Blood Flow Restriction Combined with Electrical Stimulation Attenuates Thigh Muscle Disuse Atrophy

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ABSTRACT

PURPOSE: To investigate the effects of blood flow restriction (BFR) combined with electrical muscle stimulation (EMS) on skeletal muscle mass and strength during a period of limb disuse.

METHODS: Thirty healthy participants (22 ± 3 years; 23 ± 3 kg m⁻²) were randomly assigned to either: control (CON; n=10), BFR alone (BFR; n=10), or BFR combined with EMS (BFR+EMS; n=10). All participants completed unloading of a single-leg for 14-days, with no treatment (CON), or while treated with either BFR, or BFR+EMS (twice daily, 5 day/week). BFR treatment involved arterial 3 cycles of 5 min occlusion using suprasystolic pressure, each separated by 5-min of reperfusion. EMS (6s on, 15s off; 200 µs; 60Hz; 15 % MVC) was applied continuously throughout the 3 BFR cycles. Quadriceps muscle mass (whole thigh lean mass via DEXA and Vastus Lateralis (VL) muscle thickness via ultrasound) and strength (via knee-extension maximal voluntary contraction (MVC)) were assessed before and after the 14-day unloading period.

RESULTS: Following limb unloading, whole thigh lean mass decreased in the control (-4 ± 1%; p < 0.001) and BFR group (-3 ± 2%; p = 0.001), but not in the BFR+EMS group (-0.3 ± 3%; p = 0.8). VL muscle thickness decreased in the control group (-4 ± 4%; p = 0.005), and was trending toward a decrease in the BFR group (-8 ± 11%; p = 0.07) and increase in the BFR+EMS group (+5 ± 10%; p = 0.07). Knee-extension MVC decreased over time (p < 0.005) in the control (-18 ± 15%), BFR group (-10 ± 13%), and BFR+EMS (-18 ± 15%) group, with no difference between groups (p > 0.5).

CONCLUSION: Unlike BFR performed in isolation, BFR+EMS represents an effective interventional strategy to attenuate the loss of muscle mass during limb disuse, but it does not demonstrate preservation of strength.

KEYWORDS: electromyostimulation; occlusion; immobilization; weakness
INTRODUCTION

It is well established that even short periods of skeletal muscle disuse will elicit muscular atrophy and reductions in strength (1). Maintaining a certain minimal level of physical activity during these periods of reduced activity or immobilization can attenuate muscle mass and strength loss (2, 3); unfortunately, during limb immobilization physical activity is often prohibited.

Blood flow restriction (BFR) is emerging as a novel training methodology with potential as an interventional strategy during rehabilitation. While precise mechanisms of action remain to be elucidated, accumulating evidence in healthy participants demonstrates that the addition of BFR to relatively light-load exercise (20-40% 1-repetition maximum) has the capacity to augment the adaptive training response (4-6). During times of forced muscle disuse, such as limb immobilization post-injury, such techniques could help attenuate skeletal muscle mass and strength losses; however, these techniques are traditionally applicable only once a patient is sufficiently able to perform active muscle contractions and joint movements needed for light-load exercise. Given evidence of the benefits of early intervention for a variety of musculoskeletal rehabilitation conditions (7, 8), intervening as early as possible during the immobilization period stands to offer the greatest possible benefit.

In the absence of an exercise stimulus, the repeated application of BFR to the lower extremity has been reported to attenuate immobilization-induced weakness and post-operative disuse atrophy (9) using both high (200mmHg) (10) and low (50 mmHg) (11) restriction pressures. Interestingly, it appears that the use of a higher restriction pressure may be more
effective for preventing some losses during muscle disuse, likely resulting from accumulated tissue-level stress associated with a greater degree of blood flow occlusion. While there are limits to the tissue level stress that can safely and effectively be applied via BFR, further metabolic stress can be achieved by increasing muscle metabolism. Since typical exercise requires active muscle contractions and joint movement, which may not be possible at early stages of limb immobilization, an alternative is to use involuntary muscle contractions evoked by electrical muscle stimulation (EMS), which cause muscular contractions, but not necessarily joint movement. Because EMS is a passive modality, such training can be applied in a variety of settings, including patients who are unable to voluntarily activate muscle mass. To date, no study has investigated the use of BFR treatment combined with EMS (BFR+EMS) as a rehabilitative tool during a period of disuse. Given that BFR+EMS provides a stronger training stimulus compared to BFR treatment alone (12, 13), BFR+EMS should be more effective to attenuate losses in skeletal muscle mass and strength during periods of disuse compared to BFR treatment alone.

