurement, participants were blinded to the treatment.

The day of the race, participants arrived at an area close to the start line, 30 minutes before the onset of the race (after their habitual warm-up), and were weighed in their competition clothes (±50-g scale; RADWAG Balances and Scales, Radom, Poland). Participants were instructed to avoid pain-relieving strategies (eg, analgesic medications, manual massage, ice) on the day before the race and during the race. At this time, participants were informed if they had to run with the compression stockings (experimental group) or with conventional socks (control group) and were encouraged to put the assigned clothing on prior to the start of the race. After this, participants were directed to the start line and completed the race, with no instructions about food or drinking strategies, running at their own pace. The marathon race (Rock and Roll Marathon in Madrid) was held in April 2013 in the area surrounding Madrid city. The lowest altitude of the race was 600 m and the highest altitude was 720 m. The race started at 9:00 AM and was performed under a cloudy sky, with a mean dry temperature of 8°C ± 1°C (range, 6°C-10°C; temperature readings at 30-minute intervals from 0 to 5 hours after the race onset) and a relative humidity of 62% ± 8% (range, 42%-83%). During the race, participants wore a race bib with a time chip to calculate the actual amount of time that it took them from the starting line of the race to the finish line (net time). Race time was

TABLE 2 Variables Assessed in the Compression Stockings Group (n = 17) and the Control Group (n = 17)

Variable	Control*	Compression Stockings*	Mean Difference†	*P* Value
Race time, min	210 ± 23	214 ± 22	−4.2 (−19.5, 11.1)	.58
Running pace, m·s^{-1}	3.4 ± 0.3	3.3 ± 0.4	0.1 (−0.2, 0.3)	.57
Rate of perceived exertion, arbitrary units	16 ± 2	16 ± 2	0 (−2, 1)	.79
Muscle pain, arbitrary units				
Postrace	7 ± 2	7 ± 2	0 (−1, 1)	.94
24 h postrace	6 ± 2‡	5 ± 2‡	1 (0, 2)	.04
48 h postrace	3 ± 2‡§	3 ± 2‡§	0 (−1, 2)	.91

*Values are mean ± SD.
†Values in parentheses are 95% confidence interval.
‡Different from postrace values (P<.05).
§Different from 24-h values (P<.05).*

also measured at 5-km intervals during the race. The utilization of the compression stockings and conventional socks during the entire race was confirmed by visual observation at the start, the halfway point, and the finish line.

Within 3 minutes of the end of the marathon race, participants went to a finish area, and body mass was immediately measured using the same apparatus described previously. Participants were instructed to avoid drinking from the finish line until the postrace weighing, and an experimenter ensured compliance. After that, participants performed 2 countermovement vertical jumps, and lower-leg volume was measured using the same procedures described for the prerace measurement. Participants then rested for 5 minutes, and a venous blood sample and postrace blood oxygen saturation were obtained. The rating of perceived exertion after the race was assessed using the Borg scale (from 6 to 20 arbitrary units), whereas lower-limb muscle soreness (from 0 to 10 arbitrary units) was self-rated using a visual analog scale. After that, participants were provided with fluid (water and sports drinks) and finished their participation in the study. Twenty-four hours after the end of the race, via telephone, participants were asked about their lower-limb muscle soreness using the same visual analog scale.

Blood Samples

A portion of each blood (0.1 μL) sample was analyzed with a blood glucose analyzer (ACCU-CHEK; Roche Diagnostics, Basel, Switzerland) to determine glucose concentration and with a lactate analyzer (Lactate Pro; ARKRAY, Inc, Kyoto, Japan) to determine blood lactate concentration. The remaining blood was allowed to clot, and serum was separated by centrifugation (10 minutes at 5000 *g*) and frozen at −80°C until the day of analysis. At a later date, the serum portion was analyzed for osmolality (1249; Advanced Instruments, Inc, Norwood, MA) and sodium, potassium, chloride (Nova 16; Nova Biomedical Corporation, Waltham, MA), and calcium concentrations (BioSpectrometer; Eppendorf AG, Hamburg, Germany). In addition, myoglobin, creatine kinase, and lactate dehydrogenase (LDH) concentrations were measured as blood markers of muscle damage by means of an autoanalyzer (AU5400; Beckman Coulter, Inc, Indianapolis, IN). The 5 different types of LDH isoenzymes were measured in each serum sample.

