Increases in Thigh Muscle Volume and Strength by Walk Training with Leg Blood Flow Reduction in Older Participants

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We examined the effects of walk training combined with leg blood flow reduction (BFR) on muscle hypertrophy as well as on peak oxygen uptake (VO_{2peak}) in older individuals. Both the BFR walk training (BFR-Walk, $n = 10$, age; 64 ± 1 years, body mass index [BMI]; 22.5 ± 0.9 kg/m^2) and control walk training (CON-Walk, $n = 8$, age; 68 ± 1 years, BMI; 23.2 ± 1.0 kg/m^2) groups performed 20 minutes of treadmill walking at an exercise intensity of 45% of heart rate reserve, 4 days per week, for 10 weeks. The BFR-Walk group wore pressure belts (160–200 mm Hg) on both legs during training. After the training, magnetic resonance imaging–measured thigh muscle cross-sectional area (3.1%, $p < .01$) and muscle volume (3.7%, $p < .01$) as well as maximal isometric (5.9%, $p < .05$) and isokinetic (up to 22%, $p < .01$) strength increased in the BFR-Walk group, but not in the CON-Walk group. Estimated VO_{2peak} during a bicycle graded exercise test increased ($p < .05$) and correlated with oxygen pulse in both groups. In conclusion, BFR walk training improves both muscle volume and strength in older women.

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Aн age-related decline of cardiovascular fitness (eg, maximal oxygen uptake [VO_{2max}]) has been attributed in part to changes in body composition, particularly a loss of skeletal muscle mass, and referred to as "senile sarcopenia" (1). Sarcopenia leads to an increased risk of developing osteoporosis, insulin resistance, type 2 diabetes, and obesity (2), as well as reduced levels of daily activity and physical function. Additionally, it has been reported that a low age-related VO_{2max} level is a risk factor for both cardiovascular disease and all-causes mortality in middle-aged and elderly populations (3). Based on existing evidence, cardiovascular fitness and muscular strength must be maintained in an optimal range to minimize the potential risks of age-related diseases.

To improve muscular strength and cardiovascular fitness in middle-aged and elderly populations, several societies (4,5) have published guidelines that recommend combining training intensity, volume, and frequency to optimize muscle hypertrophy and strength gains as well as improve VO_{2max}. In general, the magnitude of the acquired training adaptation is proportional to the training stimulus, depending on the individual's training experience and/or initial physical fitness level. For instance, a training intensity of more than 65% of one repetition maximum (1-RM) is

considered the minimum intensity required to achieve muscle hypertrophy and strength gains (6). On the other hand, normally, the magnitude of change in VO_{2max} induced followed a training increases as exercise intensity is raised above 50% VO_{2max}. The minimum stimulus necessary to evoke change is more than 40% or 50% of VO_{2max}. In fact, a few studies (7,8) have reported an increase in VO_{2max} after training at intensity as low as 45% of VO_{2max}. The guidelines also recommend a training frequency of 3–5 days per week for aerobic training and 2–3 days per week for resistance training (4). Because the typical duration of these training sessions is approximately 60 minutes, including warm-up and cool down, about 300–480 minutes (5–8 hours) per week would be needed to complete the program. However, the vigorous training intensity and/or high training frequency might constitute major hindrance, preventing middle-aged and elderly populations from participating in the training programs.

Muscular blood flow reduction (BFR) during resistance training has been shown to elicit muscle hypertrophy and strength gains similar to those elicited by traditional high-intensity resistance training (HI-RT), but with much lower exercise intensities (9,10). An intensity as low as that associated with walking, when combined with BFR, can

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lead to significant improvements in knee joint strength and leg muscle size (11,12). Improvements in leg muscle size and aerobic capacity using a single exercise of BFR walk training may warrant the use of this training method in the broader population, including the frail and elderly population. During exercise with BFR, the decline in venous return to the heart from blood flow–restricted limb muscles results in a decreased stroke volume (SV) and an increased heart rate (HR) while maintaining cardiac output (13). Consequently, the increased HR at the same systolic blood pressure during exercise with BFR may produce high mechanical stress on the heart, as indicated by a greater rate-pressure product (14). In addition, the increases in muscle activation (15) and oxygen uptake (11) observed during BFR exercise may be the result of an increased arterial and mixed venous blood oxygen (a-v) O_2 difference because cardiac output during exercise with and without BFR is the same (13). The increase in the (a-v) O_2 difference may stimulate adaptations in the mitochondria, the myoglobin content of muscles, and/or muscle capillarization. We hypothesized that the potential benefits of BFR walk training could include not only an anabolic response by the muscular system but also improvements in the cardiovascular system. However, there are few published studies documenting concurrent improvements in VO_{2max} and muscle hypertrophy using a single exercise training for older participants (16,17). Thus, the purpose of this study was to investigate the effects of BFR walk training on muscle size and function as well as aerobic capacity in the older women.

