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ORIGINAL PAPER

Influence of cuff material on blood flow restriction stimulus in the upper body

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Abstract The purpose of this study was to examine the acute skeletal muscle and perceptual responses to blood flow restriction (BFR) exercise to failure between narrow nylon and elastic inflatable cuffs at rest and during exercise. Torque and muscle thickness was measured pre, post, and 5, 20, 40, and 60 min post-exercise with muscle activation being measured throughout exercise. Resting arterial occlusion pressure was different between the nylon [139 (14) mmHg] and elastic [246 (71) mmHg, $p < 0.001$] cuffs. However, when exercising at 40 % of each cuff's respective arterial occlusion pressure [nylon: 57 (7) vs. elastic: 106 (38) mmHg, $p < 0.001$], there were no differences in repetitions to failure, torque, muscle thickness, or muscle activation between the cuffs. Exercising with cuffs of different material but similar width resulted in the same acute muscular response when the cuffs were inflated to a pressure relative to each individual cuff.

Keywords Arterial occlusion · Brachial systolic blood pressure · Brachial diastolic blood pressure

Introduction

Blood flow restriction (BFR), by itself or in combination with low-load resistance training, has been shown to elicit beneficial adaptations in skeletal muscle. For example, low-load resistance training in combination with BFR has been shown to lead to similar adaptations as traditional high-load resistance training [1–4]. In addition, the restrictive stimulus has been shown to promote a muscle hypertrophic response to low-intensity aerobic exercise [5], and appears to attenuate atrophy during prolonged skeletal muscle disuse [1]. The mechanisms through which BFR works are not completely understood; however, it is believed that muscle cell swelling, and metabolically induced changes in muscle fiber type recruitment are two of the primary contributors [6, 7]. Notably, less dependence on mechanical tension provides a safe alternative through which low-load resistance training may be used as a means to elicit marked increases in muscle size and strength. As such, BFR appears to provide a useful alternative for clinical populations, which may include: individuals recovering from injury [8], individuals coming off bed rest [9], or those limited by other musculoskeletal disorders, in whom the ability to perform traditional resistance exercise may be limited [8]. Additionally, BFR exercise has been shown effective in resistance-trained populations. For example, it has been shown to improve strength in college athletes when added to their existing resistance-training program [10, 11]. Therefore, this modality has vast applications to many different populations, both trained and untrained. As such, it is necessary to thoroughly understand the stimulus applied in order to prescribe the appropriate pressure to facilitate the desired adaptation.

With a growing understanding of BFR and its applications for skeletal muscle, recent work has focused on the

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proper application of the restrictive stimulus in order to elicit the intended response. Specifically, within the literature there has been a gradual move towards standardization, particularly with regard to cuff size and the application of relative [3, 12–14] as opposed to absolute [15, 16] restrictive pressures. Additionally, recent work has shown that limb circumference explains a large portion of the unique variance of the occlusion stimulus in both the upper and lower body [17, 18]. However, within the BFR literature, not all methodological concerns have been addressed. Specifically, depending on the device, cuffs are made from different materials. For example, the most commonly used cuff inflators, Hokanson and Kaatsu, utilize nylon and elastic cuffs, respectively. In addition, each manufacturer makes a "narrow cuff" (nylon 5 cm and elastic 3 cm) that is commonly utilized for the upper body [19]. Loenneke et al. [20] examined differences in cuff type (nylon vs. elastic) in the lower body, finding that there were no differences in the repetitions to fatigue or perceptual response between different type of cuffs, suggesting that the BFR stimulus was relatively similar. However, differences in cuff type have not been examined in the upper body. This is potentially problematic, as similar protocols are often employed despite different cuff materials used [19, 21]. If the cuff type (nylon vs. elastic) does in fact influence the restrictive stimulus, the intended pressure may be under or over-prescribed. In addition, due to anatomical differences, previous results from the lower body cannot necessarily be applied to upper-body exercise. Therefore, the purpose of the current study was to examine the acute skeletal muscle and perceptual responses to BFR exercise to failure between nylon and elastic cuffs, which are typically used in the literature. In doing so, we answer the following questions:

1. Is resting arterial occlusion in the upper body different between two narrow cuffs made of different materials?
2. Is exercise to fatigue (surrogate marker of blood flow) different between two narrow cuffs made of different materials?
3. Are the acute skeletal muscle and perceptual responses different between two narrow cuffs made of different materials?