Statistical Analysis

The normality of each variable was initially tested with the Shapiro-Wilk test. For the variables obtained once during the experiment (total race time, body mass change, and rate of perceived exertion), the comparison between groups (compression stockings group versus control group) was performed using the Student *t* test for independent samples. For the variables obtained twice or more during the experiment (jump performance, blood variables, running pace), the comparison between groups was performed using a 2-way analysis of variance (time by treatment). Mean differences and 95% confidence intervals were also calculated for pairwise comparisons between the compression stockings group and the control group. The data were analyzed with the statistical package SPSS Version 19.0 (SPSS Inc, Chicago, IL). The significance level was set at $P<.05$. Data are presented as mean ± SD.

RESULTS

Race Time, Running Pace, and Perceived Fatigue and Muscle Pain

Total race time was very similar for the control group and for the compression stockings group (**TABLE 2**) ($P = .58$). Average running pace during the marathon was very similar between groups, and there were no differences at any point in the race (**FIGURE**). The change in body mass during the race was similar between groups (−2.2% ± 1.0% in the control group and −2.6% ± 1.2% in the compression stockings group; $P = .36$). Just after the race, there were no differences between groups in the ratings of perceived exertion ($P = .79$) and lower-limb soreness ($P = .94$). Twenty-four hours after the race, participants in the compression stockings group rated their lower-limb soreness with lower values than those of the control group ($P = .04$), although this between-group difference was not present 48 hours after the race (**TABLE 2**) ($P = .91$).

Blood and Serum Responses

Prerace and postrace values for the blood and serum variables are shown in **TABLE 3**. From similar prerace values between groups, blood oxygen saturation decreased and osmolality and serum sodium, chloride, and potassium concentrations increased after the race ($P<.05$ for all prerace-to-postrace comparisons), with no differences between the control group and compression stockings group in these variables or in the magnitudes of prerace-to-postrace change ($P>.05$). Serum calcium concentration remained stable after the race, without differences between groups. From prerace values (approximately 2.1 ± 0.5 mM), blood lactate concentration similarly increased to 3.1 ± 1.0 mM in the control group and to 3.4 ± 1.0 mM in the compression stockings group ($P = .38$). Furthermore, postrace glucose concentration was similar between groups (138 ± 28 mg·dL^{-1} and 148 ± 36.1 mg·dL^{-1}, respectively; $P = .34$).

Blood Markers of Muscle Damage

Prerace and postrace values for the blood markers of muscle damage are shown in **TABLE 4**. There were no differences between groups in prerace values for serum myoglobin, creatine kinase, and LDH concentrations. After the race, the concentrations of these variables significantly increased in both groups ($P<.05$), although there were no differences between the control and compression stockings groups in these variables or in the magnitudes of prerace-to-postrace change ($P>.05$). Serum myoglobin concentration was the blood marker of muscle damage that presented the highest increase after the race, with postcompetition values 15-fold the prerace values in both groups (**TABLE 4**). While LDH isoenzymes 1, 2, and 3 significantly decreased from prerace to postrace ($P<.05$), the serum concentration of LDH isoenzymes 4 and 5 increased after the race ($P<.05$).

Leg Volume and Countermovement Jump

Lower-leg volume was very similar between groups before the race (**TABLE 5**). After the race, lower-leg volume significantly decreased in both groups, but the magnitude of change did not present any difference between the participants in the control group and the compression stockings group. Before the race, mean jump height in the control group was comparable to the values in the compression stockings group (**TABLE 5**). After the race, mean jump height significantly decreased in both groups ($P<.05$), and the magnitude of the change was similar between the control and compression stockings groups. The mean power production during the jump also decreased after the race (**TABLE 5**), but postrace values and the magnitude of change during the race were unaffected by the use of compression stockings. From similar prerace values, the drop of the center of gravity during the landing phase tended to be less affected ($P = .08$) in the group of marathoners wearing compression stockings than in the control group (**TABLE 5**).