Methods

Participants

A total of 18 sedentary women, aged 57–73 years, volunteered to participate in the present study. The participants were recruited through printed advertisements and by word of mouth and had not participated in a regular exercise program for at least the previous 3 years. All participants were free of overt chronic disease as assessed by medical history, physical examination, and complete blood chemistry and hematologic evaluation. Candidates who had smoked in the previous 4 years or were taking medications or female hormone supplements were excluded. All participants were informed of the methods, procedures, and risks, and signed an informed consent document before participating in the study. The study was conducted according to the Declaration of Helsinki and was approved by the Ethics Committee for Human Experiments of the University of Tokyo, Japan. Participants were subsequently divided into either BFR walk training group (BFR-Walk, $n = 10$) or a walk training group without BFR (CON-Walk, $n = 8$) in random order but balanced the participants to match anthropometric variables between groups.

Training Protocol

The participants in both the BFR-Walk and CON-Walk groups performed 20 minutes of treadmill walking at a predetermined exercise intensity of 45% of heart rate reserve (HRR). 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, walking speed and grade were adjusted for each participant during a submaximal walking test, and the exercise load condition of each participant was determined and remained constant throughout the training period. The mean treadmill speed and grade were 4.5 ± 0.0 km/h and 1.6 ± 0.4 degrees in the BFR-Walk group and 4.4 ± 0.1 km/h and 1.5 ± 0.5 degrees in the CON-Walk group. Age-predicted maximum heart rate (HR_{max}; $220 -$ age) was used to determine the HRR for each participant. Training sessions were conducted 4 days per week for 10 weeks. During all training sessions, HR was recorded at the 5th minute, 10th minute, and 15th minute for both the CON-Walk and BFR-Walk groups. Ratings of perceived exertion were also recorded every 5 minutes during the session.

Blood Flow Restriction and Its Safety

Participants in the BFR-Walk group wore elastic cuffs (5 cm wide) (Kaatsu-Master system; Sato Sports Plaza, Tokyo, Japan) on the most proximal portion of each leg during the training sessions. Before the training sessions, the participants were seated on a chair, and the upper thigh-mounted cuff was inflated at 120 mm Hg (the approximate systolic blood pressure at heart level for each participant) for 30 seconds, and then the pressure was released. The air pressure was increased by 20 mm Hg, held for 30 seconds, and then released for 10 seconds before the next occlusive stimulation was performed. This process was repeated until a final occlusion pressure for each training day was reached. On the first day of training, the final cuff air pressure was 140 mm Hg. As participants adapted to the occlusive stimulus during the early phase of the training, the air pressure was increased by 10 mm Hg each week until a final cuff pressure of as much as 200 mm Hg was reached. Because of significant muscle fatigue experienced by participants during the training sessions, only five participants got to 160–180 mm Hg. The air pressure of 140–200 mm Hg was selected for the BFR stimulus based on a review of the data in elderly participants (12). Blood flow to the leg muscles was reduced during each training session in the BFR-Walk group, and the cuff air pressure was released immediately upon completion of the session.

To ascertain the safety of BFR walk training in these older women, seven participants in the BFR-Walk group performed a treadmill walk test with and without BFR on two separate days, with an interval of more than 2 days between the two tests. The exercise protocol was the same as the predetermined individual training protocol (45% HRR).

We confirmed that BFR walk exercise has no impact on blood clotting as assessed by changes in fibrin D-dimer (before BFR walk training, 0.17 ± 0.02 µg/mL; immediately after BFR walk training, 0.55 ± 0.44 µg/mL; 15 minutes after BFR walk training, 0.20 ± 0.05 µg/mL) and fibrin degradation products. These were in accordance with the results of a previous study in young men (18). In addition, previous studies have reported that unlike complete blood flow occlusion and reperfusion, moderate restriction of blood flow while performing low-intensity exercise does not affect the production of reactive oxygen species, as assessed by plasma lipid peroxide (19), blood glutathione status, and plasma protein carbonyls (20). These findings together support the notion that BFR walk training does not pose any immediate health concerns in older individuals.

