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Full Length Research Paper

Examination of the time course of the acute consequences of BFR slow walk

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Walk training combined with blood flow restriction (BFR) leads to hypertrophic effects in leg muscle, but the underlying physiological mechanisms are poorly understood. We examined the time course of the acute effects of BFR slow walk (BFR-slow; walking speed 56 m/min), BFR fast walk (BFR-fast; walking speed 87 m/min), and control walk (CON-slow; walking speed 56 m/min) on ultrasound-measured muscle thickness (MTH) and on isometric knee extension strength in 8 young men. No differences in baseline MTH and isometric strength were observed between the sessions. MTH of the quadriceps and triceps surae increased ($p < 0.05$) during and immediately after the BFR-slow (8 to 11% and 2 to 4%, respectively) and BFR-fast (7 to 8% and 3 to 5%, respectively) sessions, but not in the CON-slow (-2% and 0%, respectively) session. There were no significant differences in quadriceps and triceps surae MTH between the BFR-slow and the BFR-fast sessions. No changes in MTH were observed for the lumbar multifidus following each walking session. Isometric strength was unchanged during and immediately after the BFR-slow, BFR-fast, and CON-slow sessions. Our results indicated that acute increases in muscle size occurs following walk exercise combined with leg blood flow restriction regardless of gait speed which may influence BFR-walk induced muscle hypertrophy.

Key words: Vascular occlusion, ultrasonography, muscle size, maximum voluntary contraction.

INTRODUCTION

Muscle blood flow restriction (BFR) during low-intensity resistance exercise training has been shown to elicit muscle hypertrophy and strength gains similar to that elicited by traditional high-intensity resistance training (Karabulut et al., 2010a; Takarada et al., 2000). An intensity as low as that associated with slow walking, when combined with BFR, can also lead to significant improvements in muscle strength and size in young (Abe et al., 2006) and older adults (Abe et al., 2010; Ozaki et al., 2011). Recent studies demonstrated that an acute bout of low-intensity (20% of one repetition maximum, 1-RM) resistance exercise with BFR stimulates the anabolic cell signaling pathway (that is, Akt/mTOR) and muscle protein synthesis within 3 h after exercise in young (Fujita et al., 2007) and older men (Fry et al., 2010). Similarly, the downregulation of proteolytic transcripts have been observed at 8 hours following low-intensity exercise (20% of 1-RM) with BFR (Manini et al., 2011).

The physiological mechanisms that promote muscle growth associated with low-intensity exercise combined with BFR are poorly understood, although several possibilities exist (Manini and Clark, 2009; Loenneke et al., 2010).

Muscle fatigue (a decrease in strength) during resistance exercise might be responsible for a greater hypertrophic response compared to that of moderate fatigue (Goto et al., 2005). Under BFR, maximal isometric strength, percent voluntary activation, potentiated twitch force and EMG amplitude decreased to a greater extent compared to the same exercise intensity without BFR immediately following exercise (Karabulut et al., 2010b). However, it is unknown whether the maximal isometric strength decreases during slow or fast walk exercise when combined with BFR.

Additionally, acute cell swelling has been shown to stimulate protein synthesis and suppress proteolysis

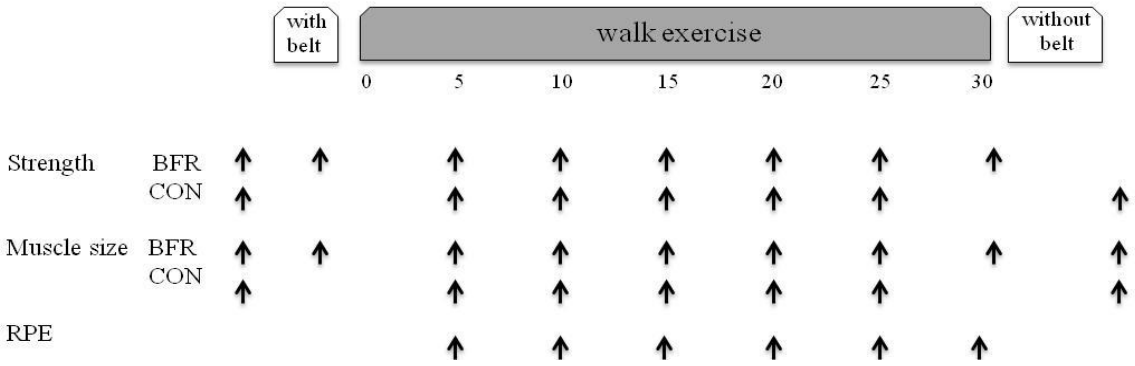

Figure 1. Study design. Strength and muscle size were measured at the times indicated by the arrows. Exercise was performed immediately after baseline measurements. BFR, blood flow restriction trial; CON, control trial.

