Adaptations to Low–Load Resistance Training with Blood-Flow Restriction: A Pilot Study

For correspondence:
l.j.macgregor1@stir.ac.uk

Lewis J Macgregor[1] and Valerio Biancone[1]

[1]Faculty of Health Sciences and Sport, University of Stirling

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Author Lewis Macgregor *@LJMac_SportSci* can be reached on Twitter.

ABSTRACT

Purpose: To assess early adaptations in strength, hypertrophy, and muscle contractile properties to resistance exercise using low loads with blood-flow restriction (BFR) compared to high loads, among novice resistance exercisers.

Methods: A convenience sample of seven healthy-active, but non-resistance trained individuals completed seven training sessions involving unilateral leg press and leg extension. One leg was trained using low-load (40% of 1-RM) with BFR, the other was trained using high-load (80% of 1-RM). Pre- and post-training: 1-RM leg press and leg extension, and MVC knee extension were measured to assess strength; and thigh circumference and volume were measured to estimate quadriceps mass. Tensiomyography was used to measure muscle stiffness and contraction velocity of vastus lateralis pre-, mid- (before the fourth training session), and post-training.

Results: Leg extension 1-RM (P = 0.001), knee extension MVC (P = 0.019), and thigh circumference (P = 0.001) and volume (P = 0.001) increased following both resistance training conditions. Leg press 1-RM (P = 0.103) and vastus lateralis stiffness (P = 0.483) and contraction velocity (P = 0.585) did not change with training. There were no differences between conditions nor interactions between condition and time for any variable.

Conclusion: Seven resistance training sessions increased strength and markers of muscle mass. Greater relative demand of leg extension exercise may explain the improved 1-RM and knee extension MVC observed, while leg press 1-RM remained unchanged. Similar early adaptations to resistance exercise may be achieved using relatively low loads accompanied by BFR. These findings may be useful in instances when exercising with higher loads is undesirable.

Introduction

Resistance training induces neuromuscular changes resulting in increased strength and skeletal muscle mass (hypertrophy). To optimize strength and hypertrophy gains, current guidelines recommend training with relatively high loads exceeding 60% of one-repetition maximum (1-RM)[1]. Such loads are suggested to recruit close to the whole motor unit pool, including MUs with the highest activation threshold, maximising neuromuscular adaptation to exercise[2]. When commencing a resistance training programme, the nervous system adapts to the new stimuli, leading to gradual adaptations including increased musculotendinous stiffness, faster motor unit recruitment and firing rate, reduced α-motor neuron inhibition, and greater motor unit synchronisation[3,4]. These neural adaptations are responsible for the initial strength improvements observed soon after the start of a new training programme;

subsequently, further strength gains can be attributed to muscle hypertrophy[3]. However, in specific circumstances such as during injury rehabilitation[5] or in advanced age[6], high-load resistance training may not be feasible or may be perceived to be undesirable.

Blood-flow restriction (BFR) resistance training - combining relatively low-load resistance exercise with blood-flow occlusion - has demonstrated similar strength and hypertrophy benefits to high-load training[7,8]. As such, BFR has become increasingly popular among resistance training professionals in recent years[9,10,11]. Occluding blood-flow in the exercising limb limits arterial flow and fully restricts venous return of deoxygenated blood. The resultant blood pooling creates a hypoxic environment with consequent accumulation of metabolites, simulating metabolic fatigue and additional MU recruitment ordinarily observed when exercising with far greater loads[12]. Combining BFR with low-load training has been shown to stimulate hypertrophic responses early after the onset of training, allowing for gains in muscle mass that are not typically associated with the initial weeks of a new resistance training programme[13]. It remains unclear whether initial gains in strength are driven entirely by neural adaptation, as observed in traditional training, or in-part by early-onset hypertrophy[14].

Changes in muscle architecture (muscle thickness and pennation angle) - typically reported after 5-14 weeks of resistance training - are associated with enhanced force production[15,16]. Increases in pennation angle are associated with increased physiological cross-sectional area[17,18,19], which is believed to increase force production, as observed following resistance training. Such changes in architecture, as a result of resistance training, may alter contractile properties of the muscle. Non-invasive mechanomyographic methods such as tensiomyography (TMG) can be used to assess muscle contractile properties[20,21]. TMG allows contractile properties of individual muscles to be evaluated by measuring spaciotemporal parameters during a single evoked twitch[22]. Contraction time (Tc) and muscle belly radial displacement (Dm) are commonly recorded from the twitch-time curve[20]. Dm represents muscle belly stiffness[23] and is altered by fatigue[24,25] and training status[26,27,28]. Tc is related to muscle fibre-type composition[29,30,31], but is a measure of time, not rate; to measure contraction rate we[25] and others[32,33] propose the calculation of contraction velocity (Vc) as the change in Dm over time (*i.e.*, Dm/Tc). We previously demonstrated that changes in Dm reflected changes in muscle thickness and pennation angle following a 6-week resistance training programme[21]. Further longitudinal studies, integrating TMG assessment of contractile properties with well-understood physiological measures, are required to further validate the applications of TMG as an assessment of resistance training adaptation[20].