Methods

Participants

Seventeen resistance-trained (regularly performing upper-body resistance training) males and females volunteered for the present study. Two individuals did not complete all of the testing sessions; therefore, their data were excluded from all further analyses. Thus, 15 young adults (12 males, three females) were included in the present analysis. All participants were instructed to refrain from: (1) eating 2 h prior and (2) consuming caffeine 8 h prior to arterial occlusion measurements during the first visit. In addition, participants were instructed to refrain from exercise 24 h before all visits. Participants were excluded if they had more than one risk factor for thromboembolism [22], which included the following: obesity (BMI $\geq$30 kg/m^2); diagnosed Crohn's disease; a past fracture of the hip, pelvis or femur; major surgery within the last 6 months; varicose veins; a family history of deep vein thrombosis or pulmonary embolism; personal history of deep vein thrombosis or pulmonary embolism. The study received approval from the University's Institutional Review Board and each participant gave written informed consent prior to participation.

Study design

All participants visited the laboratory on three occasions, separated by 7–10 days. Upon arriving for the first visit, participants filled out an informed consent document and a brief health history questionnaire. After confirming they did not meet any exclusion criteria, each participant's height, body mass, and arm circumference (50% distance from acromion process to lateral epicondyle) was measured. Participants were then randomized to exercising their right or left arm and the same arm was used in all subsequent visits. Following this, participants were seated in a quiet room for 10 min of rest prior to resting arterial occlusion measurements. Resting occlusion pressure was measured with both a 5-cm nylon and a 3-cm elastic cuff, in randomized order. The two arterial occlusion pressure measurements were separated by 10 min of quiet rest. Upon completion of arterial occlusion pressure measurements, one-repetition maximum (1RM) biceps curl strength was determined and participants were familiarized with isometric testing. During experimental visits 2 and 3, participants completed four sets of biceps curls at 30 % of one-repetition maximum (1RM) with 40 % of the resting arterial occlusion for each respective cuff applied at the proximal portion of the arm. Cuff-type was randomized between visits 2 and 3. Prior to, immediately after, and 5, 20, 40 and 60 min after the completion of the exercise protocol, muscle thickness (an index of muscle swelling) was measured using B-mode ultrasound and isometric strength was assessed on a dynamometer. Electromyography (EMG) was used to estimate the electrical activity of the muscle on during the exercise protocol.

Determination of arterial occlusion pressure

Following 10 min of seated rest, a nylon (5 cm wide) or elastic (3 cm wide) cuff was applied to the most proximal portion of the previously determined arm in the standing position. Pressure was regulated by the E20 Rapid Cuff Inflator (Hokanson, Bellevue, WA, USA) for the 5-cm nylon cuff and the Kaastu Master Apparatus (Kaatsu Master, Tokyo, Japan) for the 3-cm elastic cuff. The pulse was measured during inflation using a hand-held bidirectional MD6 Doppler probe (Hokanson, Bellevue, WA, USA) placed on the radial artery. Both auditory and visual signals from the Doppler probe indicated if the pulse was present. For the 5-cm cuff, the pressure was first inflated to 50 mmHg and then gradually increased until the arterial flow was no longer detected. For the 3-cm elastic cuff, the cuff was tightened to an initial pressure of 30 mmHg (i.e., the amount of pressure applied to the arm prior to inflation), and gradually inflated: first by 50 mmHg and then by 10-mmHg increments until arterial flow was no longer detected. Arterial occlusion pressure was recorded to the nearest 1 mmHg for the 5-cm nylon cuff and to the nearest 10 mmHg (this machine cannot regulate to nearest 1 mmHg) for the 3-cm elastic cuff, as the lowest cuff pressure at which a pulse was not present. When arterial flow was no longer detected, the cuff was immediately deflated and removed from the arm.

One-repetition maximum

Following a warm-up at approximately 50 % of estimated 1RM, unilateral dumbbell biceps curl strength was measured. Participants stood with their back and shoulders against a wall to ensure strict form. The load was then set to an estimated 90 % 1RM before progressively increasing the weight until participants were no longer able to complete a full repetition with proper form. A 1RM was usually obtained within 3–5 attempts.