Muscle Cross-sectional Area and Muscle Volume

Magnetic resonance images were prepared using a General Electric Yokogawa Signa 0.2-T scanner (GE Yokogawa, Tokyo, Japan). A T1-weighted, spin-echo, axial plane sequence was performed with a 520-millisecond repetition time and a 20-millisecond echo time. To avoid an influence of fluid shifts within the muscle, magnetic resonance imaging (MRI) procedure was performed around the same time before and 3 days after the final exercise. Prior to all scans, the participants rested quietly in the magnet bore in a supine position, with their legs extended. The great trochanter was used as origin point and continuous transverse images with 1.0-cm slice thickness (0-cm interslice gap) were obtained from the great trochanter to the lateral condyle of the femur for each participant. All MRI data were transferred to a personal computer for analysis using specially designed image analysis software (Tomo Vision, Montreal, Canada). For each slice, skeletal muscle tissue cross-sectional area (CSA) was digitized, and the muscle tissue volume (cm^3) per slice was calculated by multiplying muscle tissue area (cm^2) by slice thickness (cm). Muscle volume of the leg muscle was defined as the sum of the slices of muscle. An average value for the right side of the body was used. We had previously determined that the coefficient of variation of this measurement was less than 1% (21).

Maximum Isometric and Isokinetic Strength

Maximum voluntary isokinetic strength of the knee extensors and flexors was determined using a Biodex System 3 dynamometer (Biodex Medical Systems, Shirley, NY). Participants were carefully familiarized with the testing procedures of voluntary force production for the thigh muscles during several submaximal and maximal performances about 1 week before testing. Each participants was seated on a chair with the hip joint angle positioned at 85°. The center of rotation of the knee joint was visually aligned with the axis of the dynamometer's lever arm, and the ankle of the right leg was firmly attached to the lever arm with a strap. Several warm-up contractions were performed before testing. Participants were then instructed to perform maximal isometric knee extension at a fixed knee joint angle of 75° followed by maximal isokinetic knee extensions and flexions, from 0° to 90°, at 30° and 180° per second. A knee joint angle of 0° corresponded to full extension of the knee. Whole muscle–specific tension was also calculated by dividing maximum isometric knee extension strength by mid thigh muscle CSA.

Estimation of Peak Oxygen Uptake

Oxygen uptake (VO$_2$) was measured during a bicycle graded exercise test (GXT) using an automated breath-by-breath mass spectrometry system (Aeromonitor AE-300S; Minato Medical Science, Tokyo, Japan). For this test, the pedaling rate was maintained constant at 60 revolutions per minute. The load was initially set at 40 W and increased by 5 W every minute until the participants reached approximately 80% of their age-predicted HR$_{max}$. Each participant's electrocardiograph was monitored throughout and used to measure HR at intervals of 60 seconds. Peak oxygen uptake (VO$_{2peak}$) was estimated by fitting the age-predicted maximum HR value into the linear regression equation computed from the individual VO$_2$ and HR value during GXT. Oxygen pulse (O$_2$ pulse) was calculated by dividing VO$_2$ by HR at each submaximal exercise load.

Functional Ability Tests

Two tests were used to assess functional abilities for each participant before and after the training program. The Up & Go test measured the time it took for participants to stand up from a chair without the use of their arms, walk 2.4 m, turn around, walk back to the chair, and return to a seated position. The second functional test, the chair-stand test, required participants to stand up from a seated position, as many times as possible, within 30 seconds (22).

Statistical Analyses

Results are expressed as means and standard error for all variables. Statistical analyses were performed by a two-way analysis of variance (ANOVA) with repeated measures [Group (BFR-Walk and CON-Walk) × Time (pre- and post-testing)]. Post hoc testing was performed using a paired *t* test when appropriate. All baseline differences and percent changes between the BFR-Walk and CON-Walk groups were evaluated with one-way ANOVA. Statistical significance was set at *p* < .05.

RESULTS

Before training, there were no significant differences between the two groups for age and anthropometric variables

Table 1. Changes in Anthropometric Variables, Skeletal Muscle Size, and Volume After 10 Weeks of BFR-Walk or CON-Walk Training

