The Influence of Compression Socks During a Marathon on Exercise-Associated Muscle Damage

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Abstract:

Context*:* Compression socks have become increasingly popular with athletes due to perceived enhancement of exercise performance and recovery. However, research examining the efficacy of compression socks to reduce exercise-associated muscle damage has been equivocal, with few direct measurements of markers of muscle damage. ***Objective****:* To examine the influence of compression socks worn during a marathon on creatine kinase (CK) levels. ***Design****:* A randomized controlled trial. ***Setting****:* 2013 Hartford Marathon, Hartford, CT. ***Participants****:* Adults (n = 20) randomized to control (CONTROL; n = 10) or compression sock (SOCK; n = 10) groups. ***Main Outcome Measures****:* Blood samples were collected 24 hours before, immediately after, and 24 hours following the marathon for the analysis of CK, a marker of muscle damage. ***Results****:* Baseline CK levels did not differ between CONTROL (89.3 [41.2] U/L) and SOCK (100.0 [56.2] U/L) ($P = .63$). Immediately following the marathon (≤1 h), CK increased 273% from baseline ($P < .001$ for time), with no difference in exercise-induced changes in CK from baseline between CONTROL (+293.9 [278.2] U/L) and SOCK (+233.1 [225.3] U/L; $P = .60$ for time × group). The day following the marathon (≤24 h), CK further increased 1094% from baseline ($P < .001$ for time), with no difference in changes in CK from baseline between CONTROL (+ 1191.9 [1194.8] U/L) and SOCK (+889.1 [760.2] U/L; $P = .53$ for time × group). These similar trends persisted despite controlling for potential covariates such as age, body mass index, and race finishing time (Ps > .29). ***Conclusions****:* Compression socks worn during a marathon do not appear to mitigate objectively measured markers of muscle damage immediately following and 24 hours after a marathon.

Keywords: endurance exercise | mechanical prophylaxis | creatine kinase | marathon-induced

Article:

The benefits of regular sustained aerobic exercise are indisputable; however, extreme endurance events, such as a marathon foot race (42.2 km), can be associated with marked muscle damage, inflammation, and injury.[1–3] Compression socks have become increasingly popular to wear during and/or after marathons due to an athlete's perceived enhancement of performance and/or recovery. Such purported improvements are largely fueled by a manufacturer's claims that

compression socks reduce microtrauma, enhance venous return, reduce swelling space, and/or accelerate clearance of exercise metabolites.[4,5]

However, studies examining the efficacy of compression socks to reduce muscle damage during exercise and/or in the recovery period have been equivocal.[6–10] This is in part due to the difficulty of conducting placebo-controlled trials and the use of *subjective*, qualitative reporting as primary outcome measures.[7] Further complicating this, studies measuring *objective* physiological markers of muscle damage have been vastly heterogenous in terms of (1) the type of compression garment used (eg, whole body, sleeves, knee high socks) and/or (2) the modality of exercise being tested.[7] Only one randomized controlled trial exists that has sought to examine the influence of compression socks worn during a marathon on muscle damage.[11] This is surprising given that marathon participation has increased 40% over the past decade.[12] Given the increasing use of compression socks for athletes participating in long course endurance events such as a marathon,[13] establishing their efficacy for use is an important and valuable investigation.

Consequently, this investigation sought to examine the influence of wearing compression socks during a marathon run on creatine kinase (CK; a marker of muscle damage) levels, before, immediately after, and the day following a marathon, among recreational athletes running the 2013 Hartford Marathon (Hartford, CT). We hypothesized that CK levels would increase immediately and 24 hours after competing in the Hartford Marathon, and the increase in marathon-induced CK levels would be lower in athletes who ran the marathon with compression socks compared with controls.

