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Effects of Intermittent Pneumatic Compression on Delayed Onset Muscle Soreness (DOMS) in Long Distance Runners

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ABSTRACT

International Journal of Exercise Science 13(2): 75-86, 2020. The purpose of this study was to observe the effectiveness of intermittent pneumatic compression (IPC) on reducing C-reactive protein (CRP) and DOMS after long distance running. Ten distance runners, five males and five females, ages 20-53 years performed two 20-mile runs at 70% VO₂ max. Each run was followed by either no treatment (control) or IPC treatment for five consecutive days. For the IPC run, participants were treated for one hour immediately following the run and daily for five more days thereafter. On control runs, participants did not receive any treatment. Serum CRP was measured pre- and post-run, and daily thereafter for five days for both trials. Results indicated no significant difference ($p > 0.05$) between control and treatment runs in CRP levels. Subjective pain ratings indicated no significant difference in pain between control and treatment runs. In conclusion, there appear to be no substantial benefits of IPC in promoting recovery.

KEY WORDS: Inflammation, endurance trained individuals, 20-mile run, 70% VO₂ max, muscle recovery, C-reactive protein

INTRODUCTION

Delayed onset of muscle soreness (DOMS) results from performing an exercise that places a great deal of strain on the skeletal muscles, especially eccentric exercise (5). Armstrong (2) proposed that DOMS is associated with damage to the sarcolemma, and ensuing inflammation. Inflammation denotes the onset of the healing process and may be indicated by a rise in C-reactive protein (CRP). This process can last from several days to several weeks, which can limit progression of training programs. Consequently, there is a great deal of interest in determining techniques that may expedite the recovery process.

The proposed mechanism by which intermittent pneumatic compression (IPC) works is synonymous with massage. The IPC recovery system (NormaTec, Newton Center, MA) is

claimed to act as an air pressured massage with the intent of increasing circulation allowing for a brief alleviation of aches and pains, which could possibly benefit active individuals both physically and psychologically (32). The system consists of a boot that is divided into five sections, each with inflatable bladders or cells. Cell one is located on the foot and each cell continues up the leg to the top of the thigh where cell five is located. Each bladder or cell inflates or compresses the limb for 30 seconds. According to the manufacturer, the sequential pulse compression technology of IPC combines three distinctive massage techniques to speed the body's natural recovery process (32). The first technique is pulsing, which employs dynamic compression to more effectively mimic the muscle pump of the legs and arms. This dynamic compression is claimed to enhance the movement of fluid and metabolites out of the muscles after intense workouts. The second technique is gradients which use gradient hold pressures to prevent body fluids from being forced down to the feet by the pulsing actions described previously. The gradient hold allows maximum pressure to be delivered throughout the entire limb and the effectiveness of the pulsing action is not curtailed at the top of the limb. The third technique is distal release. The sequential pulse technology releases the held pressures placed on the limb once they are not needed to prevent backflow of blood. In releasing the held pressure in each zone as quickly as possible, each portion of the limb reportedly gains maximal recovery time without a significant pause between compression cycles (32). A diagram of the sequential pulse compression technology can be seen in Figure 1.