	BFR-Walk			CON-Walk			
	Pre	Post	%	Pre	Post	%	Time Effect
Anthropometric variables							
Age, y	64 (1)			68 (1)			
Standing height, m	1.54 (0.02)			0.52 (0.02)			
Body mass, kg	53.5 (1.4)	53.1 (1.3)	−0.8	53.4 (2.8)	52.8 (2.1)	−1.2	$p < .01$
BMI, kg/m²	22.5 (0.9)	22.4 (0.8)	−0.8	23.2 (1.0)	22.9 (1.0)	−1.2	$p < .01$
Midthigh girth, cm	47.1 (0.8)	47.5 (0.8)	0.8	48.3 (1.3)	48.2 (1.3)	−0.3	
Lower leg girth, cm	33.8 (0.3)	34.3 (0.4)*	1.4†	33.7 (1.0)	33.8 (0.9)	0.2	$p < .05$
Muscle CSA, cm²							
Midthigh	96.4 (3.5)	99.3 (2.9)*,‡	3.1‡	93.9 (4.8)	93.9 (4.5)	0.1	
Midquadriceps	43.2 (1.7)	44.5 (1.5)*,‡	3.0‡	43.6 (1.8)	42.9 (1.9)	−1.6	
Muscle volume, cm³							
Thigh	1335 (44)	1384 (40)*	3.7‡	1329 (63)	1327 (64)	−0.1	$p < .01$
Quadriceps	612 (23)	628 (22)*	2.7‡	620 (28)	616 (28)	−0.6	$p < .05$

Notes: Data are given as mean (±SE). BFR-Walk = BFR walk training; BMI = body mass index; CON-Walk = control walk training; CSA = cross-sectional area.
*$p < .01$, Pre versus Post; †$p < .05$, ‡$p < .01$, BFR-Walk versus CON-Walk.

(Table 1). After the training program, lower leg girth was increased ($p < .01$) in the BFR-Walk group, and there were significant ($p < .01$) time effects in body mass and BMI (Table 1).

During training sessions, mean HR and estimated exercise intensity for CON-Walk participants were 104 ± 5 beats per minute and $44 \pm 2\%$ of HRR, respectively. In the BFR-Walk participants, they were 122 ± 7 beats per minute and $62 \pm 9\%$ of HRR, respectively. The ratings of perceived exertion were slightly higher ($p < .05$) in the BFR-Walk group than in the CON-Walk group at the 5th minute (11.5 ± 0.3 and 10.4 ± 0.3, respectively), 10th minute (11.7 ± 0.2 and 10.6 ± 0.3, respectively), and 15th minute (12.0 ± 0.2 and 10.9 ± 0.3, respectively) of the walk sessions.

After training, the CSA of the thigh and quadriceps muscle (3.1% and 3.0%, respectively) and muscle volume (3.7% and 2.7%, respectively) were increased ($p < .01$) in the BFR-Walk group, but not in the CON-Walk group (Table 1). Maximal isokinetic knee extension (up to 8%, $p < .01$) and

flexion (up to 22%, $p < .01$) strength were also increased in the BFR-Walk group but not in the CON-Walk group (Table 2). There were significant ($p < .05$) time effect in isometric knee extension. There were no significant changes for whole muscle–specific tension in both training groups (BFR-Walk group: 2.0%; CON-Walk group: 1.1%).

There were significant ($p < .05$) time effects in both absolute and relative VO_{2peak} (Table 3). There was also significant ($p < .05$) time effect in O_2 pulse at 75% HR_{max} during the submaximal exercise test (Table 3). There was a positively correlation ($p < .05$) between changes in O_2 pulse and absolute VO_{2peak} in both the BFR-Walk ($r = .67$) and CON-Walk ($r = .77$) groups.

The Up & Go test improved ($p < .01$) in only the BFR-Walk group (10.7%). On the other hand, there was significant ($p < .05$) time effect in the chair-stand test although percent change tended ($p = .14$) to be higher in BFR-Walk group (BFR-Walk: 20.5%; CON-Walk; 7.8%). In the BFR-Walk group, the change in the Up & Go test results tended

Table 2. Changes in Maximum Isometric and Isokinetic Knee Extension and Flexion Torque and Functional Performance After 10 Weeks of BFR-Walk or CON-Walk Training

	BFR-Walk			CON-Walk			
	Pre	Post	%	Pre	Post	%	Time Effect
Knee extension torque (nm)							
Isometric	120 (5)	127 (6)	5.9	120 (8)	122 (10)	1.6	$p < .05$
30° per second	103 (5)	112 (5)*	8.4§	98 (6)	98 (6)	0	$p < .05$
180° per second	66 (3)	68 (3)	2.9‡	65 (3)	64 (4)	−1.9	—
Knee flexion torque (Nm)							
30° per second	48 (2)	56 (2)*,§	16.1§	44 (4)	42 (4)	−3.2	$p < .05$
180° per second	31 (2)	38 (2)*,§	22.3§	30 (2)	29 (2)	−4.2	$p < .01$
Functional performance							
Up & Go test, s	5.0 (0.2)	4.5 (0.1)*	−10.7‡	4.9 (0.2)	4.9 (0.2)	−0.1	$p < .05$
Chair stand test, times	23 (1)	27 (1)	20.5	24 (2)	26 (2)	7.8	$p < .05$

Notes: Data are given as mean (±SE). BFR-Walk = BFR walk training; CON-Walk = control walk training.
*$p < .01$, Pre versus Post; ‡$p < .05$, §$p < .01$, BFR-Walk versus CON-Walk.

