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Authors: Kelly A. Brock¹, Lindsey E. Eberman¹, Richard H. Laird IV², David J. Elmer³, and Kenneth E. Games¹

Affiliations: ¹Neuromechanics, Interventions, and Continuing Education Research (NICER) Laboratory, Department of Applied Medicine and Rehabilitation, Indiana State University, Terre Haute, IN. ²Department of Exercise Science & Physical Education, McDaniel College, Westminster, MD. ³Department of Kinesiology, Berry College, Mt. Berry, GA.

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Sequential Pulse Compression’s Effect on Blood Flow in the Lower Extremity

Authors:

Kelly A. Brock, LAT, ATC*

Doctorate in Athletic Training Student
Neuromechanics, Interventions, and Continuing Education Research (NICER) Laboratory
Department of Applied Medicine and Rehabilitation
Indiana State University
Terre Haute, IN
E-mail: kbrock4@sycamores.indstate.edu

Lindsey E. Eberman, PhD, LAT, ATC

Neuromechanics, Interventions, and Continuing Education Research (NICER) Laboratory
Department of Applied Medicine and Rehabilitation
Indiana State University
Terre Haute, IN
E-mail: Lindsey.Eberman@indstate.edu

Richard H. Laird IV, PhD, CSCS

Department of Exercise Science & Physical Education
McDaniel College
Westminster, MD
E-mail: rlaird@mcdaniel.edu

David J. Elmer, PhD, CSCS

Department of Kinesiology
Berry College
Mt. Berry, GA
E-mail: delmer@berry.edu

Kenneth E. Games, PhD, LAT, ATC

Neuromechanics, Interventions, and Continuing Education Research (NICER) Laboratory
Department of Applied Medicine and Rehabilitation
Indiana State University
Terre Haute, IN
E-mail: Kenneth.Games@indstate.edu

* Corresponding author contact information: Kelly A. Brock, LAT, ATC, Neuromechanics, Interventions, and Continuing Education Research (NICER) Laboratory, Department of Applied Medicine and Rehabilitation, 567 North 5th Street, Indiana State University, Terre Haute, IN 47809. E-mail: kbrock4@sycamores.indstate.edu Phone: 812-237-3961

Abstract

Several interventions are available to reduce the intensity and duration of the unwanted effects (e.g. muscle soreness) associated with physical activity such as massage, compression garments, and sequential pulse compression (SPC). Such interventions aim to increase blood flow to alleviate symptoms. However, there is a lack of evidence to support the use of SPC to alter total hemoglobin concentration (THb) in active individuals. The aim of this study was to examine the acute effects of a single session of SPC on hemoglobin concentration compared to a control condition. Thirty-four physically active and healthy participants (females=12, males=22) completed the study. We randomly assigned participants to first receive the experimental (SPC) or control condition. Measures were recorded pre- and post-condition. Participants returned to the laboratory to complete the second condition ≥ 24 hours after the first condition. Relative change in THb, oxygenated hemoglobin (O₂Hb) and deoxygenated hemoglobin (HHb) measures were recorded using near-infrared spectroscopy placed on the muscle belly of the medial gastrocnemius of the dominant limb. SPC significantly increased THb ($P < 0.001$, $d = 0.505$) and O₂Hb ($P < 0.001$, $d = 0.745$) change scores compared to the control condition. No statistical difference in HHb change scores were found between SPC and control conditions, but a medium effect size suggests potential biological significance ($p = 0.055$, $d = 0.339$). Overall, SPC increases THb to the lower extremity, and may be a viable option in the management of muscle soreness related to physical activity.

Word Count: 230 words.

Introduction

Exercise-induced muscle damage (EIMD) is the consequence that occurs when an individual participates in an unfamiliar or eccentrically based activity. These activities may result in delayed onset muscle soreness (DOMS). The severity of muscle damage is dependent on the duration, intensity, and experience of the individual performing said activity.¹ These conditions may leave the individual with DOMS symptoms such as soreness, inflammation, and decreased strength¹ which may affect his or her performance. Symptoms can begin as early as eight hours post-exercise² and last up to four days³ with a peak in perceived soreness approximately forty-eight hours post-exercise.¹ Due to the varying severity and length of symptoms, many strategies have been instituted to try to overcome deficits that accompany DOMS and to decrease the amount of time an individual’s body needs to recover from the muscle damage.