Procedures

Participants

Runners (10 men and 10 women) were recruited through an e-mail sent to all participants registered for the 2013 Hartford Marathon. Subjects were nonsmokers between 20 and 51 years of age; free of known cardiovascular, metabolic, and/or coagulatory disease; free of known acute or chronic injuries; and had not previously used compression socks. Female subjects were premenopausal and did not take any form of hormone-based contraceptives. In addition, subjects agreed to refrain from taking medications or supplements 24 hours before, during, or after the marathon, such as aspirin or nonsteroidal anti-inflammatory drugs. All subjects provided written, informed consent to participate as approved by the Hartford Hospital Institutional Review Board (Protocol #ZALE004311HU) in agreement with the guidelines set forth by the Declaration of Helsinki.

Study Design

Subjects reported to the marathon exposition the day before the marathon (October 11, 2013) for assessment of pre-exercise (PRE) measures. Following assessment of height and weight and the calculation of body mass index, resting blood pressure and heart rate (Welch Allyn, Inc, 52000 Vital Signs Monitor; Skaneateles Falls, NY) were measured. Subjects provided a detailed medical and exercise history, which included training volume leading up to the marathon.

Venous blood was obtained to measure CK and hematocrit (Hct). Blood was also obtained immediately after completion of the marathon (FINISH) in the main medical tent approximately 100 m from the finish line and within 24 hours of the race finish (POST) at Hartford Hospital.

Using www.randomization.com, subjects were randomly assigned to one of 20 parallel groups (1:1 replication seed #2278) by the study coordinator (ALZ) to the compression sock (SOCK; 5 men and 5 women) or the control (CONTROL; 5 men and 5 women) group upon initial screening. A product donation from 2XU (2XU North America LLC, Carlsbad, CA) ensured that all subjects in SOCK wore foot-to-knee, graded compression socks with the same pressure grade (Compression Performance Run Sock; 19–25 mm Hg at the ankle; 2XU LLC). Subjects in SOCK were sized according to self-reported calf circumference and shoe size and received their socks at the marathon exposition the day before the marathon. Subjects in SOCK were instructed to wear their socks to the race start and throughout the duration of the marathon and FINISH blood draw, but refrain from wearing compression socks between FINISH and POST blood draw. Subjects in CONTROL were instructed to wear their typical socks, but refrain from compression sock usage during training, the marathon, or the day after the marathon.

Assessment of Physical Activity

All subjects completed a physical activity recall for the 24-hour periods before and after the marathon using question #8 from the Paffenbarger Physical Activity Questionnaire[14] to compare physical activity levels between groups so that any potential differences in the CK response to exercise could be attributable to the influence of the intervention (ie, compression socks) and not differences in physical activity. Subjects categorized their physical activity by hours spent in sedentary behaviors; light-, moderate-, and vigorous-intensity physical activity; and sleep.

Blood Sample Collection

Following a period of 5-minute seated rest, whole blood (25 mL) was collected from an antecubital vein without stasis by single venipuncture, centrifuged (2000×*g*, 10 min), and aliquoted into cryogenic vials to be archived within 4 hours at −80°C for future analysis.

Blood Sample Analyses

Whole blood was delivered to Clinical Laboratory Partners at Hartford Hospital (Hartford, CT) at the end of each study day for analysis of Hct to be used for the estimation of plasma volume changes over the course of the marathon. CK activity was measured in duplicate via kinetic assay (Sekisui Diagnostics, Charlottetown, Canada) with absorbance measured spectrophotometrically (Versa Max Microplate Reader; Molecular Devices, Sunnyvale, CA) at a wavelength of 340 nm every 30 seconds. The intra-assay coefficient of variation was 4.1%. CK was corrected for the estimated exercise-induced changes in plasma volume, according to the formula of van Beaumont.[15]

Statistical Analyses

The sample size was determined using data from our previous findings in Boston Marathon participants,[16] which showed a ~300% increase in CK immediately following the marathon in CONTROL. Our calculations indicated that 10 subjects in each group would reject the null hypothesis with 87% power ($P \leq .05$). Data (presented as mean [SD]) were analyzed by SPSS (version 24.0; IBM Inc, Chicago, IL). Differences in baseline characteristics between groups were assessed with a one-way analysis of variance.