The aim of this study was to investigate the effects of repeated application of BFR+EMS on preserving skeletal muscle mass and strength during a period of limb disuse. It was hypothesized that repeated BFR+EMS treatment would be more effective than repeated BFR treatment without EMS for attenuating the loss of quadriceps mass and knee-extension strength during a 14-day leg unloading period.
METHODS

Subjects

A mixed-sex group of 30 healthy, young individuals (14 males, 16 females; age: 22 ± 3 years; body mass index: 23 ± 3 kg m⁻²) who were naïve to BFR training were recruited from the university and surrounding community. After being advised of the purpose and potential risks of the study, participants provided written informed consent in accordance with the guidelines of the institutional human ethics research board who approved the experimental protocol and procedures of this study in accordance with the Declaration of Helsinki.

Study Design

Participants were randomly allocated to either the control (CON; n = 10), BFR (n = 10), or BFR+EMS (n = 10) group. All three groups underwent a 14-day period of single-leg muscle unloading through use of a knee brace and crutches. Unloading was performed using the left leg of all participants to allow safe operation of a motor vehicle during the study. Over the 14-day unloading period, participants had no intervention (CON), or underwent treatment with either BFR or BFR+EMS twice daily, 5 times per week, for a total of 20 treatment sessions. Treatments were performed in the morning (7:00-12:00 h) and afternoon (13:00-18:00 h), and each treatment session took approximately 30 min with a minimum of 4 h and maximum 8 h between the two daily sessions. For those allocated to the CON group, participants were instructed to visit the lab at least once daily, 5 times per week for visual inspection of the leg. On two separate days, 24 h before and immediately after the 14-day unloading period, muscle mass and strength were assessed. The experimental protocol is depicted in Figure 1.
Outcomes

Muscle Mass

Participants visited the laboratory in the fasted state, with no food or liquid for 12 h. Two measures of muscle mass were performed, with participants resting supine for 10 min preceding each measurement (14). First, fat-free lean mass (g) of the whole left thigh was assessed via dual-energy X-ray absorptiometry (DEXA) using the Discovery DEXA System (Christie InnoMed Inc., Mississauga, Canada) calibrated to a manufacturer-provided phantom spine. Whole-thigh lean mass was analyzed by placing a horizontal line at the lowest point of the ischial tuberosity as the upper margin for the thigh and a horizontal line at the knee joint as the lower margin for the thigh (15) (Hologic Software, Hologic Inc., Bedford, USA).

Immediately following the DEXA scan, Vastus Lateralis (VL) muscle thickness was assessed via ultrasound (Vivid I, GE Healthcare, Chicago IL, USA) as an index of whole VL muscle size, which is strongly correlated to muscle cross-sectional area determined by magnetic resonance imaging (16). VL muscle thickness was measured in the supine position at 50% of the distance between the greater trochanter and lateral epicondyle of the femur. The site was landmarked to ensure consistency of measures, with the 50% distance (cm) recorded and replicated pre- and post-intervention. Two images of the VL were acquired using B-mode ultrasound with a linear-array probe (8L-RS Transducer, GE Healthcare, Chicago, USA) with minimal pressure applied to avoid compression of the underlying tissue. Images were analyzed immediately post-acquisition and muscle thickness was assessed by measuring the distance (cm) from the superficial to the deep aponeurosis at the exact center of the fasciae (Vivid I software, GE Healthcare), with all values expressed as an average of the two separate images. Sonographer
reliability for acquisition of these measurements was assessed two times each day over three consecutive days on preserved human cadavers (which offer zero biological variability between tests) and was found to have a coefficient of variation of < 2%. Researchers were blinded to participant groups during analyses of both measures of muscle mass.