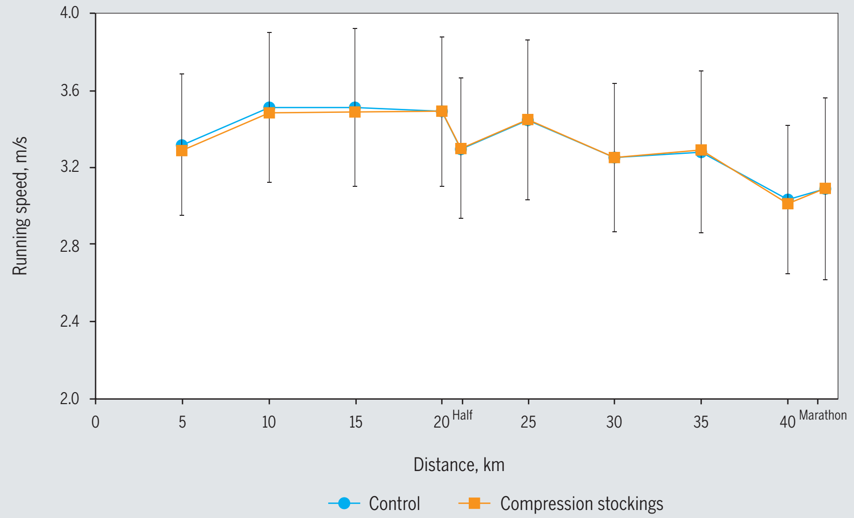

FIGURE. Running pace during a marathon for the compression stockings group (n = 17) and the control group (n = 17). Values are mean ± SD.

DISCUSSION

The purpose of this study was to investigate the effectiveness of using graduated compression stockings during a marathon competition to prevent muscle fiber damage and to subsequently maintain running and muscle performance. For this purpose, a group of experienced marathoners completed a real marathon competition wearing commercially available compression garments, and leg volume, blood samples, and jump variables were obtained before and just after the race. The outcomes of the participants in the compression stockings group were compared to a pair-matched control group of marathoners who completed the same race with conventional socks. The main results of this investigation were (*a*) total race time and running pace during the entire marathon competition were very similar between the control and the compression stockings groups (**FIGURE**); (*b*) postrace values of serum myoglobin, creatine kinase, and LDH, typical markers of exercise-induced muscle damage, were very similar between groups (**TABLE 4**); (*c*) the participants in the compression stockings group experienced the same lower-leg volume changes and muscle performance reductions as the control group (**TABLE 5**); and (*d*) the use of compression garments did not affect perceived fatigue and lower-leg soreness during the race but improved the feelings of muscle soreness 24 hours after the race. All this information

TABLE 3 Blood Osmolality and Serum Electrolyte Concentration for the Compression Stockings Group (n = 17) and the Control Group (n = 17)

Variable	Control*	Compression Stockings*	Mean Difference†	*P* Value
Blood oxygen saturation, %				
Prerace	96.7 ± 2.7	96.1 ± 2.9	0.6 (−1.3, 1.5)	.52
Postrace	88.0 ± 2.7‡	89.2 ± 2.9‡	−1.2 (−8.5, 6.2)	.75
Blood osmolality, mOsm·kg^{-1}				
Prerace	285.6 ± 4.8	286.7 ± 3.9	−1.1 (−4.2, 1.9)	.44
Postrace	294.1 ± 4.3‡	294.8 ± 5.3‡	−0.7 (−4.0, 2.6)	.67
Sodium concentration, mM				
Prerace	140.0 ± 2.1	140.4 ± 2.0	−0.4 (−1.8, 1.0)	.58
Postrace	143.5 ± 3.4‡	143.9 ± 3.4‡	−0.4 (−2.8, 1.9)	.64
Chloride concentration, mM				
Prerace	97.8 ± 2.5	97.9 ± 2.2	−0.1 (−1.7, 1.5)	.92
Postrace	99.2 ± 3.1‡	98.7 ± 2.4‡	0.5 (−1.5, 2.4)	.63
Potassium concentration, mM				
Prerace	3.9 ± 0.3	4.0 ± 0.4	−0.1 (−0.4, 0.1)	.37
Postrace	4.6 ± 0.5‡	4.7 ± 0.6‡	−0.1 (−0.5, 0.3)	.64
Calcium concentration, mM				
Prerace	9.8 ± 0.2	9.9 ± 0.3	−0.1 (−0.3, 0.1)	.16
Postrace	9.9 ± 0.5	10.0 ± 0.3	−0.1 (−0.4, 0.2)	.52