Creatine kinase was logarithmically transformed before analysis to normalize distribution. To determine the effects of compression socks on changes in CK, we used a linear mixed model for 1-wayrepeated measures analysis of variance (RMANOVA), incorporating time as the within-subjects factor and group (CONTROL vs SOCK) as the between-subjects factor. Potential categorical factors (eg, sex) that could affect the relationship among the main effects and outcomes were investigated within the model. Continuous variables (eg, age, training mileage, and finishing time) were investigated using analysis of covariance.

Characteristics such as age, sex, body mass index, distance run the week before the race, and finishing time were not significant factors in the repeated measures model for CK. Training mileage was entered and evaluated in the final RMANOVA as a covariate. The RMANOVA model was also used to assess group differences in physical activity before and after the marathon. An alpha level of $P \leq .05$ was considered statistically significant.

Table 1. Mean Physical and Performance Characteristics (SD) of the SOCK (n = 10) Versus CONTROL (n = 10) Subjects

Variable	CONTROL (n = 10)	SOCK (n = 10)
Age, y	35.5 (8.0)	36.9 (8.4)
Body weight, lb	152.0 (27.3)	159.4 (34.0)
Body mass index, kg/m^2	23.0 (2.1)	23.9 (4.3)
SBP, mm Hg	134.3 (21.3)	139.2 (17.8)
DBP, mm Hg	73.3 (11.6)	79.7 (10.6)
HR, bpm	63.5 (14.9)	67.0 (10.4)
Training mileage, miles/wk	26.3 (0.2)	38.6 (12.2)*
Official finishing time, h:min:s	4:20:42 (0:38:33)	4:02:33 (0:38:29)

Abbreviations: DBP, diastolic blood pressure; HR, heart rate; SBP, systolic blood pressure. Note: Training mileage = average miles run per week during training for the Hartford Marathon.
*$P < .05$; CONTROL versus SOCK.

Results

Subject Characteristics

Baseline characteristics were similar between groups (Table 1), with the exception that athletes in SOCK trained on average ~12 miles more per week than CONTROL ($P < .05$). It is important to note that 2 outliers (CONTROL, n = 1; SOCK, n = 1) deviated >2 SD of the mean and removal of these 2 outliers results in no statistical difference in weekly running volume between those wearing compression socks (34.8 [9.5] miles) versus control (28.6 [7.4] miles; $P = .16$). However, a data management decision was made to report on these data given the small sample

size. There were no differences in groups in terms of reported “marathon running years” among those wearing compression socks (3.7 [2.5] y) versus control (4.2 [6.1]; $P = .60$).

Race Day Characteristics

Race day weather was optimal with an average temperature of 54°F (high 62°F, low 46°F), no precipitation, low humidity, and partly cloudy.

Physical Activity

There were no group differences in hours spent in vigorous-, moderate-, and light-intensity physical activity, as well as sitting or sleeping time (Ps > .05) at PRE or POST; however, both groups spent less time in light-intensity exercise ($P < .02$) and more time sleeping at POST relative to PRE ($P < .03$). There were no correlations between marathon-induced increases in CK and hours spent in vigorous-, moderate-, or light-intensity physical activity, sitting, or sleeping time at POST (Ps > .23).

Marker of Muscle Damage

Baseline CK levels did not differ between CONTROL (89.3 [41.2] U/L) and SOCK (100.0 [56.2] U/L) ($P = .63$), and were within normal reference ranges for males and females (Figure 1). Immediately following the marathon (≤1 h; FINISH), CK increased 273% from baseline ($P < .001$ for time), with no difference in exercise-induced changes in CK from baseline between CONTROL (Δ = +293.9 [278.2] U/L) and SOCK (Δ = +233.1 [225.3] U/L; $P = .60$ for time × group). The day following the marathon (≤24 h; POST), CK further increased 1094% from baseline ($P < .001$ for time), with no difference in changes in CK from baseline between CONTROL (Δ = +1191.9 [1194.8] U/L) and SOCK (Δ = +889.1 [760.2] U/L; $P = .53$ for time × group). These similar trends between CONTROL and SOCK persisted despite controlling for potential covariates such as age, sex, body mass index, and race finishing time (Ps > .29).