Isometric maximal voluntary contraction

While seated on a dynamometer (Biodex System 4 Medical Systems, Shirley, NY, USA) participants performed two maximal 3-s isometric contractions (MVC) at 60° elbow flexion, separated by 60 s of rest. Measurements were taken before, immediately after, and 5, 20, 40, and 60 min following the acute exercise bout. Only one MVC was performed immediately afterwards to measure true fatigue and allow the measurement of muscle thickness within 30 s of the last repetition of exercise. Signals were gravity corrected for lever arm and body limb weight, and the seat back and lever-arm length were adjusted for each individual to make sure the elbow joint was in-line with the axis of rotation. The highest value of the two MVCs was recorded as maximal peak torque.

Exercise protocol

During visits 2 and 3, participants performed four sets of unilateral biceps curls to failure at 30 % of 1RM with the cuff inflated to 40 % of resting arterial occlusion pressure for each cuff. This relative pressure was chosen as it is the lowest effective pressure that has been examined in the literature and appears to elicit a similar muscle activation and muscle growth response in the upper body as higher pressures (90 % resting arterial occlusion) [14]. For the individual whose arterial occlusion was not reached, we used 40 % of the maximal capability of the device (500 mmHg). Failure was defined as the inability to complete another repetition with proper form, or a break in form despite completion of a repetition. Each set was separated by 30 s of rest. All biceps curls were performed to the beat of a metronome allowing 1 s for both the eccentric and concentric portion of the lift.

Perceptual response

The Borg scale of rating of perceived exertion (RPE) was used to measure a participant's perceived effort following each set of exercise. Immediately following each set, during the 30-s rest, participants were asked to rate their perceived effort on a scale of 6 (none at all) to 20 (maximal effort). In addition, 20 s after each set, participants were asked to rate their discomfort using the Borg discomfort scale (CR10 +). In short, discomfort was rated on a scale of 0 (no discomfort at all) to 10 (Maximal discomfort); however, participants were allowed to exceed 10 if discomfort was greater than any they had previously experienced. This measurement was taken 20 s into rest as we have anecdotally found discomfort to be the greatest during the last portion of the rest periods. Further details can be found elsewhere [23].

Electromyography

EMG was used to measure the electrical activity of the biceps brachii during exercise. Electrodes were placed on the line between medial acromion and the antecubital fossa at a distance of 1/3 from the antecubital fossa, in line with the recommendations of Hermans et al. [24]. Prior to application, the skin was shaved, abraded, and cleaned with isopropyl alcohol. Bipolar electrodes were placed on the center of the muscle belly with an interelectrode distance of 20 mm. The ground electrode was placed on the 7th cervical vertebrae at the neck. The surface electrodes were connected to an amplifier and digitized (iWorkx, Dover, NH, USA). The signal was filtered (low-pass filter 500 Hz; high-pass filter 10 Hz), amplified (1000×) and sampled at a rate of 1 kHz. Before the exercise bout, the participant performed two isometric MVCs with the biceps brachii at a joint angle of 60° with 60 s of rest between MVCs on an isokinetic dynamometer. The EMG was recorded continuously from the biceps brachii during each exercise bout. Software provided by the company was used to analyze the data. EMG amplitude (root mean square, RMS) was analyzed from the average of the first three repetitions and the average of the last three repetitions for each set and expressed relative to the highest pre exercise MVC (% MVC).

Muscle thickness

B-mode ultrasound (Aloka, SSD-500 with 5-MHz probe) was used to provide a one-dimensional measurement of the anterior upper arm. Muscle thickness was measured with ultrasound using electronic calipers, as the distance between the muscle–fat interface and underlying bone. Two measures were taken during each testing session. Muscle thickness measurements were taken at 70 % of the distance from the acromion process to the lateral epicondyle, measured with a standard tape measure. All participants were asked to remain normally hydrated for all testing visits. The minimal difference (i.e., reliability) needed to be considered real for the anterior portion of the upper was calculated previously at 0.2 cm.