In this pilot study, we aimed to assess the early adaptations to BFR resistance training with low loads among novice resistance exercisers. Thigh volume was measured as a surrogate of quadriceps mass, and strength was assessed through 1-RM and maximal voluntary contraction (MVC). TMG was used to assess muscle contractile properties (Dm and Vc). The pilot data collected during this study will be used to inform future study designs. We hypothesised that during a 4-week lower-limb resistance training programme BFR training will lead to more-rapid gains in muscle mass and strength than traditional high-load training – and that these rapid adaptations will be reflected by decreased Dm and increased Vc.

Methods

Participants

Seven non-resistance trained, but otherwise healthy and active, individuals (3 male; 4 female) were recruited via convenience sampling to take part this study; one male participant was excluded following pre-screening (due to systolic blood pressure > 130 mmHg). The remaining six participants (age 32 (6) years, height 1.70 (0.08) m, body mass 66.4 (14.2) kg, BMI 22.2 (2.7) $kg{\cdot}m^{-2}$) provided written informed consent after being fully informed about nature of the study, its risks, and possible outcomes. During pre-screening, all eligible participants completed a physical activity readiness questionnaire. The study was approved by the local Research Ethics Committee (approval number 2433), and all procedures performed were in accordance with the ethical standards set out in the latest amendment of the Declaration of Helsinki. Participants were eligible if they were aged 18-40 years, had not engaged in any resistance exercise within six months prior participating in the study, had no known history of neuromuscular or musculoskeletal disorders, had BMI < 30 $kg{\cdot}m^2$ and systolic blood pressure < 130 mmHg. Since strength and hypertrophy responses vary across different phases of the menstrual cycle, the first day of female participants' previous menses was noted[34]. For the duration of the study participants were instructed to maintain habitual diet and aerobic physical activity.

Experimental Design

Participants underwent full familiarisation of the exercise and assessment procedures involved in the study. Unilateral one repetition maximum (1-RM) leg press and leg extension were assessed for dominant and non-dominant legs; 1-RM was assessed twice, during sessions separated by 72-96 hours. The second 1-RM was recorded for further analysis and was used to prescribe training loads. During a separate session, baseline measurements of thigh volume, vastus lateralis (VL) contractile properties, and maximal voluntary isometric knee extension (MVC) were recorded. Following determination of 1-RM and baseline measurements, participants attended seven training sessions separated by 48-72 hours. During training sessions leg press and leg extension exercises were performed unilaterally; dominant and non-dominant leg were allocated to either high-load (HL) or low-load with blood-flow restriction (BFR) via block randomization. Forty-eight hours after the final training session, thigh volume, VL contractile properties, MVC, and 1-RM were reassessed. A further assessment of VL contractile properties was completed between the third and fourth training sessions (Figure 1). All measurements were performed by the same skilled investigator.

Figure 1. Study design schematic (resistance training = 7 sessions unilateral leg press and leg extension, dominant and non-dominant leg were randomly assigned low-load blood-flow restriction or high-load. 1-RM = one repetition maximum; TMG = muscle contractile properties measured with tensiomyography; MVC = maximal voluntary isometric knee extension contraction.

One Repetition Maximum (1-RM) and Resistance Training

Unilateral 1-RM was determined for leg press and leg extension according to the protocol described elsewhere[35,36]. Briefly, two sets of 10 repetitions were performed using loads of 40% and 60% of predicted 1-RM, respectively. Next, three sets were performed: 3 repetitions at 75% of predicted 1-RM, and 1 repetition each at 90% and at 100% of predicted 1-RM. Load was then increased by ~2.25 kg until the participant was unable to complete a repetition. A rest period of 120 seconds was taken between each set or following a failed attempt. Up to two attempts were permitted for each load. Values for 1-RM determined in the familiarisation session were used as predicted 1-RM in the subsequent session. The second 1-RM determined was used to prescribe training loads for all training sessions.

All training sessions were scheduled for the same time of the day and participants were asked to follow the same routine for the 24 hours leading up to each session. Training sessions were completed in the order: i) leg press (leg 1), ii) leg press (leg 2), iii) leg extension (leg 1), iv) leg extension (leg 2); leg 1 and leg 2 were randomly assigned to HL or BFR for each participant. A similar warm-up set was performed for each leg and exercise: 20 repetitions were performed without blood-flow restriction, using a load equivalent to 40% of 1-RM. Following warm-up three sets were performed for each condition: HL consisted of 10 repetitions at a load of 80% of 1-RM for two sets, followed by a set of as many repetitions as possible (AMRAP); BFR consisted of 25 repetitions at a load of 40% of 1-RM for two sets, followed by a set of AMRAP. A rest period of 60 seconds was taken between each set, 120 seconds was taken between exercises. The actual number of repetitions successfully performed can be seen in Table 1.