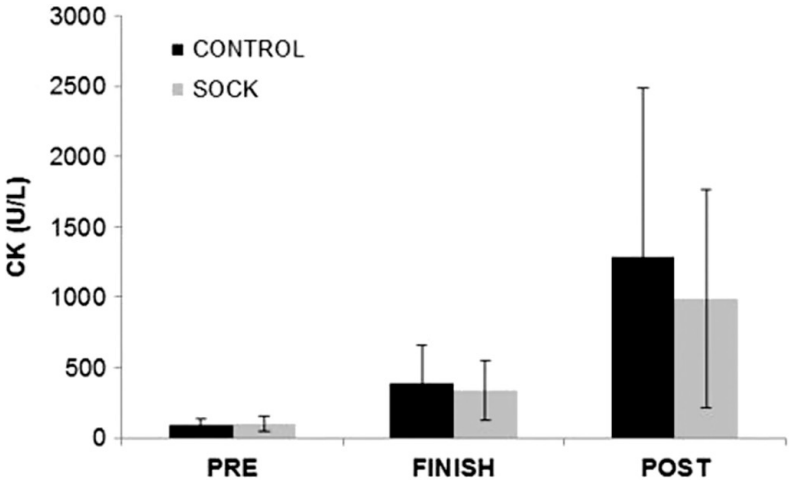

Figure 1. Group mean (SD) of creatine kinase activity (CK) before (PRE), immediately after (FINISH), and the day after the marathon (POST). CK data were log transformed for analysis.

Five of the marathoners (CONTROL, n = 2; SOCK, n = 3) had CK levels that met the clinical definition of a marked CK elevation (CK > 10 times the upper limit of normal) 24 hours after the marathon (ie, FINISH); however, chi-square analysis indicated no significant difference between groups ($\chi^2 = 0.267$; $P = .50$).

Plasma Volume Changes

Hematocrit decreased from FINISH to POST (CONTROL: 43.1% [4.1%] vs 41.0% [3.0%] and SOCK: 41.7% [2.5%] vs 40.7% [2.8%]; *P*s < .01), suggestive of an increase in plasma volume from immediate postexercise to the following day. There were no group differences in changes in Hct ($P = .57$), and adjustment CK for Hct to account for changes in plasma volume[15] did not change the nature of the results.

Discussion

This study sought to examine the influence of compression socks worn during a marathon foot race on exercise-induced muscle damage in endurance athletes. Compression socks worn during a marathon did not appear to mitigate a well-established marker of muscle damage (ie, CK) at any individual time point (ie, FINISH, POST) compared with the control condition.

To the best of our knowledge, one randomized controlled trial exists that sought to examine the influence of compression socks on exercise-induced muscle damage among marathon runners. Areces et al[11] examined serum CK concentrations before and immediately after a marathon among 34 experienced runners randomly assigned to wear foot-to-knee graduated compression socks (n = 17) or conventional socks (n = 17) during a marathon. Similar to the present study, the authors found no differences in marathon-induced increases in CK from baseline between SOCK (215.5 [131.0] U/L to 487.0 [227.0] U/L) and CONTROL (164.1 [64.9] U/L to 390.4 [166.1] U/L; $P = .16$). The present study confirms the findings of Areces et al[11] that compression socks worn during a marathon do not appear to attenuate the expected rise in CK immediately following a marathon. The present study further adds to the literature by being the first to report on CK changes 24 hours *following* a marathon; a critical time point to assess muscle damage. Exercise-induced increases in CK follow a biphasic response, reaching peak concentrations ∼24 hours and ∼4 days following an acute bout of exercise.[17–20] Indeed, the day following the marathon (≤24 h; POST), CK concentrations further increased 1094% from baseline ($P < .001$), but with no difference in CK elevations from baseline between CONTROL and SOCK ($P = .53$).

