

## Effects of low-intensity, elastic band resistance exercise combined with blood flow restriction on muscle activation

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We examined the effects of blood flow-restricted, low-intensity resistance exercise (termed kaatsu) using an elastic band for resistance on muscle activation. Nine men performed triceps extension and biceps flexion exercises (four sets respectively) using an elastic band for resistance with blood flow restriction (BFR) or CON (unrestricted blood flow). During a BFR session, subjects wore pressure cuffs inflated to 170–260 mmHg on the proximal region of both arms. Surface electromyography (EMG) was recorded from the triceps brachii and biceps brachii muscles, and mean integrated EMG (iEMG) was analyzed. Blood lactate concentration was obtained before (Pre) and immediately after two exercises (Post). During

triceps extension and biceps flexion exercises, muscle activation increased progressively ( $P < 0.05$ ) under BFR (46% and 69%, respectively) but not under CON (12% and 23%, respectively). Blood lactate concentration at Post was higher ( $P < 0.05$ ) under BFR than under CON (3.6 and 2.1 mmol/L, respectively). Blood lactate concentration at Post was significantly correlated with increased iEMG in both triceps extension ( $r = 0.65$ ,  $P < 0.01$ ) and biceps flexion exercises ( $r = 0.52$ ,  $P < 0.05$ ). We conclude that kaatsu training using elastic bands for resistance enhances muscle activation and may be an effective method to promote muscle hypertrophy in older adults or patients with a low level of activity.

Age-related skeletal muscle loss (sarcopenia) inhibits mobility and increases the risk of developing several diseases such as diabetes, osteoporosis, and heart disease (Visser et al., 2002; Guillet & Boirie, 2005). High-intensity resistance training can induce muscle hypertrophy and improve insulin resistance and type-2 diabetes in the elderly (Frontera et al., 1988; Fiatarone et al., 1990; Dunstan et al., 2002), suggesting that high-intensity resistance training leads to prevention and/or improvement of sarcopenia in the elderly. 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 (Zion et al., 2003; Ribeiro et al., 2009; Colado et al., 2010). 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 (Mikesky et al., 1994). Elastic bands are also portable and are less expen-

sive and easier to use than weight machines/free weights. Elastic resistance training has thus been shown to be a feasible alternative to high-intensity resistance training (Colado & Triplett, 2008; Ribeiro et al., 2009; Andersen et al., 2010). However, as elastic resistance training is commonly performed at a low-to-moderate intensity level, this training typically has little or no effect on muscle hypertrophy (Mikesky et al., 1994; Hostler et al., 2001; Colado & Triplett, 2008).

In the past decade, several studies have reported that muscle hypertrophy can be produced with low-intensity resistance training [20–30% one-repetition maximum (1RM)] combined with muscular blood flow restriction (BFR), termed “kaatsu training,” regardless of age (Takarada et al., 2000, 2002; Abe et al., 2005; Fujita et al., 2008). Kaatsu training is also a potentially useful method for promoting muscle hypertrophy with a low risk of injury (Nakajima et al., 2006; Madarame et al., 2010; Loenneke et al., 2011; Ozaki et al., 2011). Elastic resistance training with BFR may thus be an effective home-based resistance training program for promoting both muscle strength and hypertrophy. The mechanism by which BFR potentiates the training effect of low-intensity resistance training remains obscure but appears

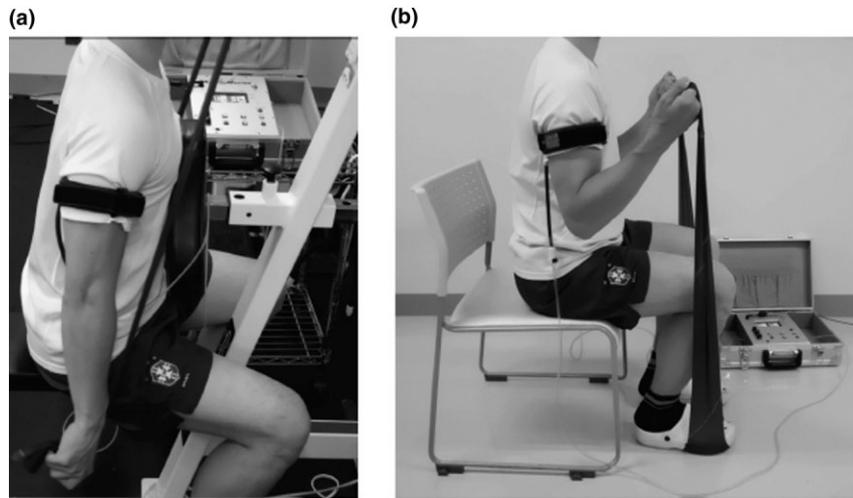


Fig. 1. Illustrations show the body position used for exercises. Triceps extension (a) and biceps flexion (b) were performed with an elastic band.

to be related, in part, to an increase in muscle activation (Moritani et al., 1992; Takarada et al., 2000; Yasuda et al., 2008, 2009). The purpose of this study was thus to examine the effect of combined BFR and elastic band resistance exercise on muscle activation.

