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Original Article

Effects of Low-Load, Elastic Band Resistance Training Combined With Blood Flow Restriction on Muscle Size and Arterial Stiffness in Older Adults

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Abstract

We examined the effect of low-load, elastic band resistance training with blood flow restriction (BFR) on muscle size and arterial stiffness in older adults. Healthy older adults (aged 61–85 years) were divided into BFR training (BFR-T, $n = 9$) or non-BFR training (CON-T, $n = 8$) groups. Both groups performed low-load arm curl and triceps down exercises (four sets, total 75 repetitions for each) using an elastic band, 2 d/wk for 12 weeks. The BFR-T group wore inflated pneumatic elastic cuffs (120–270 mm Hg) on both arms during training. Magnetic resonance imaging-measured muscle cross-sectional area of the upper arm, maximum voluntary isometric contraction of the elbow flexors and extensors, cardio-ankle vascular index testing, and ankle-brachial pressure index were measured before and 3–5 days after the final training session. Muscle cross-sectional area of the elbow flexors (17.6%) and extensors (17.4%) increased, as did elbow flexion and elbow extension maximum voluntary isometric contraction (7.8% and 16.1%, respectively) improved ($p < .05$) in the BFR-T group, but not in the CON-T group. In cardio-ankle vascular index and ankle-brachial pressure index testing, there were no changes between pre- and post-results in either group. In conclusion, elastic band BFR-T improves muscle cross-sectional area as well as maximal muscle strength but does not negatively affect arterial stiffness in older adults.

Key Words: Electromyography—Muscle hypertrophy—Sarcopenia—Strength—Vascular occlusion

Age-related skeletal muscle loss (sarcopenia) inhibits mobility and increases the risk of falls, fractures, disability, and heart disease (1,2). High-load resistance training (HL-T) can induce muscle hypertrophy and improve insulin resistance and type-2 diabetes in the elderly (3,4), suggesting that HL-T prevents and even improves sarcopenia in the elderly (5). However, the use of heavy weights with weight machines/free weights required for muscle adaptation with traditional resistance exercise may not be practical and may even be dangerous when carried out without proper supervision. Thus, the effectiveness of alternative exercise methods should be investigated.

Elastic bands/tubing have been used widely in rehabilitative medicine and in health enhancement for resistance training (6,7). A previous study reported that a home-based resistance training program for older adults using elastic bands could serve as a practical and effective means of improving muscle strength (8). Elastic bands are also portable and are less expensive and easier to use than weight machines and/or free weights. Elastic band resistance training has thus been shown to be a feasible alternative to conventional training with free weights or machines (9,10). However, as elastic resistance training is commonly performed using low-to-moderate resistance level, this training typically has little or no effect on muscle hypertrophy (8,9).

In the past decade, several studies have reported that muscle hypertrophy can be produced with low-load resistance training (20%–30% one-repetition maximum [1RM]) combined with blood flow restriction (BFR-T), termed "kaatsu training," regardless of age (11,12). The mechanism by which BFR potentiates the training effect of low-load resistance training remains obscure but appears to be related, in part, to an increase in muscle activation (11,13–15). Recently, Yasuda and colleagues (16) revealed that muscle activation increased progressively during BFR-T when exercises were performed at low-resistance levels using an elastic band as well as when using free weights. BFR-T using elastic bands for resistance may thus be an effective home-based resistance training program for promoting both muscle hypertrophy as well as strength.

In general, reductions in arterial compliance or increases in arterial stiffness reduce the arterial buffering function of the pulsation of blood pressure and blood flow, which contribute to elevations in systolic blood pressure, left ventricular hypertrophy, coronary ischemic disease, and reductions in arterial baroreflex sensitivity (17,18). This means that prevention and treatment for decreased arterial compliance or stiffness is also important. However, HL-T has been reported to induce a 20%–30% reduction in arterial compliance in young and older adults (19,20), indicating that the use of heavy loads during resistance training has a potentially deleterious effect regarding arterial stiffness in older adults. On the other hand, previous studies have reported that BFR-T using low loads could improve or maintain arterial compliance or stiffness in young and older adults (21–23). We hypothesized that BFR-T using elastic bands may be a useful method for promoting muscle hypertrophy with a low risk of increased arterial stiffness in older adults. Thus, the purpose of this study was to examine the effect of low-load elastic band training with BFR on muscle size and arterial stiffness in older adults.

Materials and Methods

Participants

Seventeen men and women (aged 61–85 years) volunteered to participate in the study and were selected according to the exclusion criteria (blood pressure >160/100 mm Hg, body mass index >30 kg/m^2, history of anemia, cerebrovascular disease, myocardial infarction, and arthroscopic joint surgery) used to define "medically stable" older participants for exercise studies proposed by Greig and colleagues (24). In addition, volunteers who suffered from a chronic disease such as severe hypertension (>180/110 mm Hg), orthopedic disorders, deep venous thrombosis, peripheral vascular disease, or cognitive dysfunction were excluded from the study. None of the participants had participated in resistance-type training for a minimum of 6 months prior to the study. All participants were free of overt chronic disease as assessed by medical history, physical examination, and complete chemistry and hematologic evaluation. Participants were divided into either the BFR training (BFR-T) group (2 men and 7 women: n = 9; age [mean ± *SD*]: 71.8 ± 6.2 years) or the non-BFR training (CON-T) group (1 man and 7 women: n = 8; age: 68.0 ± 5.1 years). All participants were informed of the risks associated with involvement in the study and signed an informed consent document before participation. The principles of the World Medical Association Declaration of Helsinki and the American College of Sports Medicine Guidelines for Use of Human Subjects were adopted in this study. The study was approved by the Ethics Committee of the University of Tokyo.