**Muscle Strength**

Participants underwent strength testing of the knee extensors using a HUMAC NORM dynamometer (CSMi Medical Solutions, Stoughton, MA, USA). Knee extension maximal voluntary contractions (MVCs) were measured at 90° (0° equals full extension) with participants seated at 110° hip flexion. The left leg was positioned on the dynamometer by aligning the participant’s knee with the axis of the lever arm and attaching the dynamometer arm approximately 3 cm proximal to the medial malleolus. The participant was restrained at the torso using a four-point seatbelt harness and the ankle was held in place using a strap about the bracket. Force was exerted against a leg plate situated on the anterior side of the tibia, 1 cm above the lateral malleolus of the fibula. Participants were instructed to contract as “fast and forcefully as possible” until force starts to decline. Standard verbal encouragement and visual feedback were provided during each contraction. Participants completed 2-3 MVCs, which are 3-5 s in duration, separated by 3 min of rest. Voluntary activation (VA) during the MVCs was assessed using the interpolated twitch technique (ITT) to ensure maximal effort. Participants were required to reach 90% VA upon MVC testing and MVC’s were repeated until this was achieved. The contraction with the greatest torque while attaining > 90% VA was used for analyses.
Muscle stimulation for the ITT was performed using a constant current high voltage stimulator (model DS7AH, Digitimer, Welwyn Garden City, Hertfordshire, UK) where evoked twitches were delivered to the knee extensors transcutaneously using two custom electrode pads, previously described by Dalton et al. (17). Electrodes were placed perpendicular to the long axis of the femur, with the proximal pad at ~5 cm above the kneecap and the distal pad ~10 cm above the proximal electrode, covering the anterior aspect of the thigh completely. Single stimulations were used to evoke muscle twitch (pulse width: 1000 μs; 400 V; model DS7AH, Digitimer, Welwyn Garden City, Hertfordshire, UK) during the 3 s MVCs. After a resting twitch current was determined by increasing current until torque from a single twitch ceased escalation, VA was calculated as:

\[
\text{voluntary activation} = (1 - \text{superimposed twitch torque/resting twitch torque}) \times 100\%.
\]

Torque, angular velocity, position, and stimulus triggering data were sampled at 1000 Hz using a 12-bit analog-to-digital converter (PowerLab System 16/35, ADInstruments, Bella Vista, NSW, AU).

**Leg unloading**

Twenty-four hours following baseline testing of muscle mass and strength, a knee brace (ROM Hinged Knee Brace, Orthomen Inc. California, USA) was fitted and applied to the left knee of each participant. The brace was set so the knee joint was fixed at approximately a 30° angle of flexion to prevent participants from performing weight bearing activity. Each participant was instructed to walk with crutches for 2 weeks during non-weight bearing movement and only
remove the knee brace for bathing and sleeping. After 14-days, muscle mass and strength were assessed immediately after brace removal and before weight bearing activity resumed.

*Interventions*

*Blood flow Restriction*

BFR was performed with the participant in a sitting position using arterial occlusion accomplished via a PTSi automated tourniquet system (Delfi Medical Innovations Inc. Vancouver, Canada). Full arterial occlusion was chosen to maximize the metabolic stimulus and adaptive training response (18). An 11-cm wide tourniquet cuff was positioned proximally around the left thigh and inflated to a pressure that was minimally superior to systolic pressure (≥ 2 mmHg), allowing for arterial occlusion. This pressure, also referred to as the lowest effective occlusion pressure (LOP), can be detected by the Delfi system for each participant using an integrated blood pressure measurement via the tourniquet cuff to determine the pressure required to cause the distal pulse to disappear (19). Following all baseline muscle mass and strength testing, LOP was determined in duplicate for each participant and the average of these two values was used to set the pressure for circulatory occlusion used throughout the study. Tourniquet pressure ranged from 180-290mmHg across participants. Circulatory occlusion lasted 5-min and was performed 3 times, each separated by 5-min of reperfusion. No participant reported undue pain or discomfort during the leg circulatory occlusion.

*Blood flow Restriction + Electrical Muscle Stimulation*

BFR was performed in an identical method to the BFR treatments described above. Throughout the 3 cycles of BFR treatment, EMS was applied continuously to the left quadriceps.
For EMS training, identical custom electrode pads and positioning were paired with a high voltage stimulator (Digitimer), as described for muscle stimulation during ITT (above). The EMS protocol consisted of a duty cycle of 6 s on (stimulation) and 15 s off (no stimulation) with the pulse width set at 200 µs and the stimulation frequency set at 60Hz (20). EMS was delivered at a stimulation intensity or electrical current (submaximal) that produced knee extensor torque equal to 15% MVC (20). The electrical current that produced knee extensor torque equal to 15% MVC was measured by the dynamometer during the baseline knee-extension MVC testing and used throughout the training period. Electrical stimulation was well tolerated by all subjects, and no participant in any group experienced an adverse event related to EMS training.