## Methods

### Subjects

Nine healthy men aged 23–41 years with resistance training experience volunteered for the study. All subjects received a verbal and written description of the study and provided written, informed consent prior to participating in the study. The study was approved by the Ethics Committee of the University of Tokyo.

### Protocol

One week prior to experiments, all subjects completed an orientation session, which included measurement of resting blood pressure, range of motion (ROM), and familiarization with the elastic band exercises and BFR. During the orientation session, subjects sat in a chair with the testing arm placed on a table at heart level, and blood pressure was measured after a 3-min rest. The constancy of elbow joint ROM was calculated from coefficients of variation (CVs) of the mean angle values obtained during each exercise. In both triceps extension and biceps flexion exercises, the ROM of five repetitions was averaged to represent a single datum in each case. The CVs ( $n = 9$ ) for ROM were 2.2% for triceps extension and 2.6% for biceps flexion exercises.

In an experimental session, subjects performed bilateral triceps extension and biceps flexion exercises with or without BFR. Subjects participated in two experimental sessions (i.e., one with BFR and the other without) that were scheduled 1 week apart. The order of exercises was randomized. Subjects were instructed to refrain from ingesting alcohol and caffeine for 24 h before the experimental sessions and from any strenuous exercise for 48 h before the sessions.

### Exercises

During triceps extension exercise, subjects were seated comfortably on a rowing chair with the body supported in the vertical

position (Fig. 1a). Elbow joint ROM during the exercise was approximately  $140\text{--}10^\circ$  (with  $0^\circ$  being full extension). During biceps flexion exercise, subjects were seated comfortably on a chair (Fig. 1b). Elbow joint ROM during the exercise was approximately  $45\text{--}140^\circ$  (with  $0^\circ$  being full extension). Both exercises were performed using an elastic band. The exercise duration was 2.4 s and included a 1.2-s concentric and 1.2-s eccentric exercise cycle controlled by a metronome (50 beats/min). The exercise session (30 repetitions followed by 3 sets of 15 repetitions, with 30 s between sets and exercises) was determined by reference to the previous studies (Yasuda et al., 2008, 2009).

### BFR

In an orientation session, all subjects were trained to wear pressure cuffs (30-mm width; Kaatsu-Master, Sato Sports Plaza, Tokyo, Japan) at the most proximal region of both arms. The restriction pressure intensity of the cuffs (170–260 mmHg) was determined by ratings of perceived exertion (RPE) in the final set of two exercises because previous EMG studies using free weights showed that the value of RPE reached 17–18 in the same exercise protocol (Yasuda et al., 2008, 2009).

Prior to exercise with BFR, subjects were seated on a chair and the kaatsu arm cuff was tightened around the arm to a belt pressure of 40 mmHg. The cuff was then inflated to a pressure of 100 mmHg for 30 s and then deflated for 10 s. This procedure was repeated, increasing the inflation pressure 20–40 mmHg each time until the final cuff restriction pressure of 170–260 mmHg was achieved. Once the cuffs were inflated, they remained so for the entire experimental session, including rest periods between sets and exercises.

### Electromyography (EMG)

The skin was shaved, abraded with a skin preparation gel (Skin-pure, Nihon Kohden, Tokyo, Japan), and cleaned with alcohol wipes. During the experiment, skin impedance was less than 2 k $\Omega$ . The ground electrode was positioned on the lateral epicondyle. Bipolar (1-cm center-to-center) surface EMG (sEMG) electrodes (Ag/AgCl; Vitrode F; Nihon Kohden) were placed along the longitudinal axis of the triceps brachii and biceps brachii of the left upper arm. The electrode placements on the triceps brachii and biceps brachii were both at 60% of the upper arm limb length,

respectively. EMG signals were recorded and collected on a personal computer (T7300 Macintosh, Apple, Tokyo, Japan) for subsequent analysis. All EMG signals were digitized at a sampling rate of 1024 Hz with a bandwidth of 0 Hz–500 kHz (AB 6216; Nihon Kohden). To determine integrated EMG (iEMG), signals were fully rectified and integrated (Power Lab Chart 5 software, ADInstruments, Nagoya, Japan). During the experimental session, sEMG was recorded continuously, and each repetition was analyzed individually for iEMG. Each iEMG value was divided into groups of five successive repetitions, and the average for each group of five repetitions was represented as a single data point for statistical analysis. 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 each exercise.