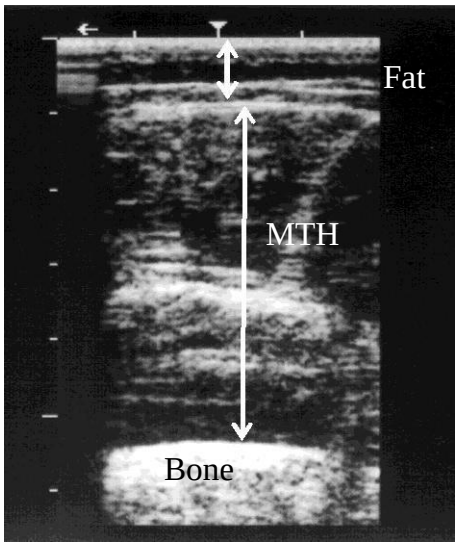

Figure 2. Typical ultrasound image showing transverse scan on the anterior thigh at 50% of thigh length.

(Haussinger et al., 1993). A previous study reported that increased leg circumference, an index of muscle size, was higher with BFR (increased by 2.5 cm) compared to non-BFR (increased by 1.3 cm) immediately after low-intensity (20% of 1-RM) knee extension exercise (Fry et al., 2010). Interestingly, following a single bout of low-intensity (30% of 1-RM) BFR bench press exercise, acute changes in muscle size were observed in both the blood flow restricted triceps muscle as well as the blood flow non-restricted chest muscle, and both the triceps and chest muscles increased muscle cross-sectional area following 6-weeks of BFR bench press training (Yasuda et al., 2011). To date, there are no published data that describes the acute changes in leg and trunk muscle sizes during walk exercise combined with BFR. Thus, the purpose of this study was to investigate the level of muscle fatigue during walk exercise combined with BFR and to assess the extent of change in muscle size (an index of acute muscle swelling) during walk exercise with BFR.

METHODS

Subjects

Eight male graduate students participated in this study. All subjects were habitually participating in recreational sports and exercise. The subjects were informed of the procedures, risks, and benefits, and signed an informed consent before participation. The study was conducted according to the declaration of Helsinki and was approved by the Ethics Committee of Human Experiments of the University of Tokyo, Japan. The average (SD) age, standing height, and body weight of the subjects were 25.4 (1.7) years, 1.74 (0.02) m, and 63.5 (3.0) kg.

Exercise protocol and blood flow restriction

Each subject performed 30 min of treadmill walking with and without leg BFR on three separate days (>2 days between trials) in random order. Treadmill speed was set at 56 m/min (BFR-slow) and 87 m/min (BFR-fast) for the BFR walk sessions and at 56 m/min (CON-slow) for the control walk session. In order to investigate the effects of the three separate conditions on maximal isometric strength and muscle size, subjects randomly completed the six different trials in which each variable was independently measured (Figure 1). Step frequency during each trial was recorded and the subjects maintained the same step frequency during each walk session and for each speed.

During the BFR walk session, an elastic belt (50 mm wide) was placed around the most proximal portion of each leg. The belt contained a pneumatic bag along its inner surface that was connected to an electronic air pressure control system, which monitored the restriction pressure (Kaatsu-Master, Sato Sports Plaza, Tokyo, Japan). The belt air pressure was set at 220 mmHg and was maintained during the entire exercise session (Abe et al., 2006).

Muscle size

Muscle thickness (MTH) was measured using B-mode ultrasound (Aloka SSD-500, Tokyo, Japan) at three sites: the quadriceps (at 50% of the thigh length) (Figure 2), the triceps surae (at 30% of the lower leg length), and the lumbar multifidus (at L4 to L5), as described previously (Abe et al., 1994; Koppenhaver et al., 2009).

Table 1. Maximal isometric strength and rating of perceived exertion before, during and immediately after walk session.