**Values are mean ± SD.*
†Values in parentheses are 95% confidence interval.
‡Different from prerace values (P<.05).

suggests that wearing graduated compression garments is an ineffective strategy to improve running pace and muscle performance during a real marathon competition.

The improvements in running performance obtained by using compression stockings have been the topic of several previous investigations.[2,3,7,15,20,23,24] The results of these previous investigations are inconclusive because most,[2,3,7,20,24] but not all,[15,23] failed to find any increment in running performance. Several of these investigations did find positive effects for wearing compression stockings during the recovery phase of a running event, such as reduced blood lactate concentration[20] and muscle soreness[2], although the importance of these benefits for a subsequent running trial has not been investigated yet. Overall, the utilization of different tests (running time until fatigue, maximal treadmill test, 10-km running trials, etc) with running distances always shorter than 15.6 km makes it difficult to apply these results to the population of marathoners and half-marathoners.

The current investigation presents some novelties with respect to previous research on this topic. To our knowledge, this is the first study to test the effectiveness of wearing compression garments during a real running competition, which increases the ecological validity and applicability of the results obtained. Second, the distance covered by the participants in this investigation (42.2 km, a full marathon) is a better scenario in which to assess the efficacy of compression stockings to prevent muscle damage, because it has been well documented that completing a marathon race produces moderate to high levels of muscle damage in experienced marathoners.[4,9,12] In fact, the increases in typical blood markers of muscle damage, especially the increment in LDH isoenzyme 5 (**TABLE 4**), which is naturally present only in human skeletal muscle,[21] indicate the occurrence of exercise-induced muscle damage during this event. Third, several other physiological variables, such as body mass change, electrolyte concentration, and glucose concentration, were measured to ensure that the findings of this investigation were exclusively related to the use of compression stockings.

Even in this more ecological and better-controlled setting, compression garments were ineffective to improve running performance or to prevent the progressive decrease in running pace experienced during the marathon (**FIGURE**).[9] The results agree with a recent investigation that also determined the inefficacy of compression stockings to improve cycling or running performance during a real half-IRONMAN competition.[8] Furthermore, in the current investigation, the participants wearing compression garments presented similar reductions in leg muscle function and analogous rises in myoglobin, creatine kinase, and LDH concentrations after the race to those of the control group, which indicates that these garments were ineffective to reduce muscle damage during the marathon.

Other than to avoid exercise-induced muscle damage, runners wear compression garments during endurance competitions to increase venous blood return and to reduce inflammation. Bovenschen et al[6] found that wearing graduated compression stockings during a 10-km running trial prevented an increase in lower-leg volume just after the exercise, but this effect disappeared only 5 minutes after the end of running. Consistent with this previous investigation, the present study found that the runners in the compression stockings group presented similar changes in lower-leg volume to runners in the control group (**TABLE 5**). Although we were unable to obtain variables related to venous hemodynamics during the marathon race, the absence of any effect of the compression garments on postrace blood lactate concentration and blood oxygen saturation indicates the lack of a significant effect of wearing compression stockings on venous blood return.