Training Protocol

BFR-T and CON-T groups performed bilateral arm curl and triceps press down exercise training 2 d/wk for 12 weeks. Both exercise groups used the "Heavy (Green)" band for men and "Thin (Yellow)" band for women (Hygenic Corporation, Akron, OH). This training was performed under the close supervision of those with technical knowledge in BFR training. One week before the start of the training study, both groups performed practice sessions for the maximum isometric strength (maximum voluntary isometric contraction [MVC]) test. In addition, BFR-T participants were familiarized with the BFR stimulus. Three or four days before training, MVC was determined. Training volume was 75 repetitions (30, 15, 15, and 15 repetitions, with 30-second rests between sets) for both exercises (90-second rests between exercises). This protocol is typical of submaximal BFR studies (12,16,22,23,25,26). Once the pneumatic cuffs were inflated, they remained so for the two exercises, including rest periods between sets and exercises. During arm curl exercise, subjects were comfortably seated on a chair (16). Elbow joint range of motion during the exercise was approximately 20–145° (0° being full extension). During triceps press down exercise, subjects were comfortably seated on a rowing chair with the body supported in the vertical position (16). Elbow joint range of motion during the exercise was approximately 140–5° (0° being full extension). Subjects were instructed not to let the band snap them back to the start position but to consciously control the return movement such that it would take twice as long as the stretching movement. The repetition duration was 2.4 seconds (1.2-second concentric and 1.2-second eccentric exercise cycle) for both exercises. The total length of the two exercises per day was 9.5 minutes for both groups.

Blood Flow Restriction

During the training sessions, BFR-T subjects wore a specially designed pneumatic cuffs (30-mm width, KAATSU Master, Sato Sports Plaza, Tokyo, Japan) around the most proximal portion of the both arms. On the first day of training, the cuffs were set at 30 mm Hg and air pressure gradually inflated to 120 mm Hg (Day 1). The air pressure was increased by 10–20 mm Hg at each subsequent training session until a pressure of approximately 270 mm Hg was reached if each subject could perform at high levels of pressure intensity. The restriction pressure was selected in accordance with previous study (16). The mean pressure intensity throughout the period of training was 196 ± 18 mm Hg (180–270 mm Hg at 24th training session). Immediately after the two exercises, the pressure cuff was quickly removed. The amount of time under BFR was approximately 11 minutes.

Measurements Schedule

Subject testing took place before the start of the study (pre) and 3–7 days after (post) the 12-week training period. The order of measurements were magnetic resonance imaging (MRI), venous blood samples, arterial function (flow-mediated dilatation [FMD], cardio-ankle vascular index [CAVI] testing, and ankle-brachial pressure index [ABI]) tests, and MVC measurements. Figure 1 shows the testing schedule for each of the measurements taken during the 12-week experimental period. All subjects were right handed except for two women (one for BFR-T and one for CON-T). All data were obtained from the right side of the body. Considering the schedule of examiners, all subjects and variable technologists, the MRI (10:00 and 15:00 hours), venous blood samples and arterial function tests (after 6–7 hours' fast, 10:00 and 15:00 hours), and MVC (10:00 and 15:00 hours) measurements were obtained in 2 days (few days interval). The subjects were instructed to refrain from ingesting alcohol and caffeine for 24-hour prior to pre- and post-training measurements.

MRI-Measured Muscle Cross-Sectional Area

Muscle cross-sectional area (CSA) was obtained using a MRI scanner (0.2-T Open MRI, Hitachi, Tokyo, Japan). A T-1 weighted, spin-echo, axial plane sequence was performed with a 500-millisecond repetition time and a 23-millisecond echo time. Subjects rested quietly in the magnet bore in a supine position, with their arms extended along their trunk. After transverse angle was set at perpendicular to the humerus in the sagittal plane, continuous transverse images (from the lateral epicondyle of the humerus to the acromial process of the scapula) with 10-mm slice thickness were obtained from the both upper arms of the body along the humerus. Although the difference in 5° of transverse angle is equal to the difference in approximately 0.4% in muscle CSA (cylindrical model), the differences between pre and post for all subjects were within 5°. All MRI data were transferred to a personal computer for analysis using specially designed image analysis software (sliceOmatic, Tomovision Inc., Quebec, Canada). Skeletal muscle tissue CSA was measured for elbow flexors (biceps brachii and brachialis) at 6 cm above the elbow joint and for elbow extensors (triceps brachii) at 16 cm above the elbow joint. The coefficient variation of this measurement was less than 1.0% (16).