Statistics

Baseline characteristics between treatment groups were compared using a one-way ANOVA. Pre- and post- interventional data were analyzed using a two-way mixed ANOVA with time (pre vs. post) as the within-subjects factor and treatment (Control vs. BFR vs. BFR+EMS) as the between-subjects factor. In case of significant interaction, a one-way repeated measure ANOVA was performed within each treatment group to determine simple main effects for time. To determine differences in simple main effects for time between groups, a one-way ANCOVA of change scores with pre values as a covariate with post-hoc pairwise comparisons was performed. Statistical significance was set at p ≤0.05. All analyses were performed using SPSS version 26 (SPSS Inc., Chicago, IL, USA). All data are expressed as mean ± standard deviation (SD) of the mean unless specified otherwise.
RESULTS

Subjects

Descriptive participant characteristics are provided in Table 1. Total body mass significantly decreased after 2 weeks of unloading in the control group (-0.66 ± 0.88 kg; p = 0.04); whereas total body mass did not significant change after 2 weeks of unloading in the BFR group (-0.36 ± 1.0 kg; p = 0.30) or in the BFR+EMS group (+0.15 ± 0.96 kg; p = 0.64).

Muscle Mass

Thigh Lean Mass

There was a statistically significant interaction by intervention group (partial $\eta^2 = 0.84$; p = 0.004) over the course of the unloading period when considering whole-thigh lean tissue mass, as measured by DEXA. Whole-thigh lean tissue mass of the experimental leg did not significantly change after 2 weeks of unloading in the BFR+EMS group (-12 ± 150 g; partial $\eta^2 = 0.006$; p = 0.8). In contrast, whole-thigh lean tissue mass of the experimental leg significantly decreased by 4 ± 1 % after 2 weeks of unloading in the control group (- 214 ± 117 g; partial $\eta^2 = 0.84$; p < 0.001) and by 3 ± 2 % in the BFR group (- 138 ± 77 g; partial $\eta^2 = 0.76$; p = 0.001; Figure 2A). The decrease in whole-thigh lean tissue mass in the control group was not significantly different from the decrease in the BFR group (ANCOVA: F = 6.88, p = 0.004; pairwise comparison: p = 0.1; Figure 2B).

Vastus Lateralis Muscle Thickness

There was a statistically significant interaction of interventions and time on VL muscle thickness (partial $\eta^2 = 0.28$; p = 0.03), as measured by ultrasound. Muscle thickness of the left leg VL
significantly decreased by 7% after 2 weeks of unloading in the control group (-0.19 ± 0.12 cm; partial $\eta^2 = 0.71$; $p = 0.005$). In contrast, muscle thickness of the left leg VL did not significantly change after 2 weeks of unloading in the BFR+EMS group (+0.09 ± 0.22 cm; partial $\eta^2 = 0.163$; $p = 0.07$) or BFR alone group (-0.19 ± 0.26 cm; partial $\eta^2 = 0.34$; $p = 0.07$; Figure 3A). However, the change in left VL muscle thickness after 2 weeks of unloading in the BFR+EMS group (+4%) was significantly different than the change after 2 weeks of unloading in the BFR group (-8%; ANCOVA: $F = 4.03$, $p = 0.03$; pairwise comparison: $p = 0.02$; Figure 3B). These slight differences in outcomes compared to whole thigh lean mass measured using DEXA likely represent regional differences in adaptation, as DEXA captures whole thigh changes whereas ultrasound was used to more specifically target the VL.

Muscle Strength

Following the intervention, all groups revealed a decrease in knee extension MVC strength over time (partial $\eta^2 = 0.594$; $p < 0.005$, Figure 4A). Notably, the control group declined by 18% (-32 ± 23 Nm), the BFR group declined by 10% (-17 ± 17 Nm), and the BFR+EMS group declined by 18% (-24 ± 20 Nm). Following the intervention, voluntary activation remained high and unchanged in all groups (partial $\eta^2 = 0.046$; $p = 0.282$, Figure 4B). The decrease in knee extension MVC strength was not different between groups (ANCOVA: $F = 0.94$, $p = 0.40$; Figure 4C)

DISCUSSION

Herein we present novel evidence that repeated BFR+EMS treatment entirely preserves skeletal muscle mass during a period of limb disuse. Despite this preservation of lean mass,
repeated BFR+EMS treatment did not preserve strength during a period of limb disuse, and the protection against disuse atrophy was not apparent when BFR was performed in isolation.