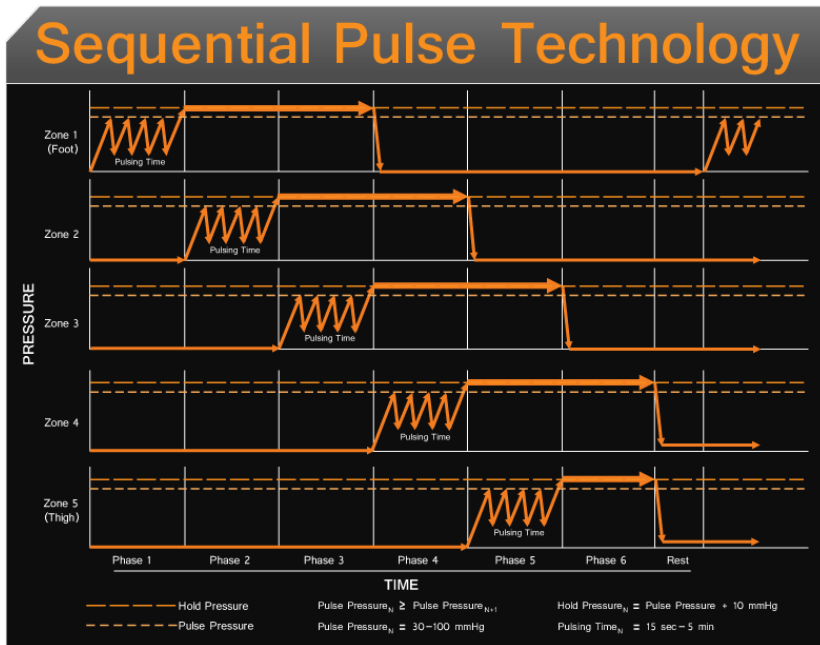


Figure 1. Functional schematic of IPC Recovery device. The different zones shown are found on the IPC device and represent what is occurring in each zone during each phase over time.

Considering that it has been proposed that IPC works similarly to massage, it is unknown if IPC therapy produces the same potential benefits as massage. Massage has been reported to reduce symptoms caused by DOMS, including inflammatory markers, muscular breakdown, and pain (10, 14-16, 21, 27, 38, 43, 45, 49). Reduction in pain due to the increased release of dopamine and serotonin and the decrease in cortisol as a result of massage therapy has been suggested in

current literature (11, 37, 52). There is debate however, regarding the direct influence massage may have on cortisol levels (31). In contrast, other studies have shown massage to be ineffective in reducing DOMS or perceived pain (1, 4, 7, 13, 17, 23, 30, 46, 48, 51, 52). The disparity in the literature seems to be mainly due to variance in the study designs and methods such as exercise type, volume of exercise, muscle groups used, as well as years of experience and type of massage practiced by the massage therapist.

IPC technology was first used in the field of sports medicine in 2007 as a recovery tool for athletes. However, more research is needed in order to determine if an IPC recovery unit is effective in the reduction of muscle inflammation (25, 26, 36, 50) after long distance running. If the IPC recovery unit can speed recovery as well as reduce the effects of DOMS on athletes (6, 19, 20, 28, 29, 34, 35, 41), this may enhance their training by helping them recover more quickly, thereby allowing them to train at a higher intensity or longer duration more frequently. Additionally, previous investigations have examined sharp increases in CRP serum levels occurring within the first few days of severe exercise in long distance runners as an inflammatory response measure (8, 24, 33, 44, 47).

Therefore, the purpose of this study was to determine the effectiveness of IPC technology on reducing CRP and DOMS in trained athletes after long distance running. We hypothesized that IPC treatment would reduce post-run CRP and DOMS.

METHODS

Participants

Ten healthy, endurance trained males (n=5) and females (n=5), age 20 to 53 years, who attended the university or lived in the surrounding area were enrolled. The participants were obtained by recruiting volunteers from local running and triathlon clubs, and from the university's women's cross-country team. The participants consisted of marathoners, ultra-marathoners, ironman triathletes, and collegiate athletes.

Table 1. Characteristics of the participants.

| Characteristics | Total Group (N=10) Mean \pm SD |
|---------------------------------|-------------------------------------|
| Age (years) | 38.7 \pm 11.2 |
| Height (cm) | 170.7 \pm 7.8 |
| Weight (kg) | 67.3 \pm 8.5 |
| VO ₂ max (ml/kg/min) | 51.4 \pm 5.8 |

Screening: All potential participants completed an informed consent. Following the informed consent, participants completed an AHA/ACSM Health/Fitness Facility Pre-participation Screening Questionnaire (3) to measure potential health risk factors for people engaging in an exercise program. Participants needed to be in the "Low Risk" category after completing the screening questionnaire. Participants were excluded from participating in the study if they had a history of musculoskeletal, cardiovascular, circulatory, or any other health problems that would prevent them from completing the protocol.