Maximum Isometric Strength Measurement

MVC of the elbow flexors and elbow extensors was measured twice by a dynamometer (Taiyo Kogyo Co., Tokyo, Japan). Each subject was comfortably seated on an adjustable chair, with the arm positioned on a stable table at chest level with the elbow bent at an angle of 90° (0° at full extension). The upper arm was maintained in the horizontal plane (at 90°), while the wrist was fixed at the end of the dynamometer lever arm in a position of supination for elbow flexion and in a position halfway between supination and pronation for elbow extension. Both forces were measured with a transducer while the subject performed two trials separated by a 60-second rest interval (90-second rests between elbow flexion and elbow extension). If MVC torque for the first two MVCs varied by more than 5%, up to two additional MVCs were performed with 60-second rest between trials (14,15). Subjects were instructed to perform an MVC as quickly as possible during a period of about 2 seconds. The recorded value for the MVC was taken as the highest and most stable approximately 1 second of the 2-second contraction. The highest MVC value was used for data analysis. The coefficient variation for this measurement from test to retest was 1.3%. The intraclass correlation coefficient of the measurements was 0.97.

Arterial Function Tests

FMD, CAVI, and ABI (arterial function) measurements were conducted in the supine position. The participants were instructed to fast 6–7 hours before testing and refrain from ingesting alcohol or caffeine for at least 12 hours prior to testing. After the participants were asked to rest in the lying position in a quiet, dark, air-conditioned room (25–26°C) for 5 minutes, a standard cuff (UNEXCUFF, no. 5) was positioned around the right arm, 2–3 cm distal the antecubital fossa and their systolic and diastolic blood pressures were assessed using oscillometric methods (UA-767PC, A&D Co., Ltd., Tokyo, Japan). Then, after the participants had rested again for at least 15 minutes in a supine position in the same room, endothelium-dependent FMD of the brachial artery was measured using an established noninvasive method (27). After basal measurements were obtained, arterial occlusion was created by inflating a cuff placed around the forearm with suprasystolic compression (50 mm Hg above systolic blood pressure) of the right forearm for 5 minutes. After 5 minutes of inflation, the cuff was deflated producing a brief high-flow state resulting in arterial dilation due to increased shear stress. The diastolic diameter of the brachial artery was

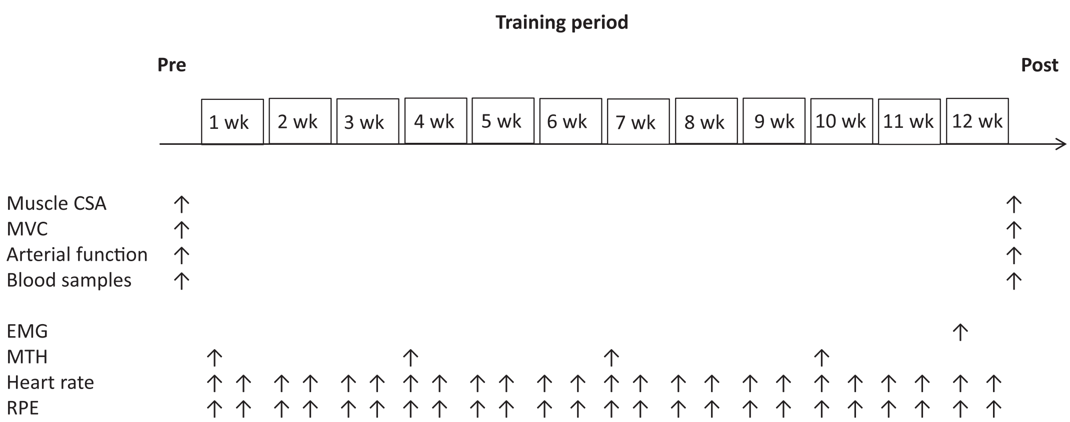

Figure 1. Experimental timeline. CSA = cross-sectional area; MTH = muscle thickness; MVC = maximum voluntary isometric contraction; RPE = ratings of perceived exertion.

determined semiautomatically using an instrument equipped with software for monitoring the brachial artery diameter (UNEX EF, Unex Co. Ltd., Nagoya, Japan). Percentage of FMD was calculated as reported previously (28,29). Then, after 20- to 30-minute rest, CAVI and ABI were measured noninvasively using a VS-1500 system (Fukuda Denshi Co., Ltd, Tokyo, Japan). Subjects were placed supine. Electrocardiogram and heart sound were monitored. CAVI is automatically calculated using the formula; a $\{2\rho/\Delta P \times \ln(P_s/P_d)\ PWV^2\} + b$ (a and b, constants; ρ, blood density; P, difference in systolic and diastolic pressure; P_s, systolic pressure wave velocity; P_d, diastolic pressure; PWV, heart-ankle pulse wave velocity). ABI is the ratio of the systolic blood pressure in the ankle to the systolic blood pressure in the right arm (30).