For BFR, a 195 mm wide latex-free occlusion cuff (Ambidex Large Adult One-Piece Velcro Cuff Double Tube, Accoson, Irvine, UK) was positioned proximally around the thigh. The cuff was inflated to a pressure equivalent to 80% of systolic blood pressure (87.3 (SD 10.4) mmHg). The cuff remained inflated for the duration of three BFR sets, including throughout 60 second rest periods.

Maximum Voluntary Isometric Contraction (MVC)

To assess peak torque, participants were secured to an isokinetic dynamometer (Biodex Medical Systems, Inc. New York, USA) using a Velcro strap proximal to the medial malleolus. Participants were instructed to perform three 5 second isometric knee extension contractions at 60° knee flexion (0° = full extension), with 60 seconds rest between contractions[37]. Consistent verbal motivation was provided during all testing to ensure maximum effort throughout contractions[38]. Before maximal contractions, an isometric warm-up was performed consisting of three contractions at 50% of perceived maximal effort, followed by three contractions at 75% of perceived maximal effort[39]. Following warm-up, participants contracted the quadriceps of the involved limb to exert peak force as quickly as possible and held each contraction for 5 seconds. The highest force output achieved across the three attempts was designated MVC and was recorded for analysis.

Table 1. Mean (SD) number of leg press (LP) and leg extension (LE) repetitions successfully performed during each training session. Low-load blood-flow restriction (BFR) was performed at 40% of 1-RM, high-load (HL) was performed at 80% of 1-RM.

		Session 1		Session 2		Session 3		Session 4		Session 5		Session 6		Session 7	
		LP	LE	LP	LE	LP	LE	LP	LE	LP	LE	LP	LE	LP	LE
BFR	Set 1	25.0 (0.0)	16.4 (5.0)	25.0 (0.0)	18.5 (2.3)	25.0 (0.0)	16.8 (1.3)	25.0 (0.0)	20.0 (2.9)	25.0 (0.0)	23.2 (2.5)	25.0 (0.0)	21.8 (2.6)	25.0 (0.0)	23.7 (2.1)
	Set 2	25.0 (0.0)	8.2 (3.3)	25.0 (0.0)	10.5 (4.5)	25.0 (0.0)	9.4 (3.2)	25.0 (0.0)	10.7 (3.3)	25.0 (0.0)	12.4 (2.6)	25.0 (0.0)	12.7 (5.6)	25.0 (0.0)	13.2 (4.9)
	Set 3	31.0 (5.3)	8.4 (3.8)	38.7 (12.4)	8.7 (4.4)	54.2 (20.2)	8.4 (3.3)	54.8 (12.9)	8.3 (2.7)	55.2 (12.8)	10.6 (5.4)	70.2 (21.1)	10.5 (4.7)	73.5 (22.7)	10.2 (1.9)
HL	Set 1	10.0 (0.0)	6.2 (2.6)	10.0 (0.0)	8.5 (1.5)	10.0 (0.0)	7.0 (1.2)	10.0 (0.0)	8.8 (1.5)	10.0 (0.0)	9.2 (1.8)	10.0 (0.0)	9.2 (2.0)	10.0 (0.0)	9.3 (1.6)
	Set 2	10.0 (0.0)	5.8 (1.5)	10.0 (0.0)	7.8 (2.0)	10.0 (0.0)	7.0 (2.8)	10.0 (0.0)	7.5 (2.6)	10.0 (0.0)	8.0 (2.4)	10.0 (0.0)	8.7 (2.4)	10.0 (0.0)	8.5 (2.1)
	Set 3	14.2 (7.2)	4.2 (2.4)	16.5 (9.2)	6.7 (2.9)	18.2 (7.9)	6.4 (2.5)	21.2 (9.3)	7.5 (4.0)	18.8 (10.3)	8.2 (3.3)	23.2 (11.8)	9.3 (4.2)	23.5 (8.9)	10.2 (4.5)

BFR Set 1 and Set 2 = 25 repetitions, Set 3 = AMRAP. HL Set 1 and Set 2 = 10 repetitions, Set 3 = AMRAP.

Thigh Volume

A flexible, non-stretch, woven fabric tape measure was used to measure thigh circumferences during before and after the resistance training programme. First, with the participant was seated on the edge of a chair with knee flexed to 90°, the greater trochanter and the superior pole of the patella were located by palpation, the distance between these two anatomical landmarks was noted to allow for accurate replication during post-intervention measurement (38.2 (SD 3.1) cm). Thigh circumference was next measured with the participant standing in anatomically neutral position; circumference measurements were taken at ¼ (C_1), ½ (C_2), and ¾ (C_3) of the distance between the patellar superior pole and greater trochanter (9.6 (SD 0.8) cm, 19.1 (SD 1.6) cm, and 28.6 (SD 2.3) cm, respectively). Thigh volume was quantified using the frustum sign model method originally described by Katch and Katch (1974)[40].