Isometric strength (Nm)	BFR-slow	BFR-fast	CON-slow
Before (no belt)	244(32)	253 (34)	247(20)
Before (with belt)	235(35)	241 (34)	------
5 min	243(44)	242 (37)	245(28)
10 min	239(50)	241 (37)	241(36)
15 min	237(48)	244 (34)	239(41)
20 min	233(46)	237 (32)	235(38)
25 min	230(51)	236 (32)	233(40)
Immediately after (with belt)	233(38)	236 (31)	------
Immediately after (no belt)	------	------	236(34)
Rating of perceived exertion			
5 min	11.8(1.3)	12.0 (0.9)*	10.8(0.7)
10 min	12.1(1.2)	12.4 (0.7)*	10.8(0.7)
15 min	12.3(1.4)	12.6 (0.9)*	10.9(1.0)
20 min	12.4(1.5)	12.9 (1.1)*	11.0(1.1)
25 min	12.5(1.7)	13.0 (1.3)*	11.0(1.1)
30 min	12.8(2.0)	13.3 (1.3)*	11.0(1.1)

Significant difference with CON-slow, *P < 0.01.

Prior to the testing, measurement points on the quadriceps, triceps surae and lumbar multifidus were marked by a felt pen and the same measurement points were used for each
testing session. At 5 min intervals during walking, the subjects stepped off the treadmill for measurements and stepped back on the treadmill as fast as possible; usually in less than 25 s. Measurements were also taken before and immediately after the walk session with and without BFR. The test-retest reliability for this method was less 1%, as described previously (Abe et al., 1994).

Maximal isometric strength

Maximal voluntary isometric knee extension strength (MVC) was measured using an isokinetic dynamometer (Biodex System 3, Sakai Medical Instruments, Tokyo, Japan). Each subject was seated on a chair with the hip and knee joint angles positioned at 85 and 75 degrees, respectively. A treadmill and an isokinetic dynamometer were set next to each other. Measurements were taken before, at 5 min intervals during, and immediately after the walk sessions. Electromyographic (EMG) muscle activity was recorded during the MVC. Prior to testing, the skin was shaved, abraded with skin preparation gel (Skinpure, Nihon Kohden, Japan), and cleaned with alcohol wipes. Bipolar electrodes were placed over the muscle belly with a constant inter-electrode distance of 20 mm. The EMG signals were collected continuously from the vastus lateralis and rectus femoris with a sampling rate of 1024 Hz using a 12-bit analog-to-digital converter (Macintosh, Power PC 750, Apple, Japan). To determine iEMG, signals were fully rectified and integrated.

Rating of perceived exertion

Borg's rating of perceived exertion (RPE), which is a scale (6 to 20) to measure subjective feelings of exertion and fatigue, was recorded at 5 min intervals during each walk session (Borg, 1982).

Statistical analysis

All data were analyzed using SPSS v. 17.0 for Windows (SPSS Inc., Chicago, IL) and results are expressed as means (SD) for all variables. Statistical analysis was performed by a two-way ANOVA with repeated measures [trials (slow- and fast-BFR and CON-slow) × exercise time (before, 5 min intervals during walk and immediately after)]. Pairwise comparisons were used for post-hoc analysis using the Bonferroni adjustment. A one-way ANOVA followed by a post-hoc Tukey test was used to detect differences among trials at each time point. Statistical significance was set at $P < 0.05$.

RESULTS

No differences in baseline MTH and isometric strength were observed between the sessions. There were no differences between isometric strength measured before treadmill walking with or without blood flow restriction (no belt vs. with belt) for either slow or fast BFR trials. Absolute and percent changes in isometric strength were also unchanged ($P > 0.05$) during and immediately after the BFR-slow (-3%), BFR-fast (-6%), and CON-slow (-2%) walk sessions (Table 1). Integrated EMG was also unchanged during and immediately after each walk session (data not shown).

Before each walk session, the quadriceps and triceps surae MTH were similar with or without blood flow restriction (no belt vs. with belt) for both BFR trials. There were no significant differences in absolute MTH of the quadriceps and triceps surae during both BFR and CON trials (Table 2). In contrast, percent changes in MTH of

Table 2. Leg and trunk muscle thickness (MTH) before, during and immediately after walk session.