Hypothetical mechanisms underlying performance and recovery benefits of compression socks differ depending on their timing of use (ie, during or after exercise), but are similar in that their mechanisms of action target components of Virchow's triad.[21]Compression socks during *exercise* are thought to reduce microtrauma and enhance venous return by applying an external, circumferential pressure gradient that reduces swelling space, improves blood flow, and in turn improves performance.[4,5]Compression socks worn during *recovery* are thought to accelerate metabolic waste clearance, attenuate edema and swelling, and improve oxygen delivery to the muscle.[22,23] A recent meta-analysis incorporating 12 studies indicates a favorable effect of compression socks to enhance recovery from muscle damage based on CK and reduced severity of delayed onset muscle soreness.[7] However, of the studies included in the meta-analysis, not

one sought to examine the influence of compression socks in response to a sustained, aerobic event (ie, marathon), making the interpretation of the findings difficult to apply to endurance athletes. A separate systematic review concluded that the available literature does not fully support or refute the use of compression socks for performance or recovery.[24] Of the trials included, 3 studies found no difference in running performance while wearing compression socks,[8,10,11] while one demonstrated improvements in running speed and performance.[25] To the best of our knowledge, only one randomized controlled trial exists that examined recovery in *marathon runners* and found that compression socks worn for 48 hours after a marathon improved functional recovery (ie, time to exhaustion on a treadmill 2 wk after a marathon) by 5.9%.[26] However, it is difficult to compare these data to the present study as we did not originally seek to examine the influence of compression socks on recovery, *per se*. Rather, we sought to isolate the influence of compression socks worn during competition only; a critical time point of exposure to perturbations in which the actual muscle damage occurs and originates from (ie, the marathon). The use of compression socks after the marathon would add a confounding factor and limit the applicability of our findings.

Limitations

We caution that our interpretations are based on a small investigation and larger studies are required to confirm these findings. Furthermore, we did not perform a comprehensive analysis of markers of muscle damage and inflammation due to financial restraints. There are myriad other factors that may have been influenced by the use of compression socks that are unrelated to the CK response to exercise such as lymph flow, muscle oscillation, microtrauma, inflammation, and blood clotting factors.[7,27] Compression pressure exerted by the garments on the skin was not directly measured. Rather, subjects in the SOCK wore graded compression socks (19–25 mm Hg) based on self-reported calf circumference. This method of sizing most closely recapitulates how athletes will use these garments and enhances the translational value of our findings to recreational marathon runners in general. We did not measure subjective ratings of perceived pain. Compression socks cannot truly be placebo controlled; therefore, it is always possible that compression socks may result in psychological advantages that translate into performance gains as compression socks are anecdotally well tolerated. Finally, the generalizability of our results may be limited to recreational, but not elite or competitive runners. It is well documented that running intensity is positively correlated to the magnitude of CK elevations following endurance exercise. Indeed, previous data from our laboratory have demonstrated a greater CK response following a marathon in runners with a finishing time of <4 hours than runners who finish ≥4 hours.[16] Compression socks may prove to be more efficacious in other runner cohorts known to have a greater CK response to a marathon such as athletes with a finishing time <4 hours, men, statin users, or any level runner competing in a race with more eccentric muscle demands (ie, a net downhill race such as the Boston Marathon).[16]

Practical Applications

Compression socks are regularly touted as an inexpensive countermeasure to mitigate exercise-associated muscle damage. The present study does not support a role for compression socks worn during a marathon to buffer the expected rise of CK during or after a marathon event in recreational runners. However, it is possible that compression socks may positively

influence *other* markers or parameters associated with exhaustive exercise that have yet to be measured or known. Should recreational marathoners choose to wear compression during a marathon, our results are reassuring in that they do not show a *negative* impact of compression socks on muscle damage following prolonged, strenuous endurance exercise. This is important given previous reports in the literature of compression garments causing undue constriction and pain.[9] To avoid these potential adverse consequences, socks should be sized according to calf circumference (vs shoe size) to avoid excessive pressure at the calf, which may be further exacerbated by compartment swelling during a marathon.[28] By following these specifications, athletes may be reassured that compression socks likely do not cause or exacerbate injury, which is critically important given the time and effort associated with training, performance, and recovery.