Contractile Properties

Before, after, and at the mid-point of the resistance training programme, TMG was used to assess contractile properties of VL. A digital TMG sensor (GK 40, Panoptik d.o.o., Ljubljana, Slovenia), with 1 µm sensitivity, was placed perpendicular to the thickest part of the VL muscle belly, identified by palpation of the site. Two 5 cm^2 self-adhesive electrodes (Axelgaard, USA) were affixed 5 cm proximal and distal to the sensor creating a 10 cm inter-electrode distance (centre to centre). The final position of electrodes and sensor were marked and measured with reference to the anterior superior iliac crest and superior pole of the patella to allow accurate replication. Participants remained in supine position with the limb rested unfixed on a supportive pad which maintained a knee angle of 60° (0° = full knee extension) (Figure 2). A single 1 ms wide square wave stimulation (TMG S2, TMG-BMC Ltd., Ljubljana, Slovenia) was applied at an initial amplitude of 20 mA with a constant voltage of 30 V. Stimulation amplitude was progressively increased by 10 mA every 10-15 seconds, until a plateau in the displacement-time curve was observed. This peak twitch-time curve was recorded using TMG software (Version 3.6.16), the following parameters were extracted to assess contractile properties: maximal radial displacement (Dm) [mm], contraction time during the linear portion of the ascending phase of the curve (10-90% of Dm) (Tc) [ms], and contraction velocity during the linear portion of the ascending phase of the curve, calculated as (0.8·Dm)/Tc (Vc) [$mm \cdot s^{-1}$][20].

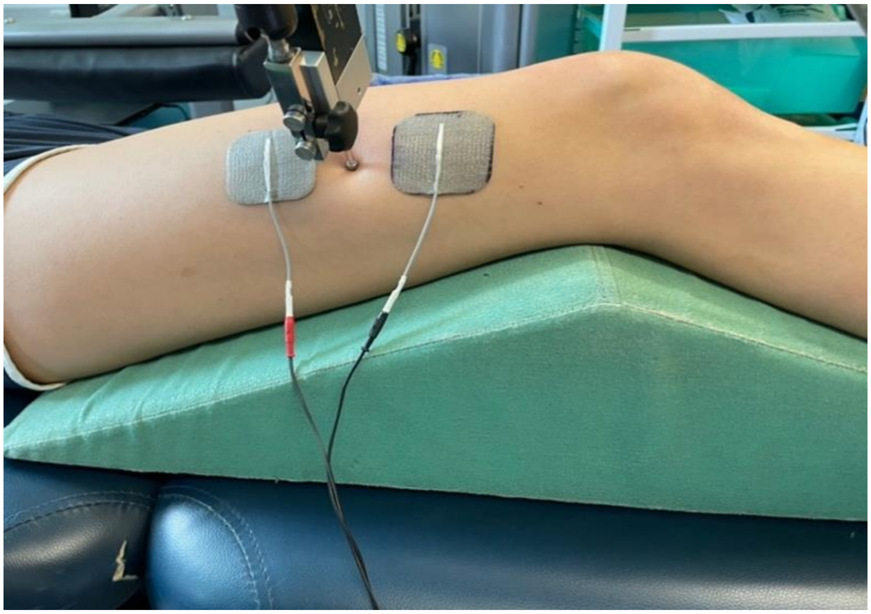

Figure 2. Positioning of electrodes and tensiomyography sensor for assessment of contractile properties of vastus lateralis.

Statistical Analysis

Absolute MVC [Nm], Dm [mm], and Vc [$mm \cdot s^{-1}$] were analysed; leg press and leg extension 1-RM [$kg \cdot kg^{-1}$], and thigh circumference [$cm \cdot kg^{-1}$] and volume [$mL \cdot kg^{-1}$] were analysed relative to participant body mass on the day of testing. All results are presented as mean (SD). Despite the pilot nature of the sample, all variables were assessed for normal distribution (Ryan-Joiner test). Comparisons were performed using a two factor repeated measures (time × condition) analysis of variance (ANOVA) with Tukey post hoc analysis (Minitab 18.1 statistical software, Minitab Ltd., Coventry, UK). Statistical significance was accepted at $P < 0.05$. Effect sizes were determined using η^2p and interpreted as: < 0.06 = small, 0.06-0.14 = medium, and > 0.14 = large.