**Relative exercise intensity**

To determine the relative exercise intensity of performing the triceps extension and biceps flexion exercises using the “extra-heavy” bands (i.e., Blue Thera-Bands; Hygenic Corporation; Akron, Ohio, USA), the iEMGs for the band exercises were compared to the iEMGs of the same exercises using free weights at predetermined relative exercise intensities (i.e., 10%, 20%, 30%, 40%, and 50% of 1RM). Measurements were also made with the same elastic band (three to five repetitions) on another experiment day. The order of exercises and loadings was randomized for each individual.

**Blood lactate concentration**

With subjects rested in a seated position, venous blood samples (15–50 µL) were taken from the antecubital vein at baseline (Pre). Immediately following two exercises, the pressure cuff was quickly removed, and blood samples were obtained at 0 (Post) and 15 min (Post-15) after the two exercises. All samples were analyzed with a rapid lactate analyzer (Lactate Pro, Arkray, Kyoto, Japan).

**Heart rate**

Heart rate was measured at baseline (Pre) and immediately after the last set of each exercise (Post) with a heart rate monitor (Marquette Dash 3000 Patient Monitor, GE, Milwaukee, Wisconsin, USA).

**RPE**

RPE was measured using the Borg scale immediately after the last set of each exercise (Post) (Borg, 1973).

**Statistical analysis**

Results are expressed as mean ± standard deviation (SD). A two-way analysis of variance with repeated measures (condition × time) was used to evaluate the training effects for all dependent variables. Post-hoc testing was performed using Tukey’s technique when appropriate. All calculations were made with JMP statistical software package v.8.0 (SAS Institute Inc., Tokyo, Japan). Pearson’s product correlation was performed to determine the relationship between change in iEMG and blood lactate concentration or RPE. Statistical significance was set at  $P < 0.05$ .

**Results**

Descriptive characteristics for the subjects are shown in Table 1. None of the subjects had high systolic

Table 1. Descriptive characteristics of nine male subjects

Variable	Mean	SD	Range
Age (years)	29.6	7.1	23–41
Height (cm)	174.7	4.4	166–180
Weight (kg)	72.3	8.7	61–88
Resting BP (mmHg)			
Systolic BP	117.8	13.2	96–127
Diastolic BP	71.8	8.3	59–84
ROM (°)			
Triceps extension	119.0	11.9	105–144
Biceps flexion	93.4	10.1	81–109
Relative exercise intensity (% 1RM)			
Triceps extension	15.0	8.3	6.0–27.6
Biceps flexion	19.9	6.7	10.2–33.6

1RM, one-repetition maximum; BFR, blood flow restriction; BP, blood pressure; ROM, range of motion; SD, standard deviation.

(≥130 mmHg) or diastolic (≥85 mmHg) blood pressure. During the first five repetitions of each exercise, mean exercise intensity according to normalized iEMG was approximately 15% of 1RM for triceps extension and approximately 20% of 1RM for biceps flexion (Table 1).

Figure 2 shows representative EMG traces during BFR exercises. During the two exercises, all subjects maintained and completed all the prescribed exercises. During triceps extension exercise, iEMG increased ( $P < 0.05$ ) progressively during exercises under BFR (approximately 46%) and was greater ( $P < 0.05$ ) than CON under BFR in the last set (Fig. 3a). In biceps flexion exercise, there was a progressive increase ( $P < 0.05$ ) in iEMG with BFR (approximately 69%), such that iEMG was greater ( $P < 0.05$ ) under BFR vs CON from the second to the last set (Fig. 3b). No significant changes in muscle activation were observed under CON during triceps extension (approximately 12%) and biceps flexion exercises (approximately 23%).