MTH (cm)	BFR-slow	BFR-fast	CON-slow
Quadriceps			
Before (no belt)	4.86 (0.57)	4.90 (0.55)	4.91 (0.58)
Before (with belt)	4.96 (0.44)	5.03 (0.60)	------
5 min	5.24 (0.56)	5.30 (0.59)	4.80 (0.57)
10 min	5.28 (0.49)	5.30 (0.63)	4.70 (0.52)
15 min	5.26 (0.53)	5.34 (0.57)	4.81 (0.63)
20 min	5.38 (0.57)	5.28 (0.57)	4.79 (0.58)
25 min	5.39 (0.56)	5.29 (0.56)	4.81 (0.61)
Immediately after (with belt)	5.35 (0.57)	5.33 (0.55)	------
Immediately after (no belt)	5.19 (0.52)	5.15 (0.51)	4.76 (0.53)
Triceps surae			
Before (no belt)	6.71 (0.60)	6.76 (0.59)	6.66 (0.63)
Before (with belt)	6.76 (0.56)	6.78 (0.62)	------
5 min	6.86 (0.54)	6.96 (0.62)	6.65 (0.58)
10 min	6.88 (0.53)	7.05 (0.59)	6.64 (0.58)
15 min	6.93 (0.57)	7.04 (0.59)	6.64 (0.59)
20 min	6.94 (0.55)	7.08 (0.61)	6.66 (0.58)
25 min	6.95 (0.54)	7.13 (0.57)	6.61 (0.60)
Immediately after (with belt)	6.95 (0.55)	7.11 (0.59)	------
Immediately after (no belt)	6.88 (0.56)	7.01 (0.62)	6.64 (0.59)
Lumber multifidus			
Before	4.15 (0.61)	4.10 (0.60)	3.94 (0.74)
5 min	4.13 (0.60)	4.04 (0.58)	3.93 (0.74)
10 min	4.10 (0.62)	4.14 (0.59)	3.89 (0.68)
15 min	4.14 (0.55)	4.09 (0.54)	3.89 (0.75)
20 min	4.11 (0.57)	4.08 (0.61)	3.94 (0.76)
25 min	4.15 (0.57)	4.08 (0.60)	3.95 (0.75)
Immediately after	4.16 (0.59)	4.08 (0.63)	3.94 (0.70)

the quadriceps and triceps surae increased ($P < 0.05$) during and immediately after the BFR-slow (8 to 11% and 2 to 4%, respectively) and BFR-fast (7 to 8% and 3 to 5%, respectively) sessions, but not in the CON-slow (2% and 0%, respectively) session (Figure 3). There were no significant differences in absolute and relative quadriceps and triceps surae MTH between the BFR-slow and BFR-fast sessions. No changes in MTH were observed for the lumber multifidus following each walking session (Table 2). RPE ranged from 11.8 to 12.8 for BFR-slow, 12.0 to 13.3 for BFR-fast, and 10.8 to 11.0 for CON-slow sessions. There were no significant differences in RPE between BFR-slow and CON-slow, but was higher ($P < 0.05$) in BFR-fast compared to the CON-slow (Table 1).

DISCUSSION

In the present study, an acute increase in MTH was observed only in the BFR walk sessions. Increases in muscle size were specific to those limb muscles where blood flow was restricted, whereas no changes were observed in the unrestricted trunk muscles. The percentage changes in quadriceps and triceps surae MTH were not significantly different between BFR-slow and BFR-fast trials, even if achilles tendon forces increased linearly with increased walking speed (Komi, 1990). Our results may suggest that increases in leg muscle size are not affected by walking speed when exercise duration is limited to 30 min. Although it is unknown whether the increase in MTH observed during BFR walk sessions was due to cell swelling, previous studies reported that dynamic exercise has been shown to temporarily induce a transcapillary fluid shift, which can be manifested by a significant reduction in plasma volume (Collins et al., 1989; Knowlton et al., 1987) and result in subsequent muscle swelling (Lindinger et al., 1994; Sjogaard and Saltin, 1982). This muscle swelling