To our knowledge, no previous study has investigated the effects of BFR+EMS treatment on preserving skeletal muscle mass and strength during a period of limb disuse, and the applications of this technique could have important implications for clinical care. Data reported here suggests that repeated BFR+EMS treatment represents an effective interventional strategy to attenuate muscle disuse atrophy, which is known to lead to reduced functional capacity (21-23), a shift in fuel metabolism (24), impaired muscle insulin sensitivity (25), a decline in basal metabolic rate (26, 27), and an increase in body fat mass (28). Given the ability to use BFR+TEMS as a “passive” treatment modality requiring no external load, these data are relevant to persons immobilized from injury or illness, persons who are differentially-abled or confined to a wheelchair, astronauts living in reduced gravity environments, or others seeking to minimize the consequences of muscle disuse atrophy. Specific applications to those rehabilitating from sports and orthopaedic injuries are perhaps obvious, and with the known association of muscle mass with cardiometabolic health and acute blood sugar maintenance through glucose uptake (29, 30), it is possible that further applications exist for persons who are faced with acute or chronic forced sedentarism. Despite the potential of BFR+EMS treatment to be an effective strategy in a variety of muscle disuse situations, it should be acknowledged that the current results may not be generalizable to all situations as participants randomized to the current study were young and healthy. Further study should determine whether the effects of BFR+EMS treatment could prevent additional functional (e.g. activities of daily living, return to strength)
and physiological (e.g. blood flow, glycemic control) impairments caused by muscle disuse atrophy.

This study was unable to mechanistically discern why BFR+EMS treatment prevents losses in muscle mass; however, it is well known that muscle disuse atrophy is characterized by an imbalance between muscle protein synthesis and breakdown rates (31, 32). Prior work suggests that metabolic stress resulting from the accumulation of metabolic byproducts can promote muscle protein synthesis and inhibit breakdown via several mechanisms including hormonal release, ROS production, and cell swelling (18, 33, 34). While isolated BFR treatment did not stimulate this effect in the current study, it seems likely that the addition of muscle contractions under ischemia induce sufficient metabolic stress to prevent an imbalance between muscle protein synthesis and breakdown rates. At present, this remains speculative and requires further investigation, but previous work combining BFR with EMS has further demonstrated this technique to be effective for eliciting gains in strength and hypertrophy, even outside the confines of a muscle disuse model (12, 13). Data were not collected on the effect of EMS alone on limb disuse atrophy, thus, we are unable to conclusively state whether the preservation of muscle mass was a result of the combination of BFR and EMS or EMS alone, which remains a limitation of this study. Indeed, EMS treatment has existed for many years, and recent systematic reviews on muscle wasting report inclusive evidence to support the use of neuromuscular electrical stimulation as an independent modality (35, 36). However, we believe that BFR+EMS likely presents a more effective method to attenuate muscle loss compared to EMS alone as a previous study shows a greater recruitment of muscle fibers when blood flow is restricted during electrically evoked muscle contractions (37) compared to when electrically evoked muscle
contractions are performed without blood flow restriction. Future study is needed to directly compare the effects of BFR+EMS and EMS alone on limb disuse atrophy. It should also be acknowledged that data were not collected on a time-matched control group who did not undergo immobilization; thus, we were unable to compare within-group changes of each outcome measure to the random error of each outcome measure across time.

The data reported here that demonstrate no effect of isolated BFR treatment on muscle mass or strength during a period of disuse differ from prior work. For example, Takada et al. (9) reported that isolated BFR treatment attenuated muscle mass loss during recovery from ACL reconstructive surgery, whereas Kakehi et al. (38) reported that isolated BFR treatment attenuated muscle mass loss during 14 days of cast immobilization. However, these studies (9, 38) reported a much higher rate of muscle loss among participants that received no treatment (> 1.0 % decrease per day) compared to participants that received no treatment in the current study (~ 0.3% decrease per day). Therefore, the BFR treatment effect may only be sufficient to attenuate high rates of muscle atrophy suffered from severe disuse and wasting. Furthermore, a recent study by Kubota et al. (10) reported that BFR treatment attenuated strength losses during a 14 day period of experimental muscle disuse using cast immobilization. While a majority of treatment variables remained the same (number of sessions per day, occlusion pressure, participant age/activity status), methodological discrepancies between the current work and this prior study (10) include the number of treatment sessions per week and the number of BFR cycles per treatment session, wherein Kubota et al. used BFR treatment 7 days per week and 5 BFR cycles per session, compared to our use of 5 days per week and 3 BFR cycles per session. It is thus possible that treatment frequency or volume alters the physiological response; however,
the specific role of altering the temporal patterns of BFR application for preserving strength requires further investigation.