At baseline, CON and BFR sessions produced no differences ( $P > 0.05$ ) in blood lactate concentration ( $1.0 \pm 0.1$  and  $1.0 \pm 0.2$  mmol/L, respectively) or heart rate ( $67.4 \pm 9.6$  and  $66.0 \pm 9.2$ , respectively). Blood lactate concentration increased ( $P < 0.05$ ) in both exercises. Blood lactate concentration at Post was higher ( $P < 0.05$ ) under BFR than CON (3.6 and 2.1 mmol/L, respectively). Blood lactate concentration remained elevated at Post-15 under BFR, but not under CON (1.8 and 1.2 mmol/L, respectively). Following the triceps extension and biceps flexion exercises, heart rate was greater ( $P < 0.05$ ) under BFR ( $99 \pm 20$ /min and  $109 \pm 22$ /min, respectively) than CON ( $87 \pm 15$ /min and  $92 \pm 15$ /min, respectively), and RPE was greater ( $P < 0.01$ ) under BFR ( $17.4 \pm 1.6$  and  $18.7 \pm 0.9$ , respectively) than CON ( $12.9 \pm 1.6$  and  $14.6 \pm 1.2$ , respectively).

Blood lactate concentration at Post was significantly correlated with increased iEMG in both exercises (Fig. 4). Following each exercise, iEMG was correlated

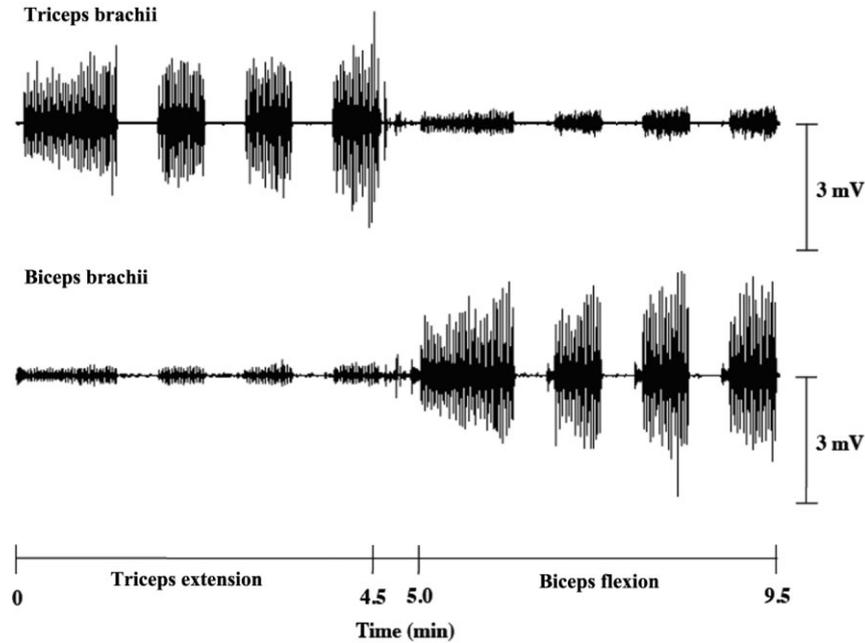


Fig. 2. Representative electromyography tracings from an experimental session with blood flow restriction. The exercises performed were triceps extension and biceps flexion was performed against elastic band resistance. The experimental session consisted of four sets of each exercise. The time line indicates the time spent performing each exercise and the 30-s rests in between. The total length of the experimental session was 9.5 min.