Statistics

All data were analyzed using SPSS 18.0 statistical software package (SPSS Inc., Chicago, IL, USA). A paired sample *t* test was used to examine differences between resting arterial occlusion pressures (nylon vs. elastic). A 2 × 4 repeated measures ANOVA was used to identify differences in repetitions to fatigue between each cuff type (nylon vs. elastic). Two, 2 × 6 (condition × time) repeated measures ANOVAs were used to identify differences in torque and muscle thickness between cuff types (nylon vs. elastic) across time (pre, post, and 5, 20, 40, and 60 min post exercise). Two, 2 × 4 (condition × set) repeated measures ANOVAs were used to identify differences muscle activation (EMG) between cuff types (nylon vs. elastic) for the fist three and last three repetitions of each exercise set. If there was a significant interaction, a one-way repeated measures ANOVA test was used to reveal where the differences were across time within each condition and a paired samples *t* test was used to reveal differences across conditions within each time point. If there was no significant interaction, main effects were examined. All data are presented as means with standard deviations (SD).

To compare differences in perceptual responses (RPE and discomfort) between cuff types, the Wilcoxon related-samples non-parametric test was used to determine if significant differences existed between conditions at different time points (pre vs. pre, 1st set vs. 1st set, 2nd set vs. 2nd set, 3rd set vs. 3rd set, and 4th set vs. 4th set). All perceptual data are presented as 25th, 50th, and 75th percentiles. Significance was set at $p \leq 0.05$ for all statistical tests.

Results

Demographics

A total of 15 resistance-trained males ($n = 12$) and females ($n = 3$) [mean (SD); age 25 (2) years; height: 179.1 (11.7) cm; body mass: 82 (11) kg; arm circumference: 34.8 (4) cm; 1RM: 23.5 (7.8) kg] were recruited to participate in this study.

Resting arterial occlusion and repetitions to fatigue

At rest, the arterial occlusion pressure was greater with the elastic cuff compared to the nylon cuff (Fig. 1). We were unable to occlude one participant with the elastic cuff; thus they were excluded from the arterial occlusion analysis ($n = 14$). When exercising at 40 % of each cuff's respective arterial occlusion pressure [nylon: 57 (7) vs. elastic: 106 (38) mmHg, $p < 0.001$], there was no significant interaction ($p = 0.089$) or condition main effect ($p = 0.757$) for repetitions completed to fatigue. However, there was a time effect (Fig. 2a, $p < 0.001$) with the number of repetitions decreasing across sets (1st set > 2nd set > 3rd set > 4th set, $p < 0.001$).

Torque and electromyography

There was no significant interaction ($p = 0.643$) or condition main effect for torque ($p = 0.711$), however, there was a time main effect (Fig. 2b), $p < 0.001$). Torque decreased from pre to post exercise and remained decreased from pre at 60 min post.

There was no significant interaction ($p = 0.728$) or condition main effect ($p = 0.545$) for muscle activation of the first three repetitions (Fig. 3a), nor was there a significant interaction ($p = 0.263$) or condition main effect ($p = 0.554$) for muscle activation of the last three repetitions (Fig. 3b). However, there was a main effect for time in the first three repetitions ($p < 0.001$) (Fig. 3a), with the activation, expressed as a percentage of maximal isometric contraction, increasing from the first set to the second set, remaining elevated for the remaining sets. For the last three repetitions, there was no main effect for time ($p = 0.054$).