Study participants were asked to refrain from all physical activity outside of activities of daily living, flu shots or other immunizations, and other recovery treatments such as stretching, ice baths, or consuming anti-inflammatory medications such as NSAIDs during the data collection periods. Participants were also not permitted to participate in the study if they had any viral or bacterial infections and were instructed to wait until they had completely recovered from any illness prior to participation. Qualified individuals signed an informed consent form approved by the Institutional Review Board at the University.

VO₂max Test: Participants who qualified for the study performed a graded VO₂max test to establish running intensity (70% VO₂max) for the running trials. Oxygen consumption and carbon dioxide production were monitored during the test using a metabolic cart. Heart rate was measured using a wireless 3-lead ECG system (Tele-Rehab, ScottCare Cardiovascular Solutions, Cleveland, OH). For the actual test, subjects performed an ~10-minute warm-up, which also served to determine a comfortable running pace on the treadmill. Once warm-up was complete and running pace was established, participants underwent an incremental exercise test. Each stage was 3 minutes in duration and consisted of running at the predetermined pace. After each 3-minute stage, the treadmill incline was increased 3% until successful test criteria were met. These criteria included: volitional fatigue, a plateau in VO₂ despite an increase in workload, a heart rate within 10 beats of their age-predicted maximum, and an RER of 1.10 or greater. At least 2 of the criteria had to be met to be considered VO₂max. The VO₂max test served to establish maximum heart rate, which was used to calculate the target heart rate for the 20-mile runs.

Study Design: A cross-over design was implemented and participants were randomly assigned to either the treatment run or the control run for their first 20-mile run to avoid order effect. The second run was completed three to four weeks after completing the first run. Test participants were asked to refrain from any physical training 48 hours prior to each of their 20-mile runs, as well as the 5 days after the run during either their control or treatment period.

Blood Collection and Weight Measurements: Immediately before each participant started their 20-mile run, baseline data was collected. Nude weights were taken immediately before and after the run using a physician's beam scale. Blood samples were obtained via venipuncture of the antecubital vein using SST BD Vacutainer serum collection tubes (3.5 mL) and were processed and analyzed for CRP. Immediately after the 20-mile run, another venous blood sample was taken from the antecubital vein for CRP. Perceived pain was assessed using the Management of Cancer Pain Scale Test (29), which ranges from 0-10, with 0 being no pain, and 10 being the worst possible pain. For five consecutive days after each run, blood samples were obtained for CRP analysis and perceived pain was recorded at approximately the same time each day. Blood samples were allowed to sit for 30 minutes to coagulate and then were spun down using a centrifuge at 2900 RPM for 10 minutes. Serum was collected and immediately stored at -80°C until analysis. Frozen serum was then transferred to a clinical site for CRP assessment.

Exercise and Recovery Treatment Protocol: Once the baseline measurements were acquired, the run took place on a premeasured course. The course was 2.5 miles in length, and very flat. Each

out-and-back was therefore 5 miles, and subjects completed the route 4 times for a total of 20 miles. Participants were accompanied by study personnel throughout the entire duration of their run. The participants completed a 20-mile run at an intensity of 70% or higher of their VO_{2max} . The intensity for each runner was based off of their VO_{2max} test. Heart rate was recorded every minute during the VO_{2max} test. Following the VO_{2max} test, we multiplied the VO_{2max} by 0.70 and then corresponded their 70% VO_{2max} value to their heart rate obtained from the max test (i.e., participant's VO_{2max} of $60 \text{ ml}\cdot\text{kg}\cdot\text{min}^{-1}$ was multiplied by 0.70 equaling $42 \text{ ml}\cdot\text{kg}\cdot\text{min}^{-1}$. We then looked at the heart rate data from the VO_{2max} test to determine what the heart rate was when the participant was consuming $42 \text{ ml}\cdot\text{kg}\cdot\text{min}^{-1}$ of oxygen and used that heart rate to set the intensity for their 20-mile run). Each runner wore a Polar heart rate monitor [FT1 (watch) and T31, T34 (chest transmitter and elastic strap), Polar Electro Inc., Bethpage, NY] to verify proper running intensity for the entire duration of the run. Participants were provided water or their preferred liquid to drink during their 20-mile runs, according to each participant's specific hydration routine. Fluid intake was monitored and recorded for each runner, and body weight was again obtained immediately after each 20-mile run to determine fluid loss from dehydration. Participants who completed the treatment run received treatment using the IPC recovery system immediately following blood sampling.