Blood Sampling and Biochemical Analyses

Venous blood samples were obtained from the antecubital vein and measured for fibrin/fibrinogen degradation products (FDP), d-dimer, and creatine kinase (CK). The plasma concentrations of these samples were measured at a commercial laboratory (SRL Inc., Tokyo, Japan) by following latex immunoassay for FDP and d-dimer and spectrophotometry for NADPH formed by a hexokinase and D-glucose-6-phosphate-dehydrogenase-coupled enzymic system for CK.

Measurements of Acute Responses to Training Session

Electromyography

The skin was shaved, abraded with a skin preparation gel (Skinpure, Nihon Kohden, Japan), and cleaned with alcohol wipes. During the experiment, skin impedance was less than 2 kΩ. The ground electrode was positioned on the lateral epicondyle. Bipolar (2-cm center-to-center) surface electromyography (EMG) electrodes (Ag/AgCl; Vitrode F; Nihon Kohden, Tokyo, Japan) were placed over the muscle belly (mid-portion) along the longitudinal axis of the biceps brachii and triceps brachii of the right upper arm (14,15). EMG signals were recorded and collected on a personal computer (MacBook Pro 10,1; Apple, Japan) for subsequent analysis. All EMG signals were digitized at a sampling rate of 1,024 Hz with a bandwidth of 0 Hz to 500 kHz (AB 6216; Nihon Kohden). To determine integrated EMG (iEMG), signals were fully rectified and integrated (Lab Chart 7 software, AD Instruments, Japan). During the experimental session, surface EMG was recorded continuously and each iEMG value was divided into groups of five successive repetitions. The average for each group of five repetitions was represented as a single data point for statistical analysis (14,16,25). To determine the iEMG ratio of agonist muscles, iEMGs during each exercise was normalized to Pre, which was iEMG without BFR before the first set of training session. EMG measurement was performed during the 23rd training session (see Figure 1). The coefficient variation for this measurement from test to retest was 5.7%.

Relative exercise loading

To determine the relative exercise loading of performing the arm curl and triceps press down exercises, the iEMGs for the elastic band exercises (three to five repetitions) were compared to the iEMGs during MVC of the elbow flexors and elbow extensors. This measurement was completed on the same day before 23rd training session.

Ultrasound-measured muscle thickness

Since muscle thickness (MTH) using B-mode ultrasound (Acuson Sequoia 512; Siemens, Tokyo, Japan) has the advantage of evaluating acute change in muscle cell swelling following exercises (25), MTH of the elbow flexors and elbow extensors was measured at 10 cm above the elbow joint and at mid-upper arm of the right upper arm, respectively. Briefly, the measurements were carried out while the subjects stood with their elbows extended and relaxed. The upper arm length (from the lateral epicondyle of the humerus to the acromial process of the scapula) was measured, and the 10 cm above the elbow joint for elbow flexors and 50% distance from elbow joint for elbow extensors were marked on the subject's skin with a pen. A 10.0 MHz scanning head (5.5 cm length probe) was placed on the skin perpendicular to the tissue interface. The scanning head was coated with a water-soluble transmission gel to provide acoustic contact without depressing the dermal surface. The subcutaneous adipose tissue-muscle interface and the muscle-bone interface were identified from the ultrasonic image. The perpendicular distance from the adipose tissue-muscle interface to the muscle-bone interface was taken as MTH. Ink markers on the elbow flexors were used to ensure similar positioning over repeated MTH measurement. The coefficient variation of this measurement from test to retest was 1.4%. The intraclass correlation coefficients of the measurements were 0.94 and 0.96, respectively (25). The same investigator (T.Y.) made all the ultrasound measurements. The MTH of the elbow flexors and elbow extensors was recorded before and immediately after the exercise bout. This measurement was completed at every 3 weeks (1st, 4th, 7th, and 10th week) of training period, and the average of 4 times for "before" or "immediately after" was represented as a single data point for statistical analysis, respectively.

Heart rate

During all training sessions, heart rate was recorded at baseline (pre) and immediately after the last set of each exercise (post) (Model 9560, Onyx II; Nonin Medical Inc.).

Ratings of perceived exertion

During all training sessions, ratings of perceived exertion based on a numerical scale of 6–20 were collected to assess subjective feelings of physical effort (ie, exertion). Ratings of perceived exertion data were recorded immediately after the last set of each exercise (31).

Statistical analyses

Results are mean ± *SD*. The data were tested for normality using Shapiro–Wilk test. Because all variables were normally distributed, parametric statistical analyses were performed. Statistical analysis was performed by a two-way analysis of variance with repeated measures group by time. When significant main effects and/or interaction were observed, post hoc testing was performed using the Tukey technique. Percent changes from pre were also compared between groups using Tukey's test. Statistical significance was set at $p < .05$. The sample size was estimated from a priori power analysis (32) to detect differences (power of 0.80, an α of 0.05, two-tailed, and an effect size of 1.7) in elbow flexors muscle CSA for the interventions planned by reference to the result of previous BFR study (25). Consequently, it was determined that a minimum of seven BFR training and seven control subjects were required to test both the main and interaction effects.