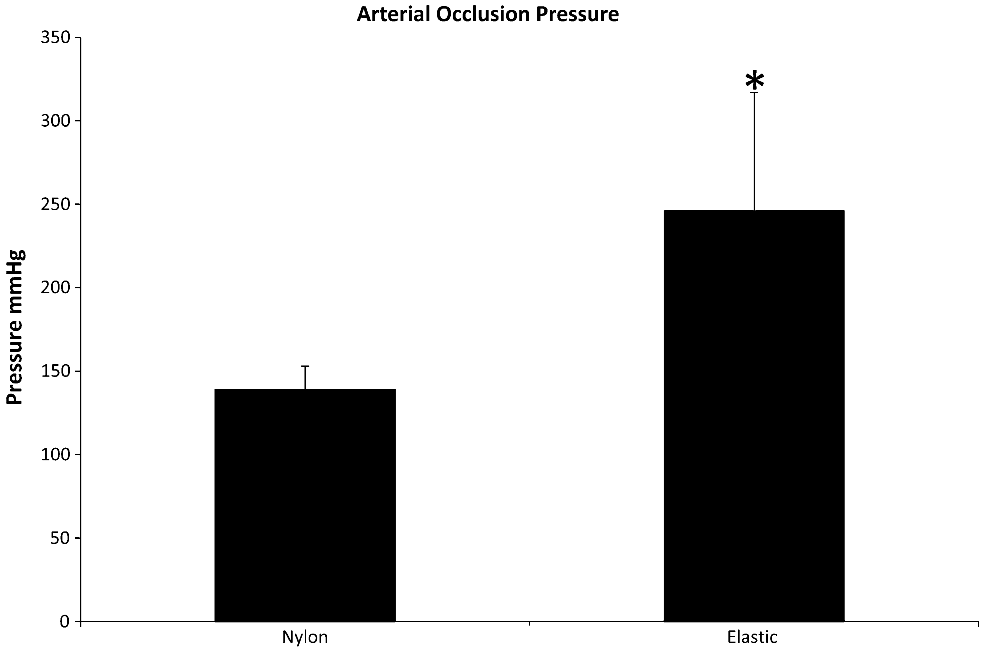

Fig. 1 Resting arterial occlusion for nylon and elastic cuffs ($n = 14$). An *asterisk* indicates significantly greater than nylon cuff

Acute muscle thickness

There was a significant interaction ($p = 0.018$) for acute changes in muscle thickness. Follow-up tests found significant differences between cuffs at the 20-min post-exercise time point ($p = 0.002$, Table 1). Within each cuff, muscle thickness increased from pre to post for both the 3-cm elastic ($p < 0.001$) and 5-cm nylon cuffs ($p < 0.001$), remaining slightly elevated at 60 min post for both cuffs (Table 1).

Perceptual response

There were no differences in RPE between cuffs at rest or across sets (Table 2). For discomfort, there were no differences at rest ($p = 0.999$) or during the first set ($p > 0.05$); however, discomfort was greater in the elastic cuff for set 2 ($p = 0.004$), set 3 ($p = 0.048$), and set 4 ($p = 0.031$) (Table 2).

Discussion

The purpose of the current study was to examine the acute skeletal muscle and perceptual responses to low-load resistance exercise to failure in combination with BFR applied using two narrow cuffs of different materials. Results showed that resting arterial occlusion pressure was different between cuffs of similar width but different material. In addition, the acute muscle thickness response showed slight differences between cuff types; although, we do not believe this is a meaningful difference. When examining the acute response to exercise at the same relative pressure, number of repetitions to fatigue, post-exercise torque decrement, and muscle activation levels did not differ. The only differences were found in discomfort, as the elastic cuff elicited greater discomfort for sets 2, 3, and 4 when compared to the nylon cuff.

Differences in resting arterial occlusion pressure, despite similar-sized cuffs, demonstrate the importance of measuring arterial occlusion pressure before applying the blood-flow-restrictive stimulus. For example, if an arbitrary pressure of 200 mmHg were applied with each cuff, the majority of individuals in the current study using the nylon cuff would be fully occluded; whereas, the elastic cuff condition would be receiving, on average, a stimulus of approximately 80 % arterial occlusion. However, there would be a great deal of individual variability in the stimulus applied. These differences in arterial occlusion pressure are contrary to the findings of Loenneke et al. [25] who observed no differences in arterial occlusion pressure between cuff types (nylon vs. elastic) in the lower body. As such, anatomical differences between the upper and lower body as well as differences in endothelial function may explain some of this discrepancy [26]. Structurally, fusiform muscles, such as the biceps, increase muscle volume during contraction, which may subsequently impact the application of the stimulus [27]. Specifically, the shortening of the biceps muscle may change the amount of tissue under the cuff. In addition, the previous study by Loenneke et al. [25] used two cuffs that were the same width. This is important to consider, as a larger cuff occludes blood flow