Results

There was a main effect of time ($F_{(1,5)} = 16.22$, $P = 0.001$, $\eta^2p = 0.76$) for 1-RM leg extension, but no difference between conditions ($F_{(1,5)} = 4.45$, $P = 0.052$, $\eta^2p = 0.47$) nor interaction between condition x time ($F_{(1,5)} = 0.00$, $P = 0.972$, $\eta^2p = 0.0003$). Specifically, 1-RM leg extension pulled across conditions increased from 0.56 (0.12) $kg \cdot kg^{-1}$ before training to 0.62

(0.11) kg·kg^{-1} after training (Figure 3A). Across the seven training sessions, participants performed greater ($F_{(1,5)}$ = 6.71, *P* = 0.011, η^2p = 0.57) volume-load with HL (680.9 (164.6) kg, 95% CI: 624.7, 737.2) than with BFR (577.4 (191.8) kg, 95% CI: 521.2, 633.7). 1-RM leg press did not alter over time ($F_{(1,5)}$ = 3.01, *P* = 0.103, η^2p = 0.38) nor between conditions ($F_{(1,5)}$ = 1.15, *P* = 0.301, η^2p = 0.19) (Figure 3B).

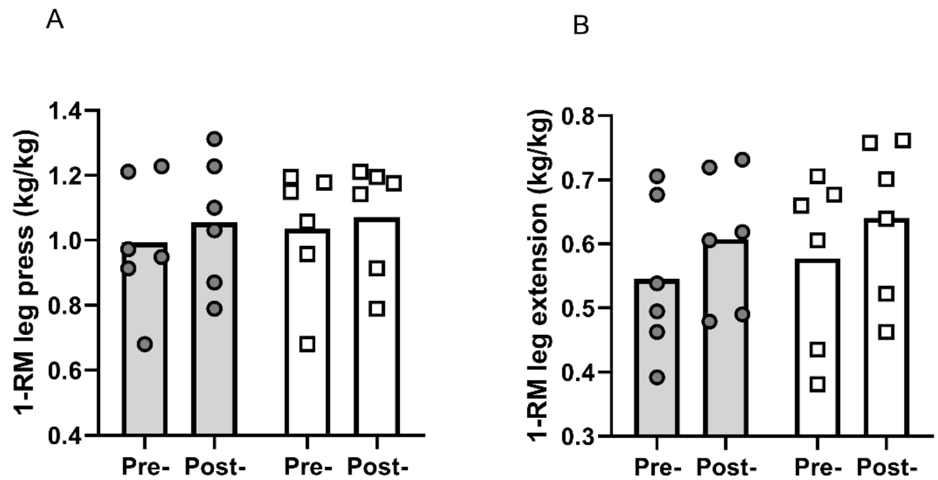

Figure 3. One repetition maximum leg press (A) and leg extension (B) pre- and post- seven training sessions with low-load blood-flow restriction (●) or with high-load (□). There was a main effect of time (*P* = 0.001) for leg extension, but no condition or interaction (time x condition) effects.

MVC knee extension displayed a main effect of time ($F_{(1,5)}$ = 6.90, *P* = 0.019, η^2p = 0.58), but no difference between conditions ($F_{(1,5)}$ = 0.62, *P* = 0.433, η^2p = 0.11) nor interaction between condition x time ($F_{(1,5)}$ = 0.29, *P* = 0.600, η^2p = 0.06). Specifically, MVC pulled across conditions increased from 182.9 (46.1) Nm before training to 202.2 (52.6) Nm after training (Figure 4).

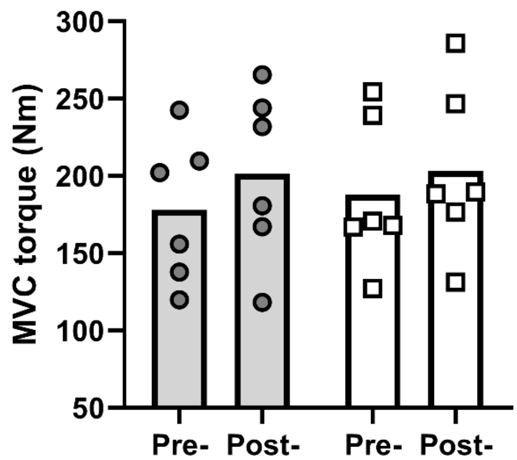

Figure 4. Maximal voluntary isometric knee extension pre- and post- seven training sessions with low-load blood-flow restriction (●) or with high-load (□). There was a main effect of time (*P* = 0.019), but no condition or interaction (time x condition) effects.