Despite the absence of meaningful physiological benefits of wearing compression stockings during the marathon race, participants who wore the compression garments reported a lower rate of muscle soreness 24 hours after the race when compared to the participants in the control group. A recent investigation reported that wearing compression tights for 72 hours following a marathon improved subjective perceptions of recovery without affecting inflammation, muscle strength, and markers of exercise-induced muscle damage.[14] Thus, it seems that wearing compression garments during and after a marathon race might improve the feelings of muscle recovery, despite minimally affecting the physiological and objective markers of muscle damage. In fact, it has been proved that using compression clothing after exercise assists in the recovery of muscle fatigue.[5]

The current investigation has some limitations related to the nature of the experimental design (a randomized controlled trial with 2 groups of participants). The great physiological challenges of completing a marathon race did not permit us to carry out a repeated-measures experiment with the same runners participating with and without compression garments. For this reason, the runners participating in this investigation were recruited from a larger group and were carefully matched for anthropometric characteristics, age, training status, and best race time in the marathon.

TABLE 4 Serum Concentrations of Blood Markers of Muscle Damage for the Compression Stockings Group (n = 17) and the Control Group (n = 17)

Variable	Control*	Compression Stockings*	Mean Difference†	*P* Value
Myoglobin concentration, ng·mL⁻¹				
Prerace	32.9 ± 14.9	35.4 ± 34.2	−2.5 (−17.0, 12.1)	.73
Postrace	568.4 ± 346.6‡	572.6 ± 270.1‡	−4.2 (−218.8, 210.4)	.97
Change, %	1625 ± 1478	1518 ± 1193		
Creatine kinase concentration, U·L⁻¹				
Prerace	164.1 ± 64.9	214.5 ± 131.0	−50.4 (−124.5, 23.7)	.18
Postrace	390.4 ± 166.1‡	487.0 ± 227.0‡	−96.6 (−232.8, 39.7)	.16
Change, %	138 ± 170	127 ± 86		
LDH, U·L⁻¹				
Prerace	301.9 ± 45.8	318.3 ± 53.4	−16.3 (−51.3, 18.6)	.35
Postrace	483.6 ± 82.7‡	524.1 ± 84.4‡	−40.6 (−98.0, 16.9)	.16
Change, %	60.2 ± 21.7	64.7 ± 18.6		
% change in LDH isoenzyme 1, U·L⁻¹	−28.2 ± 9.5	−27.9 ± 10.9	−0.3 (−7.5, 7.0)	.94
% change in LDH isoenzyme 2, U·L⁻¹	−24.6 ± 10.8	−25.7 ± 10.0	1.1 (−6.3, 8.5)	.77
% change in LDH isoenzyme 3, U·L⁻¹	−8.8 ± 10.9	−7.9 ± 8.3	−0.9 (−7.8, 5.9)	.79
% change in LDH isoenzyme 4, U·L⁻¹	32.0 ± 17.3	38.9 ± 31.3	−6.9 (−25.4, 11.5)	.45
% change in LDH isoenzyme 5, U·L⁻¹	175.8 ± 77.7	166.6 ± 85.3	9.1 (−48.9, 67.2)	.75

Abbreviation: LDH, lactate dehydrogenase.
**Values are mean ± SD.*
†Values in parentheses are 95% confidence interval.
‡Different from prerace values (P<.05).

However, the possibility remains that the between-group differences/variability affected the effectiveness of wearing compression garments during the marathon. On the other hand, this investigation included a sample of experienced runners, who had training adaptations from years of running. The use of compression garments should also be tested in inexperienced novice endurance runners. Another limitation of this study is the lack of physiological measurements during the recovery process of the marathon race. In the days following the race, blood samples and muscle performance measurements could not be obtained due to the location of the participants, and we were only able to obtain self-reported muscle pain data. Thus, the experimental design precluded assessment of the effectiveness of wearing compression stockings in the recovery of the muscle damage induced by a marathon race. However, previous investigations have determined that compression garments may reduce subjective perceptions of pain,[14] enhance the recovery of muscle strength and power,[5] and lessen the concentrations of creatine kinase after exercise-induced muscle damage.[13]

The participants in this investigation had been in previous research carried out during the 2012 edition of the same marathon race.[4] In that previous investigation, all the participants competed in the marathon with conventional socks. **TABLE 6** depicts the within-subject comparison of the race times obtained in 2012 (all with conventional socks) and 2013 (one group with conventional socks