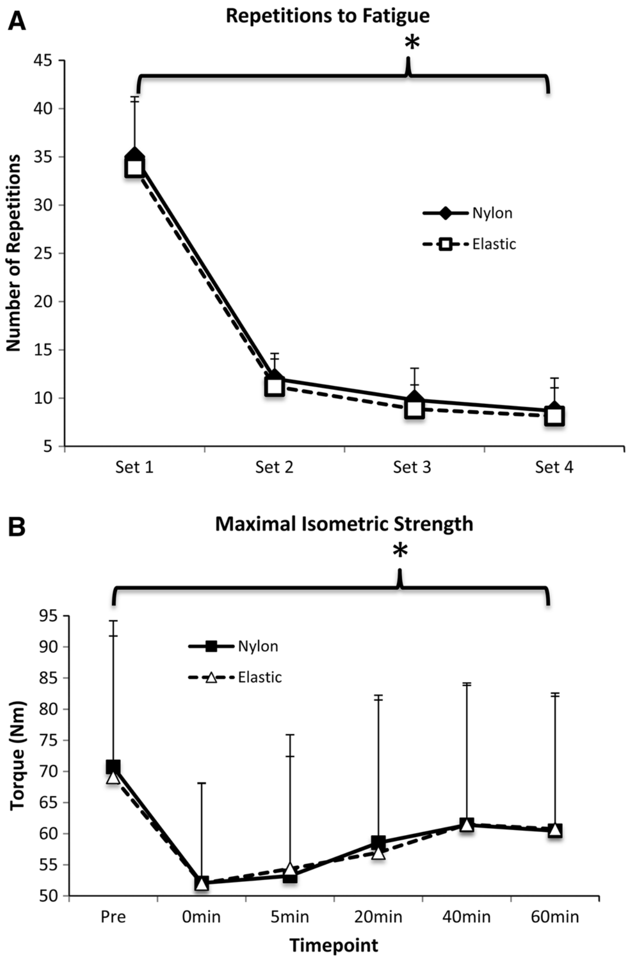

Fig. 2 **a** Repetitions to fatigue for both nylon and elastic cuffs across sets (*1–4*). **b** Changes in isometric torque at pre, and 0, 5, 20, 40, and 60 min post. An *asterisk* indicates significant differences between time points

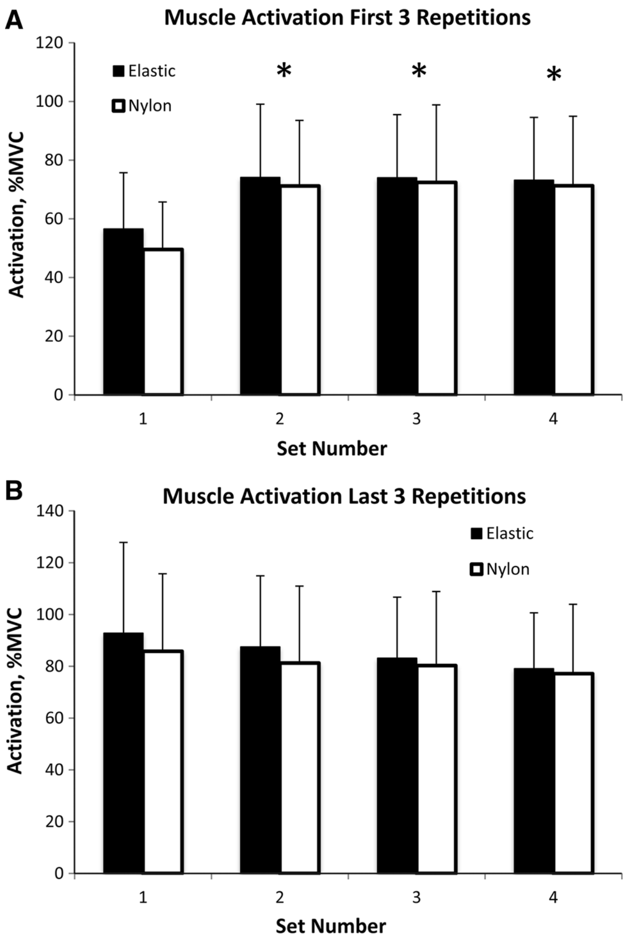

Fig. 3 Muscle activation (% MVC) for the first three repetitions (**a**) and last three repetitions (**b**) for sets *1–4* of exercise for both nylon and elastic cuffs. An *asterisk* indicates significantly greater activation than the first set