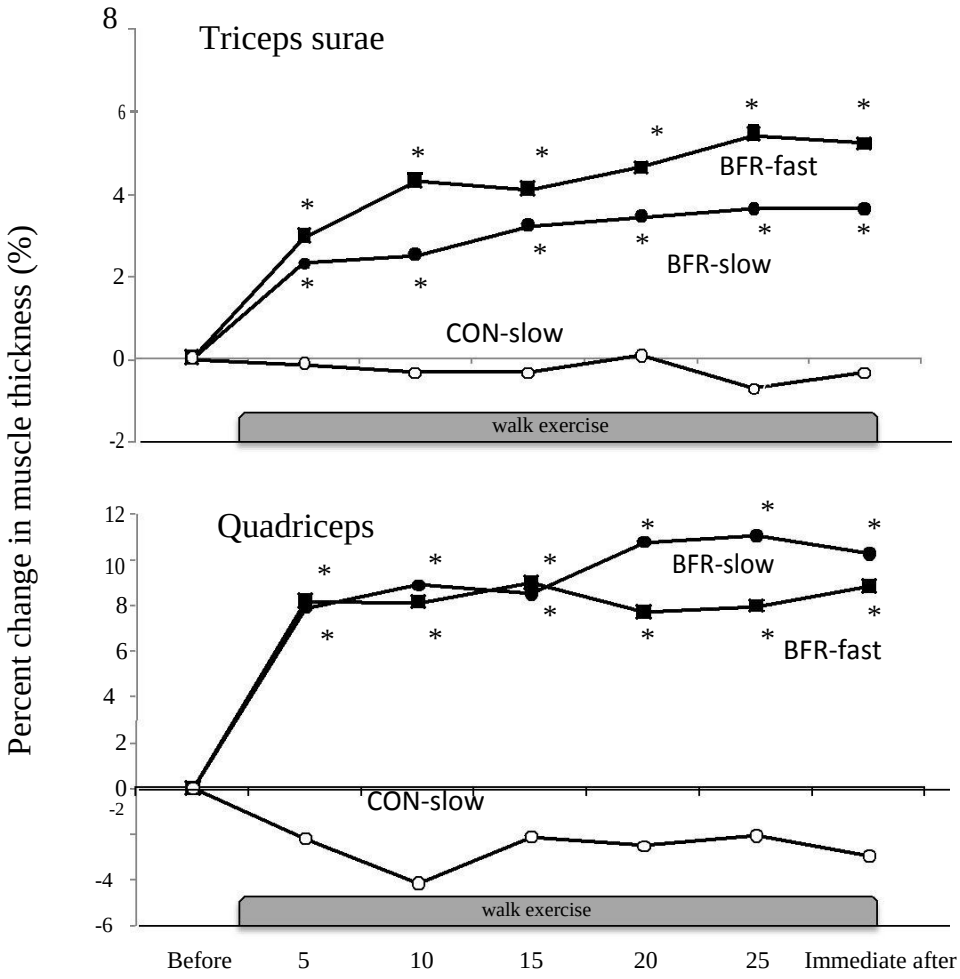

Figure 3. Changes in quadriceps and triceps surae muscle thickness during and immediately after walking session. Significant difference with CON-slow, *P < 0.01.

occurs specifically in exercising muscles and not in inactive muscles (Sjogaard and Saltin, 1982). Cell volume alteration induced by acute changes in extracellular osmolality is an important regulator of protein metabolism. As such, acute cell swelling has been shown to stimulate protein synthesis and suppress proteolysis (Berneis et al., 1999; Haussinger et al., 1993; Millar et al., 1997), thereby promoting net-protein accretion. Interestingly, in the present study, the acute increase in MTH was greater in the quadriceps than in the triceps surae, a finding that corresponds to a greater training-induced muscle hypertrophy of the thigh muscles than those of the lower leg, as reported in a previous study (Sakamaki et al., 2011). The mechanisms behind the potential anabolic effect of muscle cell swelling are not well understood. However, a recent article hypothesized that BFR exercise induced muscle cell swelling might be detected by an intrinsic volume sensor. The activation of this volume sensor may lead to a G-protein-mediated activation of a currently unidentified tyrosine kinase, which leads to an activation of mammalian target of rapamycin (mTOR) and mitogen-activated protein kinase (MAPK) signaling pathway (Loenneke et al., 2011).

Our results showed that maximal isometric strength did not change significantly during BFR walk sessions. Previous research reported that maximal isometric strength, percent voluntary activation, potentiated twitch force and EMG amplitude decreased more with low-intensity (20% of 1-RM) resistance exercise combined with BFR compared to the same exercise intensity without BFR immediately post exercise (Karabulut et al., 2010b). The magnitude of the decrease in maximal strength during BFR exercise is associated with exercise intensity (Wernbom et al., 2006), inter-repetition rest interval (Fujita et al., 2007) as well as cuff compression pressure (Sugaya et al., 2011). In the present study, RPE during BFR walk sessions were relatively low (<13 on Borg 6 to 20 scale) and the subjects did not approach muscle fatigue in the lower body muscles due to the very low exercise intensity. In conclusion, our results indicated that acute increases in muscle size occur following walk

exercise combined with leg blood flow restriction regardless of gait speed which may influence BFR-walk induced muscle hypertrophy. No muscle fatigue was observed during BFR walking which suggests muscle fatigue is not responsible for BFR-walk induced muscle hypertrophy.

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