In contrast to the finding that repeated BFR+EMS treatment preserves muscle mass during disuse, our data indicates that repeated treatment does not sustain strength following limb disuse and decreases in strength were not due to decreases in percent voluntary activation. While skeletal muscle mass is commonly associated with strength, there are several neural factors also involved (39). Previous work suggests that losses in neural factors, not losses in muscle mass, are mainly responsible for declines in strength during early stages of disuse (40). Our study similarly shows a greater relative decline in strength when compared to the loss of muscle mass, which is consistent with previous work (41, 42). This explains why BFR+EMS treatment was not able to prevent losses in strength despite preserving muscle mass. We speculate that BFR+EMS treatment would be more applicable to preserving strength during prolonged periods of disuse, when muscle mass loss becomes the main cause of the decline in strength. Alternatively, local changes to the muscle fiber may also explain the greater relative decline in strength compared to the loss of muscle mass. It is also worth noting that the only assessment of strength was immediately after the unloading period. Thus, it remains unknown whether BFR+EMS treatment during disuse can facilitate a faster return of neural or local muscle fiber factors after the disuse period.

In conclusion, the combined treatment of BFR+EMS uniquely preserves muscle mass during a period of limb disuse, while BFR treatment without EMS did not protect against this expected disuse atrophy. These results suggest that BFR+EMS treatment, but not BFR treatment
alone, represents an effective interventional strategy to attenuate muscle atrophy during a period of disuse and this may have implications across a variety of health and performance applications wherein disuse cannot be avoided.
ACKNOWLEDGMENTS

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CONFLICT OF INTEREST

The authors have no conflict of interest to disclose. The results of this study do not constitute endorsement by ACSM and are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation.

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FIGURE CAPTIONS

Figure 1. Experimental Protocol for participants who were randomly allocated into either the control (CON; \( n = 10 \)), BFR \( (n = 10) \), or BFR+EMS \( (n = 10) \) group.

Figure 2. Panel A - lean tissue mass of the whole left thigh in the control (CON), blood flow restriction (BFR), and blood flow restriction + electrical muscle stimulation (BFR+EMS) treatment groups, before (Pre) and after (Post) 14 days of left-leg unloading, as measured by dual energy x-ray absorptiometry. * \( P <0.05 \). Panel B - change in lean tissue mass of the whole left thigh in the CON, BFR, and BFR+EMS treatment groups after 14 days of left-leg unloading, as measured by dual energy x-ray absorptiometry. * \( P <0.05 \) versus CON; ** \( P <0.05 \) versus BFR; All Data are expressed as means ± SEM.

Figure 3. Panel A - muscle thickness of the left vastus lateralis in the control group (CON), blood flow restriction (BFR), and blood flow restriction + electrical muscle stimulation (BFR+EMS) treatment groups, before (Pre) and after (Post) 14 days of left leg unloading, measured using ultrasound. # \( P = 0.07 \); * \( P <0.05 \). Panel B - displays change in muscle thickness (cm) of the left vastus lateralis in the CON, BFR, and BFR+EMS treatment groups after 14 days of left-leg unloading, measured using ultrasound. * \( P <0.05 \) versus CON; ** \( P <0.05 \) versus BFR; All Data are expressed as means ± SEM.
Figure 4. Panel A - left leg knee-extension maximal voluntary contraction (MVC) strength and corresponding voluntary activation (Panel B). Data is presented for the Control (CON), blood flow restriction (BFR), and blood flow restriction + electrical muscle stimulation (BFR+EMS) treatment groups, before (Pre) and after (Post) 14 days of left leg unloading. * P < 0.5 represents a significant main effect for time. Panel C - change in left leg knee-extension MVC strength (Nm) in the CON, BFR, and BFR+EMS treatment groups after 14 days of left-left unloading. Data are expressed as means + SEM.
Figure 1
Figure 2

A

B

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Figure 3
Figure 4
<table>
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<tr>
<th></th>
<th>Total (n = 30)</th>
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<th>BFR (n = 10)</th>
<th>BFR+EMS (n = 10)</th>
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<td>167 ± 73</td>
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Values are means ± SD