at lower restrictive pressures [18]. Further, the initial pressure applied to the elastic cuff may explain some of this difference, since the previous study by Loenneke et al. [25] used an initial pressure common in the lower body of 50 mmHg. Although unlikely, it is conceivable that a greater initial pressure may have made the arterial occlusion pressures more similar between cuffs. Moreover, when interpreting BFR research in the upper body, particularly those using the same absolute pressure for everyone, it is important to note the cuff type used, as this may reflect an entirely different restriction stimulus. However, if the pressure is applied as a percentage of arterial occlusion, it appears that the acute response between the two cuff types does not differ. Moreover, the repetitions to fatigue between cuff types were similar, suggesting a similar level of blood flow restriction between cuff types, despite the different material.

Torque decreased immediately after the exercise and slowly returned towards baseline, remaining slightly depressed during the last measurement taken 60 min post-exercise in both cuff types. This is likely due to transient fatigue and not muscle damage, as muscle damage does not appear to occur at a detectible level with blood flow restriction [5, 23]. Further, the repetitions decreased across sets, similarly between cuff types, likely influenced by an accumulation of metabolites, and indicative of decreased blood flow. Decreases in blood flow are further supported by the EMG data, which shows an increase from the first set to the second set (remaining elevated for remaining sets) and also confirmed through the repetitions to fatigue, which decreased across sets. Moritani et al. [28] suggests that oxygen is reduced during occluded exercise, leading to an increase in motor unit recruitment. Thus, fatigue is likely due to a combination of accumulating metabolites, and decreases in blood flow. This may result in subsequent augmented recruitment patterns and activation of higher threshold motor units not typically associated with low-load resistance exercise. Together, these findings suggest that the relative restrictive stimulus augments the

Table 1 Muscle thickness values before, immediately after, and 5, 20, 40, and 60 min after exercise for both nylon and elastic cuffs

Cuff type	Pre	Post	5 min	20 min	40 min	60 min	Time: $p < 0.01$
Nylon	4.6 (0.8)	5.1 (0.9)	5.1 (0.9)	5.0 (0.9)	4.8 (0.9)	4.7 (0.9)	Pre vs. post, 5, 20, 40, 60 Post vs. 20, 40, 60 5 vs. 20, 40, 60 20 vs. 40, 60 40 vs. 60
Elastic	4.6 (0.8)	5.1 (0.9)	5.0 (0.9)	4.8 (0.9)*	4.8 (0.9)	4.7 (0.9)	Pre vs. post, 5, 20, 40, 60 Post vs. 20, 40, 60 5 vs. 20, 40, 60 20 vs. 40, 60 40 vs. 60

* Significant differences between cuffs. Differences across time for each cuff are noted in the last column

Table 2 Ratings of perceived exertion and discomfort for each cuff (elastic and nylon) at rest and across sets (1–4)

Elastic cuff	25th	50th	75th	Nylon	25th	50th	75th
RPE at rest	6	6	6	RPE at rest	6	6	6
Set 1	9	12	15		10	12	14
Set 2	12	13	15		12	13	15
Set 3	13	14	16		12	13	15
Set 4	13	14	17		13	14	16
Discomfort at rest	0	0	0	Discomfort at rest	0	0	0
Set 1	2	3	6		2	2	4
Set 2	3	4*	7		2	3	4
Set 3	3	5*	7		2.5	4	5
Set 4	3	4*	8		2.5	4	6

Values are displayed for 25th, 50th, and 75th percentile

* Significant differences between cuffs. Differences are noted on the 50th percentile

mechanical (muscle activation) and metabolic components (fatigue) of muscle adaptation similarly amongst different cuff types in the upper body.