There was a main effect of time ($F_{(1,5)}$ = 18.55, *P* = 0.001, η^2p = 0.79) for mid-thigh circumference, but no difference between conditions ($F_{(1,5)}$ = 0.09, *P* = 0.766, η^2p = 0.02) nor interaction between condition x time ($F_{(1,5)}$ = 0.10, *P* = 0.755, η^2p = 0.02). Specifically, thigh circumference pulled across conditions increased from 0.79 (0.11) cm·kg^{-1} before training to 0.81 (0.11) cm·kg^{-1} after training (Figure 5A). Thigh volume showed a main effect of time ($F_{(1,5)}$ = 8.90, *P* = 0.009, η^2p = 0.64), but no main effect of condition ($F_{(1,5)}$ = 0.03, *P* = 0.859, η^2p = 0.01) nor an interaction between condition x time ($F_{(1,5)}$ = 0.01, *P* = 0.939, η^2p = 0.002). Specifically, thigh volume pulled across conditions increased from 58.48 (4.50) L·kg^{-1} before training to 60.04 (5.08) L·kg^{-1} after training (Figure 5B).

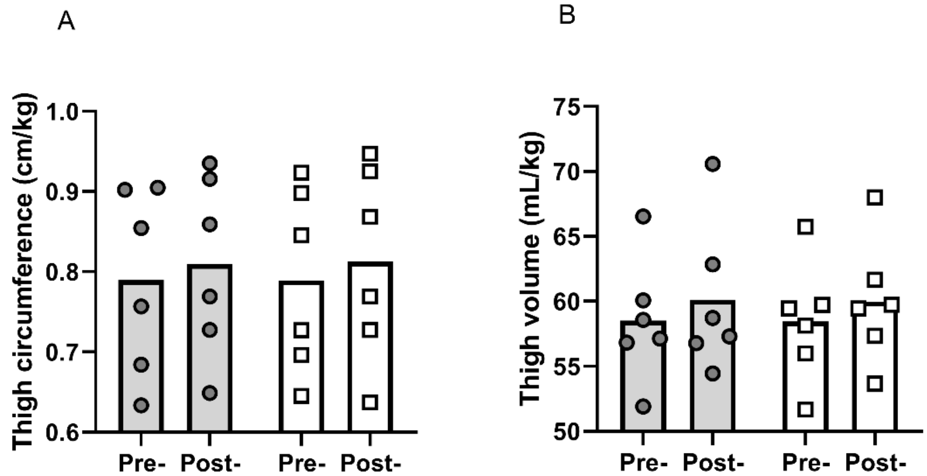

Figure 5. Mid-thigh circumference (A) and thigh volume (B) pre- and post- seven training sessions with low-load blood-flow restriction (●) or with high-load (◘). There were main effects of time for circumference (*P* = 0.001) and volume (*P* = 0.009), but no condition or interaction (time x condition) effects.

There was no main effect of time for vastus lateralis Dm ($F_{(2,5)}$ = 0.75, *P* = 0.483, η^2p = 0.23) nor Vc ($F_{(2,5)}$ = 0.55, *P* = 0.585, η^2p = 0.18). Neither was there a main effect of condition for Dm ($F_{(1,5)}$ = 0.04, *P* = 0.839, η^2p = 0.01) nor Vc ($F_{(1,5)}$ = 0.09, *P* = 0.773, η^2p = 0.04) (Figure 6).