Several treatments are proposed for EIMD and DOMS and have been investigated for their efficacy at alleviating soreness and improving performance as measured with reduced recovery times. Such treatments include massage,^{2,4-7} compression garments,^{1,4,5,8-10} cryotherapy,¹¹ non-steroidal anti-inflammatory medication,¹¹ stretching,¹¹ contrast water therapy,^{10,11} and intermittent pneumatic compression.¹¹⁻¹⁶

Intermittent pneumatic compression (IPC) was initially introduced as an intervention to prevent deep vein thrombosis.¹³ Today, IPC is still used in medicine for that same purpose, but it has started to be incorporated into treatments to aid in the recovery of highly active individuals following exercise.¹¹ The theory behind IPC is based on an external pressure gradient and its ability to compress a limb intermittently from the most distal point of an extremity to the proximal end of the extremity.^{11,13} The pressure gradient, created by the device, acts to forcibly move fluid and/or blood from the extremity. Once the pressure gradient is removed, the compressed tissue is allowed

to refill with blood from the proximal segments of the body.^{11,13} As a result of this changing pressure gradient, theoretically, the chemical byproducts of exercise can be removed from the extremities for filtering and removal with the thorax and abdomen. However, the majority of research on IPC is related to deep vein thrombosis or swelling post-operation.^{11,13}

Recently, specific patterns of pressure gradients using multi-chambered sleeves have been created and have resulted in the creation of a separate form of IPC known as sequential pulse compression (SPC). This commercially available pulse pattern is marketed as the NormaTec PRO Recovery System (NormaTec). NormaTec is similar to IPC in that it uses air to provide compression, but differs because it utilizes multiple chambers, pressure gradients, and patterned inflation to create massage like patterns which are applied to patients.¹² This specific pattern was created to mimic the body’s natural circulation and muscle pump mechanism (see instrumentation section for more details).¹² Current research on SPC, like IPC, suggests that it is beneficial to treat vascular diseases and prevent formation of a deep vein thrombosis after surgery.¹¹ Work has also examined the effect of SPC on muscular strength performance following an EIMD protocol and found that SPC treatment did not lessen the strength losses typically found following EIMD.¹¹ Despite having minimal research for musculoskeletal conditions, products using SPC are marketed to the physically active as a superior form of recovery compared to rest. Therefore the purpose of this study was to examine the acute effects of a single SPC treatment on lower extremity hemoglobin concentration in healthy participants.

Methods

Research Design

We utilized a single cohort, repeated measures design to analyze the change scores between post- and pre-application of the conditions (SPC or control). We chose to use change scores due

to known differences in day-to-day hemoglobin concentrations. Our independent variables were condition (SPC and control) and time (pre- and post-application). Our dependent variables included oxygenated hemoglobin concentration (O₂Hb), deoxygenated hemoglobin concentration (Hb), and total hemoglobin concentration (THb) measured with near-infrared spectroscopy.

Participants

Thirty-five physically active participants between the ages of 18 and 30 who were healthy and exercised at least 200 minutes per week were recruited for this study. One participant was excluded from the study due to incomplete data. Thirty-four participants completed the study (12 females, 22 males; 22 ± 2.9 years; height = 179.20 ± 11.99 cm; mass = 79.70 ± 19.23 kg). During the study, participants were asked to maintain his or her normal exercise routine and diet until completion of the study to minimize the influence of external exercise on the data collection. Prior to any data collection, participants completed a health history questionnaire to ensure eligibility and provided written informed consent. The University’s Institutional Review Board approved this study.