The acute change in muscle thickness (indicator of muscle swelling) was similar between cuff types, with significant differences only observed 20 min post-exercise. Muscle swelling is believed to reflect a fluid shift into the muscle, and has been hypothesized as a potential mechanism through which BFR elicits its adaptation [29]. Originally proposed by Haussinger et al. [30], the increase in cellular hydration may act as an anabolic proliferative signal, resulting in a shift towards anabolism. Moreover, the cell-swelling response seems probable, as Loenneke et al. [29] observed increases in muscle thickness of the quadriceps musculature while also observing a concurrent decrease in plasma volume, suggestive of a fluid shift into the cell. These acute changes in muscle thickness may suggest similar long-term adaptations between the two different cuff types. For example, a similar change in muscle thickness appears to occur with low-load resistance training with and without BFR [31]. In addition, Yasuda et al. [32] examined greater muscle swelling responses with concentric BFR exercise compared to eccentric BFR exercise, which was reflected in a greater hypertrophic response in the concentric condition. Thus, the authors suggest that the muscle swelling response may be an important mechanism for hypertrophy of skeletal muscle, although it is likely that muscle activation also played a role in these findings. Regarding the difference in muscle thickness observed at 20 min, the minimal difference (i.e., reliability) needed to be considered real for the anterior portion of the upper arm was calculated at 0.2 cm. Given that the only difference between cuffs was at a single time point, it is difficult to conclude that there were meaningful differences between conditions.

The perceptual responses of RPE were not different between cuff types (Table 1). These are similar to the findings of Loenneke et al. [18], who found no difference in the RPE between nylon and elastic cuffs in the lower body. Discomfort, however, differed between cuff types, with the last three sets showing higher values with the elastic cuff compared to the nylon cuff. This may be due to the higher pressures applied by the elastic cuff or perhaps differences in the material and the pliability of cuff type throughout the range of motion.

The current study is not without limitations. For example, we did not measure any markers in the blood or muscle. Thus, we cannot say for certain that an increase in metabolites contributed to the observed fatigue response. However, it has previously been demonstrated that increases in inorganic phosphate occur with BFR in combination with resistance exercise [33]; thus we are confident in suggesting this mechanism. Further, using ultrasound, we were not able to determine if fluid shifted into the actual muscle cell. Therefore, we can only hypothesize that muscle cell swelling occurred in the present study. In addition, we did not measure blood flow during exercise and can only infer this based off other measurements, such as repetitions to fatigue. Another potential limitation is that the device used to inflate the two different cuff types was different; however, these are the two of the most commonly used devices within the literature and are specific to each cuff type. An attempt was made to modify an inflation device for both cuffs, however, attempts were futile as cuffs are customized for each device. In addition, the device used to inflate the elastic cuff (Kaatsu Master, Tokyo, Japan) requires the setting of an initial pressure; thus these findings are specific to an initial pressure of 30 mmHg and may not reflect other initial pressures; 30 mmHg was chosen, as this is the most commonly used initial pressure for the upper body in the literature. In addition, it is possible that cuff width played a role in the difference in resting arterial occlusion pressures; however, Jessee et al. [34] found only a 25-mmHg difference between a 5-cm and a 12-cm wide nylon cuff in the upper body. Thus, the cuff material is likely playing a larger role in the present study than the 2-cm difference in cuff width. Finally, our results represent acute changes and provide limited information on the chronic adaptations observed with each cuff type; thus, future research is necessary to confirm that these adaptations reflect the acute response. However, it has been demonstrated that the chronic adaptations are similar to BFR when muscle activation is similar [14]. Despite these limitations, our findings provide a strong addition to the BFR literature, using a within-subject model to compare the two most commonly used cuff types to apply the blood-flow-restrictive stimulus. In addition, our findings are in line with previous research, providing important methodological implications regarding the importance of cuff type when applying the BFR stimulus.

Conclusions

The current study has important implications for future BFR research. Specifically, these findings add to the growing literature on methodological approaches to the BFR application. For example, research in the lower body [18] and unpublished findings from our laboratory in the upper body have shown that applying a wide cuff results in a lower arterial occlusion pressure compared to a narrow cuff. Additionally, limb circumference appears to predict a large portion of arterial occlusion pressure [17]. These findings add to what is known, further suggesting that the acute responses between different cuff types (nylon vs. elastic) are similar when the pressure is applied relative to the individual. The only difference observed was discomfort in the later sets with the elastic cuff. Further, it is important to note that arterial occlusion pressure was significantly greater when using the elastic cuff as opposed to the nylon cuff. Thus, if the stimulus is not made relative to individual and the cuff type used, the application of the stimulus may not be what is intended.

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Conflict of interest The authors declare no conflicts of interest.

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