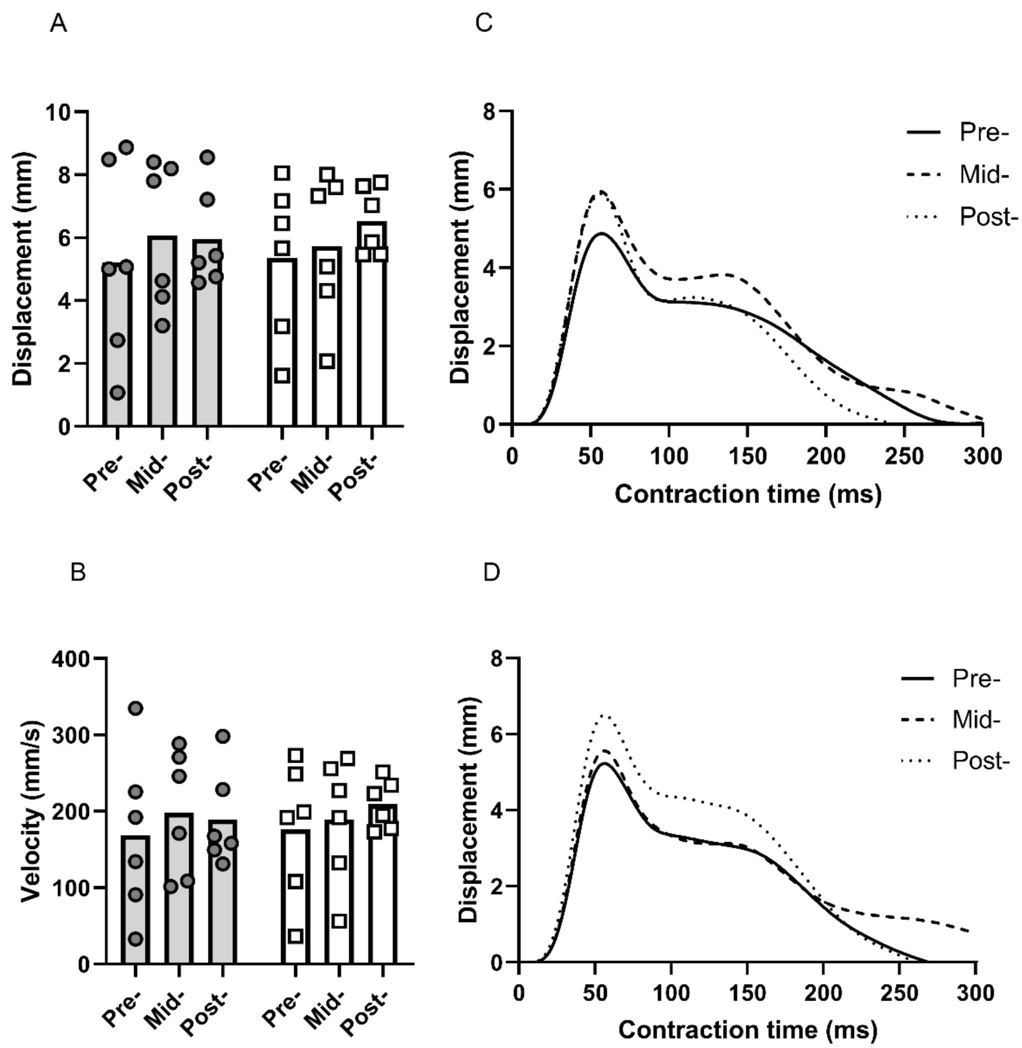

Figure 6. Radial displacement (A) and contraction velocity (B) of vastus lateralis pre-, at the mid-point, and post- seven training sessions with low-load blood-flow restriction (●) or with high-load (□); example twitch-time curves from a participant's leg trained with BFR (C) and HL (D).

Discussion

In this study, we aimed to compare responses to 4 weeks (7 sessions) of lower-limb unilateral resistance training between limbs, when one leg was trained using low-loads (40% of 1-RM) with blood-flow restriction and the other leg was trained using high-loads (80% of 1-RM). We assessed changes in lower-limb strength (1-RM of each trained exercise and MVC) thigh mass (circumference and volume), and vastus lateralis contractile properties (radial displacement and contraction velocity). We hypothesised that the brief timeframe of the resistance training programme would favour greater responses in the BFR limb compared to the HL limb. We observed an increase in thigh circumference and volume, knee extension MVC, and leg extension 1-RM following training. However, contrary to our hypothesis, there were no discernible differences between BFR and HL conditions. We found no change in vastus lateralis Dm and Vc at the mid-point nor at the end of the training period, and no change in leg press 1-RM.

Seven resistance training sessions consisting of 3 sets each of unilateral leg press and leg extension, conducted over the course of 4 weeks, resulted in 10.9% (23.3 (12.2) kg) and 7.2% (15.4 (10.2) kg) increases in leg extension 1-RM, for BFR and HL limbs respectively. Contrary to our hypothesis, applying BFR to low-load (40% of 1-RM) resistance training was not more effective than training with high-load resistance (80% of 1-RM). Non-movement-specific strength (MVC) similarly increased in both limbs, by 10.9% (182.9 (46.1) Nm) and 7.3% (15.4 (10.2) Nm), for BFR and HL limbs respectively. Previously accentuated strength gains have been described when resistance training at moderate- (50% of 1-RM)[41] or low-load (25% of 1-RM)[42] with BFR compared to the same load without BFR. Interestingly, since all sets could not be completed as prescribed, and since final sets were performed as AMRAP, our participants accumulated greater volume-load with HL than with BFR. Future studies might seek to investigate the early strength adaptations to identical volume-loads of resistance training with either BFR or HL. Nonetheless, that BFR required lower volume-load than HL to elicit similar strength gains lends some support to our original hypothesis that adaptation could be more-rapid with BFR.

It is notable that there was no improvement following training in leg press 1-RM, for either BFR (66.1 (23.2) vs. 70.3 (22.8) kg) or HL (68.0 (18.6) vs. 70.7 (18.8) kg) limbs. Unlike leg extension, all participants were able to complete all leg press sets as prescribed, with total repetitions completed across the 7 training sessions progressing from ~81 to ~125 repetitions (BFR) and from ~35 to ~45 repetitions (HL). By contrast, the mean number of leg extension repetitions completed increased from ~33 to ~48 BFR repetitions and from ~16 to ~28 HL repetitions, where the minimum targeted repetitions were 75 for BFR and 30 for HL. The greater difficulty in executing the leg extension portion of the training programme is evidence of heightened demand placed upon participants by that exercise compared to leg press. Greater demand may explain the increase in leg extension 1-RM and MVC, but absence of change in leg press 1-RM. Although MVC was included among the strength assessments to provide a non-movement-specific test (*i.e.*, a test which was dissimilar to the training stimuli), it is apparent that an isometric knee extension is more akin to leg extension than to leg press isoinertial exercise, so the similar improvements we have observed in leg extension 1-RM and MVC should perhaps not come as a surprise. Measurement of MVC also facilitates assessment of neuromuscular variables rate of force development[43] and voluntary activation[44], future studies could investigate these mechanistic variables to better understand early neuromuscular adaptations to BFR resistance training.