Instrumentation

Hemoglobin levels were measured using near-infrared spectroscopy (NIRS) (Portamon, Artinis Medical Systems BV, Zeiten, the Netherlands) and all recordings were processed using the data acquisition software (OxySoft, version 3.0.53, Artinis Medical Systems, Zeiten, The Netherlands). We utilized hemoglobin concentration, as it is a non-invasive indirect measure of blood flow in skeletal muscle.¹⁷ Prior to hemoglobin readings, the skin around the muscle belly of the medial gastrocnemius was shaved, abraded with fine grit sandpaper, and cleaned with alcohol. NIRS detectors (optodes) were attached to the belly of the medial head of the gastrocnemius muscle. The device was placed on the skin 2 cm medial to the midline of the largest lower leg

circumference.¹⁸ Flexible tape was used to secure the NIRS to the skin. Prior to baseline measures, the graph was zeroed and biased for data collection. Mean values for O₂Hb, HHb, and THb were collected for 1 minute following baseline and after each intervention.

A commercially available SPC device (NormaTec MVP PRO, NormaTec, Newton Center, MA) was utilized to apply the experimental condition. This device for the lower extremity consists of two separate “boots” that encase the legs from the toes to the groin and connects to a bifurcated hose, which attaches to a computerized air compressor. For this study, the compressor was pre-set to one of the manufacturer’s recommended settings for recovery. Each boot has five cells with independent air supplies, allowing the cells to inflate individually. Beginning at the first (most distal) cell, air is sent into the cell in a “pulsing” pattern (rapid, short bursts of air from air compressor), by increasing pressure, stopping and then continuing on until the desired pressure is attained (for this study it was a maximum of 80mmHg). At this point, static pressure was then held in cell one for 30 seconds before inflating the second cell. The same pulsing procedures are followed for cells two and three, while static pressure is continued within the distal cells. The only change is a release of pressure in cell one when cell four begins to inflate. This release is programmed to parallel the body’s natural prevention of backflow in the circulatory system. At any given point in the treatment, a maximum of two cells can be completely inflated while a third is pulsing. This pattern is continued along the entire limb and repeated for a total of 30-minutes, as recommended by the manufacturer for recovery settings.

Procedures

Participants came to the laboratory on two occasions no sooner than 24 hours apart. Participants were asked to return at the same time on the second day, but in consideration of a participant’s busy schedule, this was not a requirement. On the first day, measurements for mass,

height and dominant leg thigh girth and inseam length were performed and recorded for proper instrumentation fitting. Participants were not blinded to the intervention but were randomly assigned to either session A (SPC) or session B (control).

Prior to application of any conditions, we affixed the NIRS optodes to the medial gastrocnemius as described above and then had each participant lie supine for 10 minutes to allow the body to come to rest. After this resting period, the NIRS graph was zeroed and bias and a one-minute baseline recording was collected for THb, O₂Hb, HHb. During session A and after baseline measurements, participants received 30 minutes of SPC (NormaTec MVP PRO, MA, USA) in the supine position (Image 1). Throughout the session, the participants lay quietly and were instructed not to move. At the conclusion of application, the boots were carefully and quickly removed by the principal investigator and post intervention NIRS measures were collected. SPC boots were removed in order to maintain consistent environments for pre- and post-intervention measurements.

During session B, the same protocol was followed, however no SPC or boots were applied and the participant lay quietly in a supine position for 30-minutes.

Statistical Analysis

Seven dependent t-tests were performed to assess change scores in hemoglobin with and without SPC using Holms’ sequential Bonferroni corrections. Data were collected and entered into a custom spreadsheet (Microsoft Excel 2013, Microsoft corporation, Redwood, WA, USA). Change scores were calculated by subtracting the mean post-intervention values by the mean pre-intervention values. All data were analyzed using commercially available statistical analysis software (SPSS, version 20, IBM, Inc., Chicago, IL, USA). Significance was set at $\alpha=0.05$ *a priori*.

Results

We found a significant increase in THb change between SPC and control condition ($t_{33}=2.946$, $P < 0.001$, mean difference = 3.61 arbitrary units (au), CI (1.12-6.11), $d = 0.505$) (Table 3), indicating increased total hemoglobin in the lower leg following a bout of SPC compared to the control condition. We found a significant difference in the O₂Hb change between the SPC and control condition ($t_{33}= 4.35$, $P < 0.001$, mean difference = 4.44 au, CI (2.36-6.52), $d = 0.745$). This finding suggests that oxygenated hemoglobin levels are increased immediately after a session of IPC. We found a non-statistically significant difference in HHb change between the SPC and control conditions ($t_{33}= -1.989$, $P = 0.055$, mean difference = -1.32 au, CI (-2.66-0.030), $d = 0.339$). This finding indicates that deoxygenated hemoglobin levels were not altered following a session of SPC. If we take these results together, we can conclude that an acute bout of SPC increases total and oxygenated hemoglobin without increasing deoxygenated hemoglobin. Pre- and post-recordings are found in Figure 1.