Results

Before training, there were no significant differences between the two groups for age (p = .193) and anthropometric variables (standing height, p = .315; body weight, p = .821; body mass index, p = .157) (Table 1). A significant group by time interaction was not observed for body weight (p = .520) and body mass index (p = .469) in either group following the training.

Acute Effect of BFR-T and CON-T

A significant group by time interaction was observed for iEMG (p < .001 for both muscles) and MTH (p = .013 for elbow flexors and p = .016 for elbow extensors muscles). During the exercise session, iEMG ratio for agonist muscle increased progressively in the BFR-T group for arm curl exercise from first to last set (from p = .023 to p < .001) and for press down exercise from the third to last set (from p = .041 to p < .001) and BFR-T was greater than CON-T at last set (p = .001) for arm curl exercise (Figure 2). Immediately after the exercise session, mean MTH was greater with the BFR-T compared to the CON-T at anterior (p = .021, 14.2% vs 7.0%, respectively) and posterior (p = .024, 8.5% vs 3.3%, respectively) 50% of upper arm (Figure 3).

There were no differences in elastic band elongation between BFR-T and CON-T groups for arm curl (p = 1.000, flexed position: 11.3 ± 4.1 cm vs 11.4 ± 1.5 cm and p = .113, extended position: 68.5 ± 4.2 cm vs 63.4 ± 6.1 cm) and press down (p = .998, flexed position: 16.0 ± 4.8 cm vs 16.4 ± 4.3 cm and p = .151, extended position: 74.8 ± 6.0 cm vs 69.5 ± 3.2 cm) exercises. There were no differences in relative exercise load (p = .649 for arm curl and p = .935 for press down exercises, respectively), range of motion (p = .412 for arm curl and p = .082 for press down, respectively) between both groups. However, ratings of perceived exertion were higher in the BFR-RT group than in the CON group (p = .004 for arm curl and p = .001 for press down exercises, respectively) (Table 2).

Chronic Effect of BFR-T and CON-T

A significant group by time interaction was observed for CSA (p < .0001 for elbow flexors and p = .013 for elbow extensors muscles, respectively) and MVC (p = .008 for elbow flexion and p = .013 for elbow extension). Elbow flexors and elbow extensors muscle CSA (17.6% and 17.4%, respectively) were increased (p < .0001

Table 1. Changes in Anthropometric Variables After 12 Week of Training Period

	BFR-T			CONT-T		
	Pre	Post	%	Pre	Post	%
Anthropometric variables						
Age (y)	72(6)			68 (5)		
Standing height, m	1.60 (0.11)			1.55 (0.07)		
Body mass, kg	51.7 (11.4)	51.6 (11.4)	−0.3	52.8 (8.0)	52.3 (8.3)	−0.9
BMI, kg/m^2	20.1 (2.2)	20.1 (2.4)	−0.3	22.0 (3.0)	21.7 (2.8)	−0.9
Upper arm girth, cm	26.6 (2.0)	27.1 (1.8)*	2.1†	27.7 (2.6)	27.5 (2.4)	−0.7

Notes: Data are given as mean (±*SD*). BFR-T = BFR resistance training; BMI = body mass index; CON-T = non-BFR resistance training; upper arm girth, at 50% distal between the lateral epicondyle of the humerus and the acromial process of the scapula.

*p = .08, pre vs post.

†p < .05, BFR-T vs CON-T.

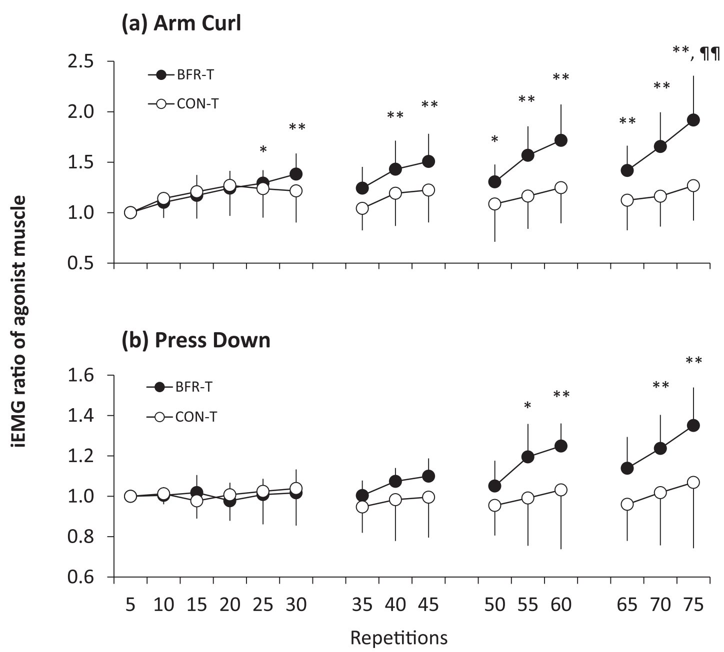

Figure 2. iEMG ratio of biceps brachii and triceps brachii muscles during arm curl (a) and triceps press down (b) for each set performed. Average for each five repetitions was represented as a single data point. Values are means and *SD*. **Different from first five repetitions, p < .01. *Different from first five repetitions, p < .05. ¶¶Different from CON-T, p < .01.