TABLE 5 Prerace and Postrace Jump Variables for the Compression Stockings Group (n = 17) and the Control Group (n = 17)

Variable	Control*	Compression Stockings*	Mean Difference†	*P* Value
Lower-leg volume, L				
Prerace	3.59 ± 0.44	3.65 ± 0.58	−0.06 (−0.41, 0.29)	.72
Postrace	3.37 ± 0.43‡	3.42 ± 0.56‡	−0.05 (−0.39, 0.29)	.76
Change, %	−6.23 ± 5.53	−6.39 ± 3.00		
Jump height, cm				
Prerace	26.8 ± 5.4	29.4 ± 4.3	−2.6 (−5.9, 0.7)	.11
Postrace	20.0 ± 5.4‡	19.9 ± 7.7‡	0.1 (−4.4, 4.7)	.95
Change, %	−25.3 ± 14.1	−32.5 ± 20.4		
Mean leg muscle power, $W \cdot kg^{-1}$				
Prerace	22.4 ± 4.1	24.4 ± 2.7	−2.0 (−4.4, 0.4)	.09
Postrace	18.0 ± 4.7‡	18.4 ± 5.2‡	−0.4 (−3.8, 3.0)	.82
Change, %	−19.8 ± 17.7	−24.8 ± 18.4		
Drop of center of gravity, $cm \cdot m^{-1}$				
Prerace	−6.7 ± 3.3	−7.8 ± 5.2	1.1 (−2.1, 4.3)	.49
Postrace	−3.5 ± 2.3‡	−5.6 ± 3.1‡	2.1 (−0.3, 4.4)	.08
Change, %	34.6 ± 45.4	25.0 ± 39.6		

*Values are mean ± SD.
†Values in parentheses are 95% confidence interval.
‡Different from prerace values (P<.05).*

TABLE 6 Marathon Race Times of the Participants

Race Edition	Control*	Compression Stockings*	Mean Difference†	*P* Value
2012, min‡	212 ± 23	217 ± 26	−5 (−23, 12)	.51
2013, min	210 ± 23	214 ± 22	−4 (−20, 11)	.58
2012-to-2013 change, %	−0.9 ± 4.3	−1.3± 4.0		

*Values are mean ± SD.
†Values in parentheses are 95% confidence interval.
‡In the 2012 edition, all participants wore conventional socks. In the 2013 edition, participants in the compression stockings group wore foot-to-knee graduated compression stockings and the control group wore conventional socks.*

and the other group with compression stockings). Interestingly, the 2 groups (control and compression stockings) reduced their marathon race time in 2013 by approximately 1%, probably due to the lower ambient temperature the day of the race (8°C in 2013 versus 27°C in 2012). However, the magnitude of the 2012-to-2013 change in race time was very similar in the runners with compression stockings and in the runners in the control group. This may indicate that compression garments would be ineffective to increase running performance even with a repeated-measures design, as previously suggested.[2,3,7,20,24]

CONCLUSION

The group of runners who wore compression stockings during a marathon race did not improve marathon race time and presented with reductions in muscle function similar to those of a group of runners who wore conventional socks. Furthermore, the use of compression garments did not modify perceived exertion or the postrace concentrations of blood markers of muscle damage. ◉

KEY POINTS

FINDINGS: The group of runners who wore graduated compression stockings during a marathon race presented the same reductions in running and leg muscle performance as those of the group of runners who wore conventional socks. Furthermore, postrace serum concentrations of muscle damage markers were also similar between these 2 groups.

IMPLICATIONS: The continuous muscle work necessary to complete a marathon leads to muscle fiber damage and local inflammation. Compression garments apply mechanical pressure to the body and compress underlying tissues. However, wearing compression stockings during long-distance running events is an ineffective strategy to avoid the deleterious effects of muscle damage on running performance.

CAUTION: This investigation was performed using 2 groups of marathoners with comparable training and physical characteristics. The possibility remains that the between-group differences/variability affected the effectiveness of wearing compression garments during the marathon. The outcomes of this investigation should be confirmed with a repeated-measures experimental design.

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