The second 20-mile run was held approximately three to four weeks after the first 20-mile run to ensure complete recovery. Participants who were previously in the treatment trial participated in the control trial, while those who were previously in the control trial participated in the treatment trial. Procedures for the second 20-mile run were exactly the same as those in the first 20-mile run. Participants who did not receive treatment after the 20-mile run underwent the same protocol except for the IPC treatment, and were able to leave the lab after blood was collected and pain was measured each recovery day.

Intermittent Pneumatic Compression Intervention: All treatment participants received the same treatment of one hour of IPC at an intensity setting of 10 (90mmHg for cell 1 and cell 5 and 100 mmHg for cells 2-4) with a compression duration of 30 seconds. It is recommended that for athletes, the intensity setting be at 10 (intensity settings range from 1-10 with 10 being the highest pressure of 90-100 mmHg) to ensure the best results for recovery, according to the manufacturer. This inflation is synchronized to mimic a massaging action and to increase blood flow. Each leg was treated simultaneously.

Statistical Analysis

Paired sample t-tests were used to determine any differences between mean weight loss, fluid intake, sweat rate, heart rate, percentage of maximum heart rate, or percentage of VO_{2max} between the first and second runs. Paired samples t-test were also used to determine any difference between the control and treatment run. The variables CRP and pain were analyzed using a 2×7 repeated measures ANOVA to determine main effects of condition (run with no IPC treatment vs run with IPC treatment) and time (pre-run, immediately post run, day one, day two, day three, day four, day five) as well as their interaction. If the ANOVA resulted in a significant interaction, then a Sidak post hoc test was used to accommodate for alpha inflation.

The alpha level of significance was set at $p \leq 0.05$ and SPSS software was used for all statistical analyses (SPSS version 25).

RESULTS

There was no significant difference in mean weight loss, fluid intake, sweat rate, heart rate, percentage of maximum heart rate, or percentage of $VO_2\text{max}$ between runs (Table 2). There was, however, a significant difference ($p = 0.038$) in running time when comparing the control run against the treatment run, with the treatment run averaging 8 minutes slower.

Table 2. Comparison between the control run and the IPC treatment run.

| Condition (N=10) | Control (Mean \pm SD) | Treatment (Mean \pm SD) | p - value |
|--------------------------------|-------------------------|---------------------------|-----------|
| Weight Loss (kg) | 1.17 \pm .74 | 1.32 \pm .72 | .370 |
| Fluid Intake (ml) | 1087.3 \pm 505.7 | 1307.8 \pm 728.2 | .308 |
| Sweat Rate (L/hr) | .37 \pm .28 | .40 \pm .23 | .649 |
| Heart Rate (bpm) | 143.9 \pm 10.8 | 147.8 \pm 12.8 | .213 |
| % Max Heart Rate | 79.8 \pm 6.5 | 81.8 \pm 5.6 | .222 |
| % $VO_2\text{max}$ (ml/kg/min) | 72.3 \pm 9.0 | 69.8 \pm 10.9 | .082 |
| Running Time (min) | 196.2 \pm 28.7 | 204.8 \pm 31.1 | .038* |

* Indicates significance between trials

In comparing the order effect of the first run vs. the second run, the results indicated no significant difference ($p > 0.05$) in any variables except for one of the pain ratings. When comparing the pain experienced immediately following the first run versus second run, runners indicated they experienced more pain following the second run (4.9) compared to the first run (3.7; $p < 0.05$). This slight increase in pain on the second run occurred regardless of whether the run was a treatment run or a control run.