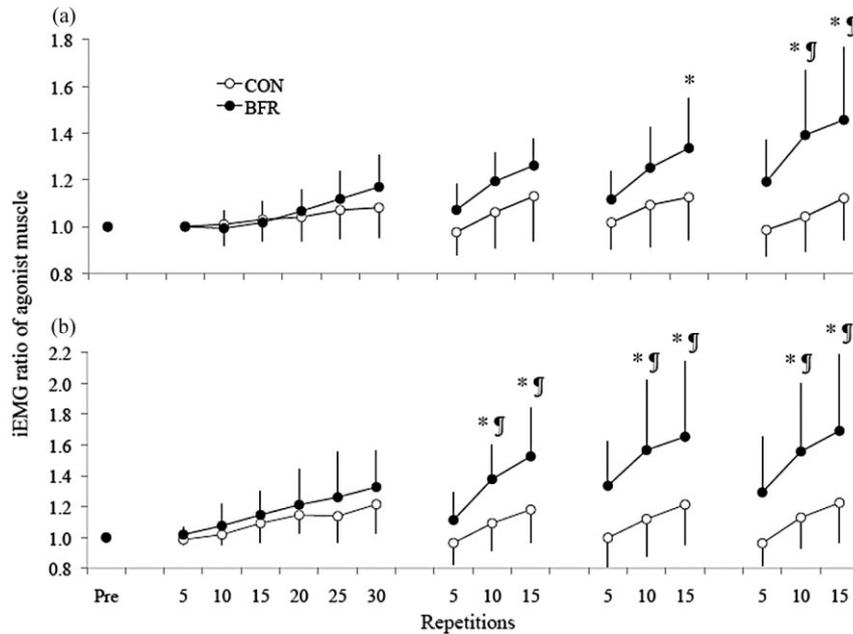


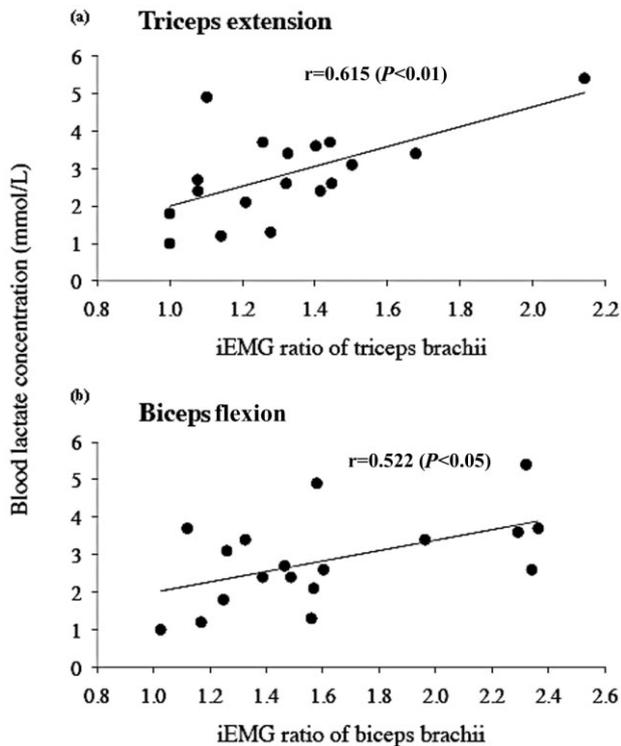
Fig. 3. Integrated electromyography (iEMG) ratio of triceps brachii and biceps brachii muscles during triceps extension (a) and biceps flexion (b) for each set performed. Pre was iEMG without blood flow restriction (BFR) before the first set of each exercise. \*Difference from Pre,  $P < 0.05$ . ‡Difference from CON,  $P < 0.05$ .

with RPE in triceps extension ( $r = 0.60$ ,  $P < 0.01$ ) and biceps flexion exercises ( $r = 0.68$ ,  $P < 0.01$ ).

**Discussion**

Muscle activation has been shown to increase during low-load exercise with BFR (Takarada et al., 2000;

Yasuda et al., 2008, 2009). However, it was unknown whether increased muscle activation could be achieved during BFR exercise using an elastic band. Our findings show that muscle activation increased progressively in a BFR session when exercises were performed at a low-intensity level (approximately 20% 1RM) using an



*Fig. 4.* Relationships between integrated electromyography (iEMG) ratio of agonist muscles for each exercise and blood lactate immediately after two exercises.

elastic band for resistance. This result was similar to those in the previously reported studies using free weights (Yasuda et al., 2008, 2009).

In our study, blood lactate concentration increased following BFR exercise and was correlated with increased muscle activation in both triceps extension and biceps flexion exercises. Previously, it was suggested that greater muscle activation during low-intensity resistance exercise with BFR may have taken place to compensate for a deficit in force development secondary to changes in energy supply (Bigland-Ritchie et al., 1986; Moritani et al., 1986). In addition, venous blood oxygen saturation, oxygen partial pressure, carbon dioxide, accumulation of blood lactate concentration, and hydrogen ions are significantly changed following BFR exercises (Takarada et al., 2000; Yasuda et al., 2010), indicating that these changes could potentially stimulate muscle activation (Leonard et al., 1994). Taken together, these results suggest that BFR combined with elastic band exercise changes blood flow, energy supply, and venous occlusion sufficiently to induce an increase in muscle activation. A BFR exercise-induced increase in muscle activation may be one important factor in the muscle hypertrophy seen in active muscle following low-intensity resistance training with BFR in previous studies (Takarada et al., 2000; Yasuda et al., 2008, 2009). Consequently, the results of our study, together with those of the previous studies, suggest that BFR training

using an elastic band as well as weight machines/free weights leads to significant muscle hypertrophy.