Discussion

We examined the acute effects of a single, 30-minute bout of SPC compared to a control condition on hemoglobin levels in the lower leg. We hypothesized that a treatment with SPC would increase hemoglobin levels to the lower extremity in healthy individuals.

A single, 30-minute session of SPC significantly increased total hemoglobin and oxygenated hemoglobin without changing deoxygenated hemoglobin in the medial gastrocnemius muscle compared to a control condition. We believe this occurred as a result of the SPC interrupting normal blood flow through repetitive and sequential compression and release of the arterial and venous vessels of the lower extremity during treatment. When the limb is compressed, blood supply is limited or occluded for a period of time and released to allow normal blood flow

to continue.¹³ This alteration to normal blood flow causes an increase in pressure within the vessels to propel the blood forward and a stretch on the vessel’s walls to accommodate for the increase in blood volume.¹³ This stretch of the endothelial cells in the vessels triggers an increase in nitric oxide synthesis that will stimulate the blood vessels to dilate and allow a considerable volume of blood to return to the area.¹³

In the present study, we recruited participants who were physically active, but had not completed a bout of physical activity prior to the data collection session. This is important to consider when interpreting the results of the present study. Our results suggest that application of 30-minutes of SPC increases total concentration of hemoglobin and oxygenated hemoglobin concentration. Potentially, increasing the availability of oxygen to resting muscles.

To reiterate our results, total hemoglobin and oxygenated hemoglobin increased and deoxygenated hemoglobin remained unchanged following a bout of SPC. This influx of oxygen would be helpful to begin the recovery process and in turn decrease the time needed for recovery. However, future work is needed to determine the magnitude of the effect SPC would have on oxygenated, deoxygenated, and total hemoglobin levels in individuals in a post-exercise state.

Previous research examining similar compression interventions on circulation found comparable results to the present study.^{15,16,19,20} The previous work had found increases in muscle oxygenation of $23 \pm 7\%$ ¹⁵ and increases in total blood flow between 29-335%.¹⁹ However, the previous work was largely completed using an animal model¹⁶ or in blood flow compromised patients (intermittent claudication¹⁹ and limb amputation²⁰). Our study found an increase in oxygenated hemoglobin concentration levels of 42% and total hemoglobin concentration increases of 138% compared to the control condition in non-blood flow compromised participants. This adds to the literature in that it provides evidence that the proposed mechanism for improved recovery

(increased hemoglobin concentration), through a single treatment of SPC, is attainable in a healthy population. This may be beneficial during post-exercise recovery since muscle damage requires nutrients and proteins, that are carried within the blood, to aid in healing.²¹ If a muscle, damaged through strenuous activity, is exposed to a period of increased hemoglobin following a treatment of SPC, the involved muscle tissue may experience an increase in available nutrients and proteins, thereby improving the post-exercise recovery environment. Future work should examine SPC’s capacity to clear biological markers of EIMD.

Recently, there has been an increased interest in examining IPC to improve physical performance or recovery time in an otherwise healthy population. One study supports IPC’s use in muscle recovery post exercise by speeding clearance of blood lactate²² whereas others refute its capacity for quick clearance of blood lactate^{14,23} and showed no changes in glycogen resynthesis, insulin, or blood glucose between intervention and passive recovery.¹⁴ Researchers studied IPC’s ability to attenuate for the muscle strength decrease that occurs after eccentric exercise and found insignificant results when compared to a non-treatment group.¹¹ Similarly, occlusion and IPC have been noted as ineffective to mitigate the negative effects of exercise after fatiguing resistance exercise compared to passive recovery.²⁴ However, daily treatments with IPC are successful at reducing muscular swelling resulting from DOMS, subjective palpation pain scores and improving range of motion at the elbow compared to a continuously worn compression sleeve.²⁵ Another study revealed no change in peak power, average power and fatigue index in repeated Wingate anaerobic tests after a 30 minute treatment with IPC.²² Yet, IPC effectively increased the mean power frequency of fatigued tibialis anterior muscles, after a fast-walking treadmill protocol, compared to passive recovery.²⁶ A study examining ultramarathon runners also shows that muscle fatigue scores were lower after multiple treatments of IPC compared to a supine-rest control