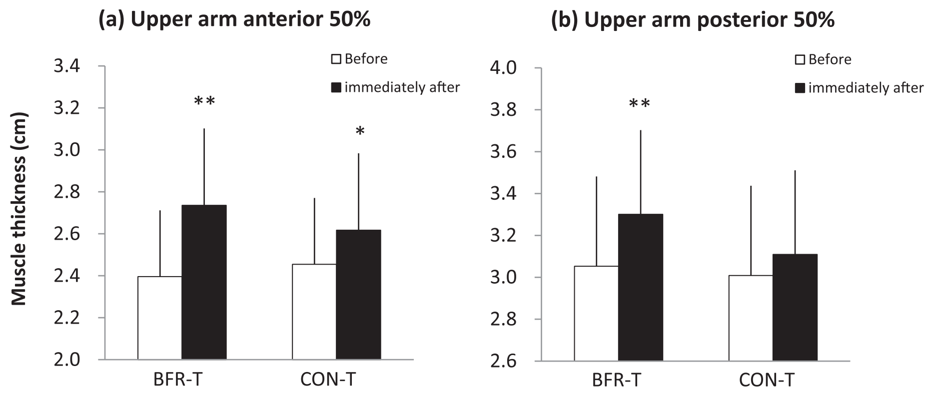

Figure 3. Muscle thickness (MTH) of the elbow flexors (a) and the elbow extensors (b) before and immediately after exercise session. Values are means and *SD*. **Different from before, $p < .01$. *Different from before, $p < .05$.

Table 2. Relative Exercise Intensity, Range of Motion, Heart Rate, and Ratings Perceived Exertion During Two Exercises

	BFR-T		CON-T	
	Mean (±*SD*)	Range	Mean (±*SD*)	Range
Relative exercise intensity, %MVC				
Arm curl	26.7 (11.1)	13.8–44.9	28.8 (6.7)	17.8–40.4
Press down	30.8 (12.3)	17.2–53.3	30.3 (7.9)	21.7–45.1
Range of motion, degree				
Arm curl	124 (14)	93–140	118 (14)	95–137
Press down	130 (5)	123–139	136 (9)	122–146
Heart rate, bpm				
Arm curl (total)	88 (15)	61–140	75 (7)	56–100
120–150 mm Hg	84 (13)	63–118	—	—
160–190 mm Hg	85 (13)	66–125	—	—
200–230 mm Hg	88 (17)	61–140	—	—
240–270 mm Hg	99 (18)	69–132	—	—
Press down (total)	89 (15)	64–141	77 (9)	51–102
120–150 mm Hg	83 (11)	68–113	—	—
160–190 mm Hg	86 (14)	67–132	—	—
200–230 mm Hg	89 (17)	64–141	—	—
240–270 mm Hg	98 (17)	73–132	—	—
Ratings of perceived exertion				
Arm curl (total)	14.1 (2.1)*	9–19	11.5 (0.7)	9–15
120–150 mm Hg	15.5 (2.1)	12–19	—	—
160–190 mm Hg	14.0 (2.5)	9–19	—	—
200–230 mm Hg	13.8 (1.9)	9–17	—	—
240–270 mm Hg	13.7 (2.0)	10–17	—	—
Press down (total)	14.0 (1.8)*	11–17	11.2 (0.5)	8–14
120–150 mm Hg	14.9 (2.4)	11–19	—	—
160–190 mm Hg	14.2 (2.4)	9–19	—	—
200–230 mm Hg	13.7 (1.9)	9–19	—	—
240–270 mm Hg	13.7 (2.1)	11–17	—	—

Notes: BFR-T = BFR resistance training; CON-T = non-BFR resistance training; MVC = maximum voluntary contraction.
*$p < .01$, BFR-T vs CON-T.

and $p = .0131$, respectively) in BFR-T group, but not in the CON group (Figure 4). Elbow flexion and elbow extension MVC (7.8% and 16.1%, respectively) were increased ($p = .0082$ and $p = .0131$, respectively) in the BFR-RT group, but not in the CON group (Figure 5).

A significant group by time interaction was not observed for heart rate ($p = .671$), systolic and diastolic blood pressures ($p = .126$ and $p = .104$, respectively), CAVI ($p = .150$), ABI ($p = .485$), FMD ($p = .116$), FDP ($p = .128$), d-dimer ($p = .506$) and CK ($p = .390$) (Table 3).