CRP: The 2×7 repeated measures ANOVA indicated that there was a significant main effect of time ($F_{6,54} = 11.3$, $p < 0.01$) but there was no significant main effect of condition ($F_{1,9} = 0.55$, $p = 0.48$) or interaction between condition and time ($F_{6,54} = 1.2$, $p = 0.33$). The post hoc analysis revealed no change in the amount of CRP when comparing pre-run (baseline) to post run but there was a significant increase in the amount of CRP on day one ($p = 0.04$, $d = 0.9$) but days two ($p = 0.28$), three ($p = 0.99$), four ($p = 1.0$), and five ($p = 1.0$) were not significantly different (Figure 2). Any values found below the detectable limit were rounded for analysis purposes which included all the pre- and post-run CRP measurements.

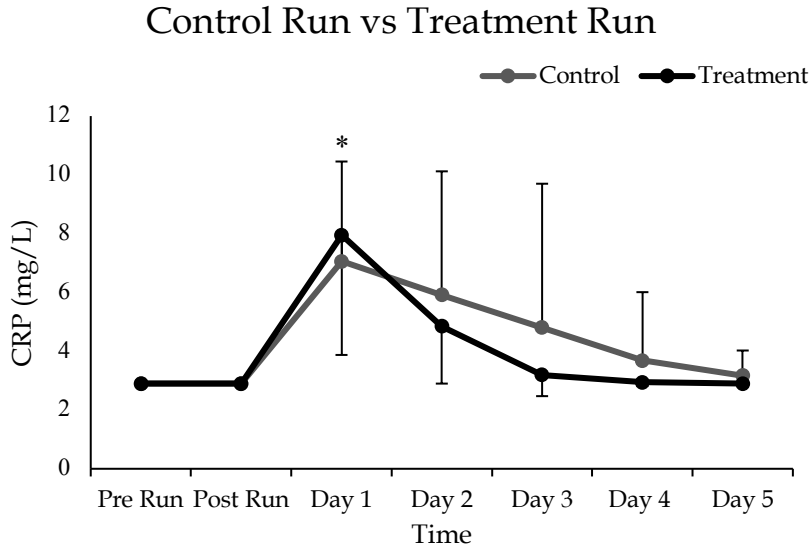


Figure 2. The control run vs the treatment run over the six days of testing (mean ± SD). * indicates a significantly higher amount of CRP compared to Pre-Run and Post-Run in both the control and treatment groups.

Pain: The 2 × 7 repeated measures ANOVA indicated that there was a significant main effect of time ($F_{6,54} = 38.8, p < 0.01$) but there was no significant main effect of condition ($F_{1,9} = 0.02, p = 0.89$) or interaction between condition and time ($F_{6,54} = 0.62, p = 0.72$). The post hoc analysis revealed pain was significantly increased when comparing pre-run (baseline) to post run ($p < 0.01, d = 1.1$), day one ($p = 0.002, d = 0.8$) and day two ($p = 0.02, d = 0.4$). However, there was no difference in pain when comparing pre-run to days three ($p = 0.23$), four ($p = 0.72$), and five ($p = 1.0$) (Table 3).

Table 3. Comparing baseline pain ratings to post run pain ratings.

| Condition (N=10) | Mean ± SD | Condition (N=10) | Mean ± SD |
|------------------|--------------|--------------------|--------------|
| Group | | Group | |
| Control Pre-Run | 0.00 ± 0.00 | Treatment Pre-Run | 0.00 ± 0.00 |
| Control Post Run | 4.10 ± 2.42* | Treatment Post Run | 4.70 ± 1.42* |
| Control Day 1 | 2.90 ± 1.51* | Treatment Day 1 | 3.00 ± 1.76* |
| Control Day 2 | 2.35 ± 1.38* | Treatment Day 2 | 2.15 ± 1.86* |
| Control Day 3 | 0.95 ± 1.26 | Treatment Day 3 | 1.00 ± 1.05 |
| Control Day 4 | 0.40 ± 0.84 | Treatment Day 4 | 0.20 ± 0.48 |
| Control Day 5 | 0.10 ± 0.32 | Treatment Day 5 | 0.00 ± 0.00 |