Conclusions

Compression socks are commonly marketed to recreational runners as an effective countermeasure to mitigate exercise-associated muscle damage. However, the present study does not support a role for compression socks worn during a marathon to buffer the expected rise of CK immediately following or 24 hours after a marathon event. Nevertheless, the present study did not reveal any adverse consequences of compression socks on muscle damage. It remains possible that compression socks may beneficially alter other physiological parameters not assessed in the present study and/or provide psychological advantages that translate into improvements in marathon performance in some, but not all individuals.

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References

1. Da Ponte A, Giovanelli N, Antonutto G, et al. Changes in cardiac and muscle biomarkers following an uphill-only marathon. Res Sports Med. 2018;26(1):100–111. PubMed ID: 29058466 doi:10.1080/15438627.2017.1393750

2. Del Coso J, Salinero JJ, Lara B, Abian-Vicen J, Gallo-Salazar C, Areces F. A comparison of the physiological demands imposed by competing in a half-marathon vs. a marathon. J Sports Med Phys Fitness. 2017;57(11):1399–1406. PubMed ID: 28222581 doi:10.23736/S0022-4707.17.07056-6

3. Schwarz V, Dusing P, Liman T, et al. Marathon running increases circulating endothelial- and thrombocyte-derived microparticles. Eur J Prev Cardiol. 2018;25:317–324. PubMed ID: 29183152 doi:10.1177/2047487317744364

4. MacRae BA, Cotter JD, Laing RM. Compression garments and exercise: garment considerations, physiology and performance. Sports Med. 2011;41(10):815–843. PubMed ID: 21923201 doi:10.2165/11591420-000000000-00000

5. Mosti G, Partsch H. Improvement of venous pumping function by double progressive compression stockings: higher pressure over the calf is more important than a graduated pressure profile. Eur J Vasc Endovasc Surg. 2014;47(5):545–549. PubMed ID: 24524814 doi:10.1016/j.ejvs.2014.01.006

6. Born DP, Sperlich B, Holmberg HC. Bringing light into the dark: effects of compression clothing on performance and recovery. Int J Sports Physiol Perform. 2013;8(1):4–18. PubMed ID: 23302134 doi:10.1123/ijspp.8.1.4

7. Hill J, Howatson G, van Someren K, Leeder J, Pedlar C. Compression garments and recovery from exercise-induced muscle damage: a meta-analysis. Br J Sports Med. 2014;48(18):1340–1346. PubMed ID: 23757486 doi:10.1136/bjsports-2013-092456

8. Ali A, Caine MP, Snow BG. Graduated compression stockings: physiological and perceptual responses during and after exercise. J Sports Sci. 2007;25(4):413–419. PubMed ID: 17365528 doi:10.1080/02640410600718376

9. Ali A, Creasy RH, Edge JA. Physiological effects of wearing graduated compression stockings during running. Eur J Appl Physiol. 2010;109(6):1017–1025. PubMed ID: 20354717 doi:10.1007/s00421-010-1447-1

10. Ali A, Creasy RH, Edge JA. The effect of graduated compression stockings on running performance. J Strength Cond Res. 2011;25(5):1385–1392. PubMed ID: 21293307 doi:10.1519/JSC.0b013e3181d6848e

11. Areces F, Salinero JJ, Abian-Vicen J, et al. The use of compression stockings during a marathon competition to reduce exercise-induced muscle damage: are they really useful? J Orthop Sports Phys Ther. 2015;45(6):462–470. PubMed ID: 25899215 doi:10.2519/jospt.2015.5863

12. Running USA. 2016 state of the sport: U.S. road race trends. 2016. www.runningusa.org

13. Fleet Feet Sports Chicago. Nine running trends to watch in 2016 according to Google. 2016.http://www.fleetfeetchicago.com/news/9-trends-in-2016. Accessed February 1, 2018.