We observed increased mid-thigh circumference and thigh volume following training, but contrary to our hypothesis, these markers of hypertrophy were not different between groups. It is unexpected for changes in muscle mass to arise after as few as 7 training sessions spread over 4 weeks, as the earliest adaptations to strength training have long been understood to be predominantly neural[3,45]. The addition of BFR to resistance training at low loads has been shown to stimulate hypertrophy as early as 14 days into a new resistance training programme[46], but in that case, resistance exercise was performed daily. Additional evidence to support enhanced hypertrophic adaptations to BFR training exists in the acute elevation of growth hormone, which has been shown to be greater with BFR compared to identical load without BFR[47] or to higher load without BFR[48]. Although, it should also be acknowledged that systemic growth hormone concentration may not contribute to stimulating muscle protein synthesis or hypertrophy[49], instead, it is more likely that local elevations are important for muscle growth. The effect of BFR on local growth factor responses has not yet been established[41], but Fujita et al. (2007)[50] did report increased p70S6 kinase phosphorylation and muscle protein synthesis following low-load resistance exercise with compared to without BFR. While future studies may focus on local hormonal responses to BFR with low-load exercise, the lack of between-condition differences we have here observed, poses additional questions. The measurements used to assess muscle growth are somewhat crude, and more-robust imaging techniques – although not without their own limitations – would likely be more sensitive to change. Further, the ability to examine changes in muscle architecture, in addition to size, provides additional value in understanding skeletal muscle remodelling in response to resistance exercise.

Despite detecting increased muscle mass, we observed no discernible change in muscle stiffness nor contraction velocity. Elsewhere it has been demonstrated that TMG detects shorter contraction time and lower Dm associated with increased exposure to strength- and power-based training programmes[26,27,28], while elevated muscle stiffness (*i.e.*, reduced Dm) mediates increased force transmission[51,52]. Furthermore, we previously reported an inverse relationship between changes in Dm and changes in pennation angle and muscle thickness, following 6-weeks of resistance training[21]. Here, we did not utilise imaging techniques to examine muscle architecture, and as suggested above, we must be cautious when interpreting the detected changes in thigh circumference and volume to represent increased muscle thickness, so our findings do not provide any further insight into the relationship between TMG-derived Dm and muscle architecture. Nonetheless, it is interesting to note that we found no changes in Dm after three nor seven training sessions. Although changes in muscle contractile properties have been observed with muscle wasting during bed-rest after as little as 24 hours[32], the time required for observable hypertrophic alterations to be detected with TMG may be as long as 8 weeks[53], future studies attempting to better understand the changes in muscle belly stiffness associated with resistance exercise adaptation may choose to adopt a longer duration training period. Rate of contraction (Vc) also did not change during our study. Similar to Dm, a longer training intervention may shed further insight on this mechanical response to exercise, however the lack of change in Vc in the current study is less surprising since the exercises performed in training were not focussed on speed, which may be required to elicit changes in contraction velocity[54,55].

Conclusion

A short resistance training programme, consisting of only 7 sessions over 4 weeks, was sufficient to increase strength, and likely muscle mass, among healthy-active, but previously untrained individuals. The application of blood-flow restriction with relatively low training loads did not result in different adaptive responses compared to training with relatively high loads. This pilot study was unable to identify different mechanisms involved in early adaptation to resistance training, however we have highlighted a number of methodological considerations for future research in this area: to permit direct comparison between training modalities, programmes involving identical volume-load should be adopted; robust muscle imaging techniques are recommended to identify architectural changes in trained muscles; and resistance training should be continued for up to 8 weeks to allow more extensive adaptation to occur. Based on our initial findings, we cannot elaborate on potential mechanistic differences that may exist between low-load blood-flow restriction and high-load training, but the similar outcomes we have observed between conditions lends support to the use of blood-flow restriction training in circumstances where high training loads are unfavourable.

Contributions

Contributed to conception and design: LJM, VB
Contributed to acquisition of data: LJM, VB
Contributed to analysis and interpretation of data: LJM, VB
Drafted and/or revised the article: LJM, VB
Approved the submitted version for publication: LJM, VB

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Data and Supplementary Material Accessibility

The datasets generated during and/ or analysed during the current study are available from the corresponding author upon reasonable request.

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