group.^{27,28} Repeated bouts of exercise on a cycle ergometer were improved by 45% after IPC was administered during a 20-minute recovery period and higher mean maximum ventilations and mean maximum heart rates were reached in the second bout.²³ IPC however, was not effective with statistical significance to clear blood lactate, decrease 5km treadmill time-trial or improve Total Quality Recovery scale score between a cycling and running bout in male triathletes.²⁹ Another study examined the effect of three interventions on heart rate, blood pressure, soreness and vertical jump. Participants performed a shuttle run and then received one hour of rest, one hour of low pressure IPC (pressures changing from 10-20 mmHg) or one hour of high pressure IPC (pressures changing from 60-70 mmHg), on three separate days.³⁰ The results show a significantly lower mean heart rate, diastolic blood pressure and mean perceived soreness in both IPC groups.³⁰ Vertical jump was reduced post-shuttle run, however, the degree of the deficit was significantly less after the IPC treatments with the high IPC pressure generating a significantly smaller mean reduction than low IPC and control conditions.³⁰ Another study examining high (80mmHg) and low (20mmHg) IPC pressures found no change in 1600m run times in collegiate runners, but the mechanics of each IPC device, different pressures and the type of activity being tested are suggested to be the reason for no improvement in performance.³¹

In addition, IPC has been shown to increase pressure-to-pain-threshold in elite athletes³² and improve flexibility.³³ Furthermore, a group of researchers studied the effect of IPC on exercise using ligated rats.¹⁶ Researchers reported ~33% increase in exercise tolerance after one hour of IPC.¹⁶ These studies suggest that IPC does not aid in eliminating strength deficits that accompany DOMS, but may alter exercise tolerance. This implies that clinical uses for IPC are limited to benefits from increased blood flow. The present study demonstrates that SPC increasing total blood flow as measured by total hemoglobin concentration in healthy physically active individuals.

Future work should continue to examine SPC’s effect on an individual’s performance (vertical jump, triple hop for distance, etc.). Future work should also be conducted with varying parameters and different SPC devices, as there are many manufacturers represented in this review, several of which operate differently from others on the market.

There are limitations to the current study such as the participant population we used. Our data were collected in young, healthy, physically active individuals. These results may not be translatable to older individuals or for those who are less physically active. Future work should examine changes in older populations and those who are less physically active. Another limitation is that the SPC boots were not worn during session B and could potentially affect temperature of the limb and therefore, blood volume.

Conclusions

SPC is an effective modality to increase blood flow in the limbs and can be used to facilitate recovery. SPC units are portable and lightweight, which makes them more feasible for sports medicine departments. SPC is a good alternative to other modalities used to increase blood flow because a health care provider does not need to physically administer the treatment. Therefore, the clinician is able to treat patients without placing large loads of stress on his/her joints. Evidence to suggest the use of SPC to improve muscle strength or performance is conflicting and should be further investigated. Further research should also examine patient’s perception of treatment using patient rated outcome measure.

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Figure 1.

Table 1.

	SPC Pre (mean ± SD)	SPC Post (mean ± SD)	Control Pre (mean ± SD)	Control Post (mean ± SD)
THb (au)	1.03 ± 2.29	10.12 ± 6.93	0.33 ± 1.32	5.81 ± 3.08
O ₂ Hb (au)	0.90 ± 2.00	10.15 ± 6.70	0.38 ± 1.35	5.20 ± 2.76
HHb (au)	0.15 ± 0.63	-0.70 ± 3.02	-0.04 ± 1.24	-0.41 ± 1.82

Abbreviations: SD, standard deviation; THB, total hemoglobin; O₂HB, oxyhemoglobin; HHB, deoxyhemoglobin