14. Paffenbarger RS Jr, Wing AL, Hyde RT. Physical activity as an index of heart attack risk in college alumni. 1978. Am J Epidemiol. 1995;142(9):889–903. PubMed ID: 7572969 doi:10.1093/oxfordjournals.aje.a117736

15. van Beaumont W, Underkofler S, van Beaumont S. Erythrocyte volume, plasma volume, and acid-base changes in exercise and heat dehydration. J Appl Physiol Respir Environ Exerc Physiol. 1981;50(6):1255–1262. PubMed ID: 7263386 doi:10.1152/jappl.1981.50.6.1255

16. Parker BA, Augeri AL, Capizzi JA, et al. Effect of statins on creatine kinase levels before and after a marathon run. Am J Cardiol. 2012;109(2):282–287. PubMed ID: 22036108 doi:10.1016/j.amjcard.2011.08.045

17. Parker B, Augeri A, Capizzi J, et al. Effect of air travel on exercise-induced coagulatory and fibrinolytic activation in marathon runners. Clin J Sport Med. 2011;21(2):126–130. PubMed ID: 21358503 doi:10.1097/JSM.0b013e31820edfa6

18. Parker BA, Augeri AL, Capizzi JA, et al. Effect of marathon run and air travel on pre- and post-run soluble d-dimer, microparticle procoagulant activity, and p-selectin levels. Am J Cardiol. 2012;109(10):1521–1525. PubMed ID: 22342849 doi:10.1016/j.amjcard.2012.01.369

19. Magal M, Dumke CL, Urbiztondo ZG, et al. Relationship between serum creatine kinase activity following exercise-induced muscle damage and muscle fibre composition. J Sports Sci. 2010;28(3):257–266. PubMed ID: 20077274 doi:10.1080/02640410903440892

20. Baird MF, Graham SM, Baker JS, Bickerstaff GF. Creatine-kinase- and exercise-related muscle damage implications for muscle performance and recovery. J Nutr Metab. 2012;2012:960363. PubMed ID: 22288008 doi:10.1155/2012/960363

21. Zaleski AL, Taylor BA, Pescatello LS, Thompson PD. Marathon maladies: venous thromboembolism risk associated with marathon running. J Clin Exerc Physiol. 2016;5:1–5. doi:10.31189/2165-6193-5.1.1

22. Hirai M, Iwata H, Hayakawa N. Effect of elastic compression stockings in patients with varicose veins and healthy controls measured by strain gauge plethysmography. Skin Res Technol. 2002;8(4):236–239. PubMed ID: 12423542 doi:10.1034/j.1600-0846.2001.80401.x

23. Bringard A, Denis R, Belluye N, Perrey S. Effects of compression tights on calf muscle oxygenation and venous pooling during quiet resting in supine and standing positions. J Sports Med Phys Fitness. 2006;46(4):548–554. PubMed ID: 17119519

24. Stanek JM. The effectiveness of compression socks for athletic performance and recovery. J Sport Rehabil. 2017;26(1):109–114. PubMed ID: 27632821 doi:10.1123/jsr.2015-0048

25. Kemmler W, von Stengel S, Kockritz C, Mayhew J, Wassermann A, Zapf J. Effect of compression stockings on running performance in men runners. J Strength Cond Res. 2009;23(1):101–105. PubMed ID: 19057400 doi:10.1519/JSC.0b013e31818eaef3

26. Armstrong SA, Till ES, Maloney SR, Harris GA. Compression socks and functional recovery following marathon running: a randomized controlled trial. J Strength Cond Res. 2015;29(2):528–533. PubMed ID: 25627452 doi:10.1519/JSC.0000000000000649

27. Zaleski AL, Ballard KD, Pescatello LS, et al. The effect of compression socks worn during a marathon on hemostatic balance. Phys Sportsmed. 2015;43(4):336–341. PubMed ID: 26212719 doi:10.1080/00913847.2015.1072456

28. Watkins WB. Compression garment sizing: challenges, issues, and a solution. Plast Surg Nurs. 2010;30(2):85–87. PubMed ID: 20543640 doi:10.1097/PSN.0b013e3181dee9e2