Discussion

It has previously been observed that BFR-T using weight machines or free weight leads to increased muscle size and maintenance of arterial stiffness in older adults as well as in young adults (22,23). However, to date, no studies have discussed the muscle size and arterial stiffness following BFR-T using elastic bands. Our findings show that low-load, elastic band resistance training (arm curl and press down) with BFR can lead to a significant increase in muscle CSA (elbow flexors and elbow extensors) as well as maximal contractile

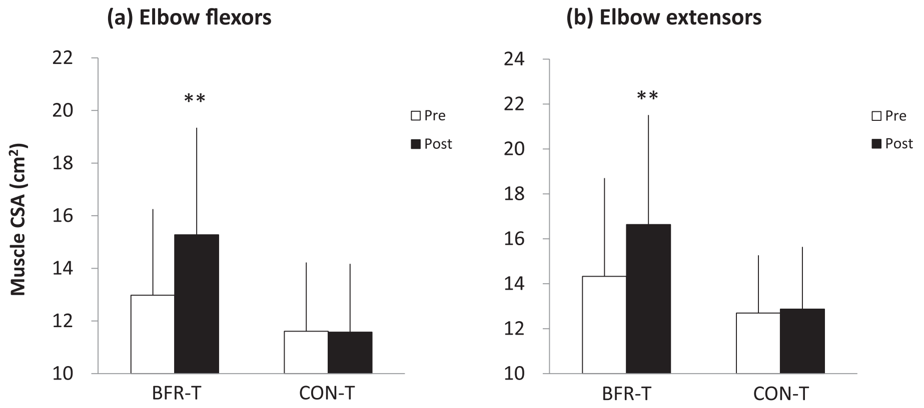

Figure 4. Muscle cross-sectional area (CSA) in the elbow flexors (a) and the elbow extensors (b) pre- and post-training period. Values are means and *SD*. **Different from before, $p < .01$.

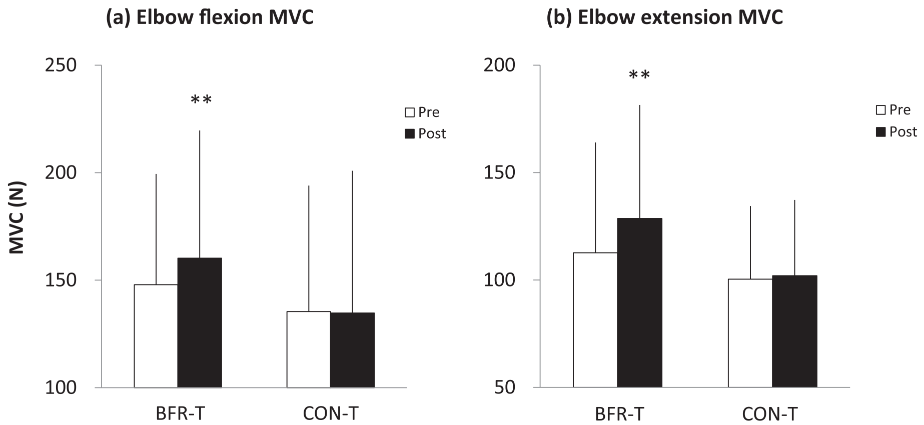

Figure 5. Maximum isometric strength (MVC) of the elbow flexors (a) and the elbow extensors (b) pre- and post- training period. Values are means and *SD*. **Different from pretraining, $p < .01$.

Table 3. Changes in Arterial Function, Coagulation System, and Muscle Damage After 12 Week of Training Period

	BFR-T		CON-T	
	Pre	Post	Pre	Post
Heart rate, bpm	68 (19)	67 (10)	63 (11)	60 (6)
Systolic BP, mm Hg	135 (16)	134 (20)	127 (17)	120 (9)
Diastolic BP, mm Hg	81 (9)	82 (9)	80 (11)	77 (8)
CAVI, m/s	8.9 (1.2)	9.2 (1.1)	8.5 (0.7)	8.2 (0.8)
ABI, unit	1.17 (0.07)	1.14 (0.09)	1.10 (0.10)	1.10 (0.09)
FMD, %	3.6 (2.1)	4.3 (3.1)	4.3 (1.6)	3.5 (2.0)
FDP, μg/dL	2.9 (0.9)	3.7 (1.1)	2.9 (0.4)	3.0 (0.8)
d-Dimer, μg/dL	0.2 (0.1)	0.3 (0.1)	0.2 (0.1)	0.3 (0.2)
CK, IU/L	186 (247)	112 (44)	91 (52)	88 (38)

Notes: Data are given as mean (±*SD*). BFR-T = BFR resistance training; CON-T = non-BFR resistance training; BP = blood pressure; CAVI, cardio-ankle vascular index; ABI, ankle-brachial pressure index; FMD, flow-mediated dilation; FDP, fibrin/fibrinogen degradation products; CK, creatine kinase.

strength in older adults. In addition, we observed no changes in hemodynamic parameters (heart rate and blood pressure), arterial stiffness (CAVI), vascular endothelial function (FMD), coagulation factors (FDP and d-dimer), and muscle damage (CK). Thus, elastic band BFR-T can be considered as a useful method for preventing and even improving sarcopenia in old healthy adults.