In general, because elastic resistance training is performed at a low-to-moderate intensity level, the training program is designed to be a high repetition form of training. Consequently, most studies have demonstrated that muscle strength and endurance capacity can be improved following elastic resistance training (Mikesky et al., 1994; Rogers et al., 2002; Colado et al., 2010). At the same time, elastic bands produced less muscle hypertrophy than weight machines (Colado & Triplett, 2008). Elastic resistance training also induced minor changes in muscle fiber size and fiber-type composition compared with high-intensity resistance training (Hostler et al., 2001). Thus, low-intensity elastic resistance training combined with BFR may be an effective training program for promoting muscle hypertrophy in practical applications.

Previous studies have demonstrated that elastic resistance training is well tolerated, as indicated by non-exacerbation of chronic disease conditions and lack of training-induced injury (Mikesky et al., 1994; Zion et al., 2003). Home-based resistance training using elastic bands has therefore been used widely for older adults and for patients with a lower level of activity (Aniansson et al., 1984; Mikesky et al., 1994; Rogers et al., 2002; Zion et al., 2003; Colado & Triplett, 2008; Colado et al., 2010). In the present study, the cuff pressure (170–260 mmHg) produced near exhaustion in subjects, as reported previously (Yasuda et al., 2008, 2009) because increased iEMG during BFR exercise was related to a high value of RPE. Consequently, high values of RPE were observed in both triceps extension and biceps flexion (17.4 and 18.7, last set, respectively). However, because RPE was generally lower in BFR exercises (14.9–15.8, last set) vs high-intensity resistance exercise (17.6–18.7, last set), there were no incidents of any pain reported in kaatsu training (Yasuda et al., 2010, 2011). Although kaatsu training is performed with restricted venous blood flow and pooling of blood in the extremities, it has no impact on blood clotting function as assessed by changes in fibrin d-dimer and fibrin degradation products after exercise or training (Madarame et al., 2010; Clark et al., 2011). Furthermore, serious side effects of kaatsu training have not been reported in approximately 13 000 people, including older adults (>80 years old) and patients with various physical conditions (Nakajima et al., 2006). All these findings suggest that elastic resistance training with BFR is a relatively safe training method, but it should be noted that a potential for adverse effects exists, especially when subjects perform until near or complete exhaustion.

Two limitations of this study should be mentioned. First, the material properties of an elastic band are an important variable for determining exercise intensity. Previous studies reported that increase in muscle

activation depends on the resistance level and stretch distance of the elastic band/tubing during exercise (Mikesky et al., 1994; Patterson et al., 2001; Andersen et al., 2010). However, the type of band used in our study (Blue, Thera-band) presented the same resistance level, and elbow joint ROM was defined arbitrarily. There were consequently large individual differences in the relative exercise intensity.

Second, cuff pressure intensity (170–260 mmHg) for arms was higher than that in the previous studies (Takurada et al., 2000; Yasuda et al., 2008, 2010, 2011), as discussed earlier. In this study, relative exercise intensities during triceps extension and biceps flexion (15.0% and 19.9%, respectively) were lower than those in previous EMG studies (20% 1RM; Yasuda et al., 2008, 2009). Furthermore, because the same elastic band was used for all subjects, there were large differences between individuals in the relative exercise intensity. In the biceps flexion exercise, cuff pressure intensity was negatively correlated with relative exercise intensity ( $r = -0.80$ ,  $P < 0.05$ ). Taken together, we speculate that a high level of cuff pressure intensity is required during BFR training at low intensity; as a result, the potential for adverse effects is increased. More work is needed to understand how BFR training using an elastic band would be advantageous for developing safe and effective methods of promoting muscle hypertrophy in older adults, and especially in patients capable of tolerating only low-load resistance exercise.

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## Perspective

Blood flow-restricted, low-intensity resistance exercise (kaatsu training) using machines/free weights leads to increased muscle activation, the response to which is an important factor in muscle hypertrophy. However, as an elastic band is inexpensive, compact, and easy to use compared with machines/free weights, elastic band resistance training could be used in home-based training programs for older subjects or for patients with a lower level of activity. As in previous BFR studies using machines/free weights, our results suggest that low-intensity, elastic band resistance exercise combined with BFR enhances muscle activation. Kaatsu training using elastic bands may therefore be an effective method to promote muscle hypertrophy in older adults or in patients capable of tolerating only low-load resistance exercise.

**Key words:** vascular occlusion, kaatsu, elastic band, EMG, upper limb.

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