Scale 0 (no pain) - 10 (worst pain possible)

* Indicates significant increase from baseline

Temperature Conditions During the 20-mile Runs: This study was conducted during both autumn and winter in a location that experiences large seasonal changes in climate. The temperature of the first run was compared to the temperature of the second run to determine if a difference occurred. The first run was significantly warmer ($p = 0.03$) (6.4 °C) compared to the second run (2.8 °C). We also examined the temperature of the control run (4.8 °C) compared to the temperature of the treatment run (4.4 °C) to determine if a difference occurred. However, no

significant difference ($p = 0.855$) was found in temperature between the control and treatment runs.

DISCUSSION

To our knowledge, no previous studies have investigated the effect of IPC recovery treatment on CRP and pain. In the present study recovery is defined as the return to baseline for CRP and pain. The findings of the study collectively reveal no significant difference in CRP or pain between the treatment and control runs.

CRP is reported to be the most plentiful of the acute phase proteins and has been reported to be elevated following exercise, especially when muscle damage has occurred (9, 12). CRP levels significantly peaked on Day 1 for both the control and treatment runs when comparing to baseline and no significant difference was found when comparing days two, three, four, and five to baseline. This is consistent with the suggestion by Fallon and colleagues (9) that the acute phase inflammatory response has been suggested to relate to skeletal muscle damage when associated with exercise. However, a study performed by Miliias et al. (28) found no significant differences in the inflammatory markers CRP, complement C3, and fibrinogen following eccentric exercise. This difference from our findings may be due to the exercise protocol, which was 36 maximal voluntary contractions of the biceps muscle. This is a much shorter protocol and uses a much smaller amount of muscle mass than our exercise protocol. In another study, Simpson et al. (42) also found no significant difference in CRP even after a hill race although muscle damage was present. Again, the incongruent findings are likely due to the fact that the race was only 7km in distance, which is much shorter than our protocol.

Perceived pain was significantly higher post run, day one, and day two when compared to baseline. No significant difference was found in perceived pain when comparing baseline to days three, four, and five. This is consistent with a study by Hilbert et al. (15) in which they tested the physiological and psychological effects of massage on DOMS. They concluded massage may provide psychological benefits as it reduces the intensity of soreness which is commonly associated with DOMS (15).

As with any study, there are limitations that need to be addressed. We did not control for pre-run diet, the type of fluid that was ingested during the run, nor the amount of carbohydrate ingested during the run between the participants. Since our population consisted of trained endurance athletes, each individual had their own pre-run and run hydration and nutrition routine. However, we did have the individuals replicate their hydration and nutrition routine from the first run on the second run. Additionally, the course was outdoors and therefore not a controlled environment, which more closely represents what an endurance athlete would experience during training or competition. Not controlling for the stated variances may have influenced the results. However, the conditions more closely replicate typical training, and may therefore provide results that are more applicable to the athletes who use IPC as part of their recovery process. Finally, a sample size of 10 is relatively small. Having a larger group of participants will provide stronger statistical power in future studies.

In conclusion, there are many devices used to help athletes recover faster. Unfortunately, many of them do not work as advertised or have not undergone sufficient scientific research to support their claims. Coaches, athletic trainers, and athletes should seek scientific support of therapeutic interventions that claim to help reduce the effects of DOMS, and speed of recovery from exercise and athletic endeavors. Previous research suggests that the use of IPC technology may facilitate recovery that both professional and recreational athletes can benefit from using (18, 22, 39, 40). However, our results indicated that IPC offered little to no benefit in recovery from a prolonged bout of running.

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