In this study, muscle size did not change in the CON-T group, suggesting that low-load elastic band training without BFR is not effective at causing significant muscle hypertrophy. On the other hand, BFR-T (<30% MVC) produced a hypertrophic potential of 0.73% per session (17.6% increase in elbow flexor muscle CSA over 24 training sessions), which is greater than that observed following traditional high-load resistance training at 80% 1RM or BFR-T using free weights at 30%–50% 1RM (0.47% or 0.59% per session, respectively) in elderly adults (11). Additionally, the observed gains in elbow flexion MVC strength (0.33% per session) was equally effective as high-load resistance training or low-load BFR training using free weights (0.39% or 0.32% per session, respectively) (11) for improving arm muscle strength in older adults. Therefore, our data suggest that low-load elastic band training combined with BFR can provide an effective hypertrophic stimulus for muscles in older adults.

There are some trigger mechanisms underlying the BFR-T induced muscle hypertrophy. In high-load training, myogenic stem cells most likely play an important role to enhance the activity of muscle protein synthesis (33). Recently, Nielsen and coworkers (34) revealed that BFR-T (23 training sessions, 20% 1RM using machine) leads to marked proliferation of myogenic stem cells, resulting in an increase in myonuclei in skeletal muscle, which is accompanied by marked myofiber hypertrophy. Therefore, there is a high possibility that myogenic stem cell-derived myonuclei provide an improved capacity for myofibrillar gene transcription, which is likely to contribute to an enhanced activity of muscle protein synthesis for BFR-T using elastic bands as well as weight machines and/or free weights.

Previous studies reported that BFR-T–induced muscle cell swelling may contribute significantly to the anabolic benefits of BFR (25,35). With respect to acute MTH responses, BFR-T exercise resulted in greater acute MTH compared with CON-T exercise. Additionally, we confirmed that low-load arm curl exercise with BFR results in a decreased plasma volume of venous blood for active muscles (ref. 36; Yasuda et al., unpublished observations). Therefore, increased muscle cell swelling may be observed following BFR-T exercise. It is known that acute cell swelling, due to osmotic water moving into the cell, simulates anabolic processes, through both an increase in protein synthesis and a decrease in proteolysis (37,38). Thus, the BFR-T exercise-induced enhancement of muscle protein metabolism may serve as the basis for the observed increase in muscle size. In addition, muscle activation during low-load elastic band exercise increased progressively only when BFR-T exercise was performed (Figure 2). In previously reported BFR studies, the greater muscle activation during low-load BFR resistance exercise was hypothesized to occur as a compensation for a deficit in force development. Such force development occurs secondary to changes in energy supply which are caused by decreased oxygen availability to the muscle and an accumulation of metabolites (36). Taken together, it appears that rapid equilibration of osmotic gradients created from the intracellular accumulation of metabolites may be higher with BFR-T compared with CON-T, and thus BFR-T may cause greater muscle cell swelling.

Previous studies have demonstrated that elastic band resistance training is well tolerated, as indicated by non-exacerbation of chronic disease conditions and lack of training-induced injury (7,8). Home-based resistance training using elastic bands has therefore been used widely for older adults and for patients with a lower level of activity (7–9). Compared with most previous BFR-T studies (11,25,26), in the present study, the pressure cuff intensity for upper arms (180–270 mm Hg) was higher when BFR-T was combined with the use of free weights. However, ratings of perceived exertion were not higher in BFR-T group for arm curls and triceps press down (14 ± 2 for both exercises) when compared to ratings in a previous study involving exercise training on resistance machines (14 ± 2 and 15 ± 2, respectively) in older adults (23). In addition, hemodynamic parameters (heart rate and blood pressure), arterial stiffness (CAVI), coagulation factors (FDP and d-dimer), and muscle damage (CK) were not changed in this study as well as in a previous study (23). Together, all of these findings suggest that BFR-T using elastic bands is a relatively safe training method. However, it should be noted that the possibility of side effects cannot be denied when subjects perform such training until near exhaustion or particularly to complete exhaustion (39,40).

The present study has some limitations. First, it should be noted that our sample size was small. In this study, the sample size was estimated by reference to the result of one BFR study (25), which had a large effect size for elbow muscle CSA in BFR studies. However, some conditions (sex, age, type of exercise, duration etc.) were different in between two BFR studies, and consequently the effect size for muscle CSA in this study was lower than that in the previous study (0.7 vs 1.7, respectively). Thus, future studies using more robust experimental design with a large sample size should be taken to verify the finding in this study. Second, since cuff pressure intensity for arms was higher than that reported in the previous studies (14,15,25,26,36), BFR-T required paying great attention to the side effects. Third, there were large individual differences in the relative exercise intensity, because it is difficult to standardize the resistance offered by the resistance bands between individuals. Fourth, we measured CAVI, which reflects changes in both central and peripheral muscle arterial compliance, although previous studies measured central and/or peripheral arterial compliance (19–22). Hence, more work is needed to understand the relationship between elastic band BFR-T and muscle size and/or arterial function in older adults.

In conclusion, low-load arm curl and triceps press down training combined with BFR using elastic bands for resistance elicited marked gains in upper arm muscle CSA and strength and did not negatively affect arterial stiffness in older healthy adults. Thus, our results demonstrate that low-load, elastic band resistance training with BFR would be beneficial in the development of safe and effective methods of promoting muscle hypertrophy in older adults.

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