Table 3. Changes in Estimated VO_{2peak} After 10 Weeks of BFR-Walk or CON-Walk Training

	BFR-Walk			CON-Walk			
	Pre	Post	%	Pre	Post	%	Time Effect
Estimated VO_{2peak}							
L/min	1.34 (0.08)	1.46 (0.10)	9.0	1.40 (0.10)	1.55 (0.11)	10.2	$p < .05$
mL/kg/min	25.0 (1.3)	27.5 (1.6)	9.7	26.3 (1.1)	29.1 (1.4)	10.9	$p < .05$
O_2 pulse							
mL	6.7 (0.5)	7.5 (0.7)	11.7	7.1 (0.4)	8.0 (0.5)	12.4	$p < .01$

Notes: Data are given as mean (±SE). BFR-Walk = BFR walk training; CON-Walk = control walk training.

to correlate with the change in knee flexion strength ($r = .59$, $p = .09$), and the change in the chair-stand test results also tended to correlate with the change in knee extension strength ($r = .61$, $p = .08$).

DISCUSSION

This study indicated that BFR-Walk training, a single mode of exercise training, performed at relatively low exercise intensity can elicit improvements in muscle volume and strength in older women. Additionally, aerobic capacity improved in both groups although its value was estimated. Previously, concurrent improvements in muscular strength and VO_{2max} by single exercise training have been achieved after high-intensity, long-duration, aerobic-type, single exercise training (23,24); yet, none of the studies demonstrated muscular hypertrophy. This suggests that the increased muscular strength was due mainly to neural adaptations. Thus, high-intensity, long-duration, single-mode, aerobic-type exercise training rarely produces significant muscle hypertrophy. It has been reported in earlier studies that maximal knee extension strength was reduced and the thigh muscle CSA was unchanged after 4 weeks of cycle training under conditions of local leg ischemia, although VO_{2max} increased (25,26). Unlike previous studies, our findings show that BFR walk training is an innovative method for improving both muscle volume and aerobic capacity in older women. Furthermore, the reported rate of perceived exertion (on a scale of 6 to 20) during walk training sessions was low in both training groups although there was a significant difference between the BFR-Walk (11.5–12.0) and the CON-Walk (10.4–10.9) groups.

In the present study, thigh muscle CSA/volume and isokinetic knee joint strength increased by 3%–4% and 3%–22%, respectively, after 10 weeks of BFR walk training in older women. Takarada and colleagues (9) reported that 16 weeks of BFR resistance training at a relatively low intensity (30%–50% 1-RM) increased upper arm muscle CSA (17%–20%) and isokinetic elbow joint strength (18%) in older women. Additionally, some studies have demonstrated that 8–12 weeks of HI-RT leads to increases in thigh muscle CSA (7%–11%) and isometric and isokinetic knee joint strength (10%–19%) in the elderly participants (27,28). The magnitude of increases in muscle size and strength in the present study are lower than those reported in some HI-RT studies (27,28) and in a BFR resistance training study (9). The differences in exercise intensity and volume or BFR stimulus might have caused the variability in the training-induced muscle hypertrophy and strength gain.

Our previous human studies have demonstrated that 20% 1-RM intensity knee extension exercise with BFR increased vastus lateralis (VL) muscle protein synthesis (40%–50% at 3 hours postexercise) through the mammalian target of rapamycin (mTOR) signaling pathway in young (29) and old (30) men, although the rate of muscle protein breakdown was not measured. These anabolic responses may contribute significantly to BFR walk training–induced muscle hypertrophy and strength gain. On the other hand, the same laboratory using the same technique reported that 70% 1-RM intensity knee extension exercise without BFR increased VL muscle protein synthesis (48% at 2 hours postexercise) and through the mTOR pathway in young men (31). Those results indicated that increases in postexercise muscle protein synthesis are probably similar between high-intensity resistance exercise and low-intensity BFR resistance exercise.

Our results showed that aerobic capacity improved in both groups although its value was estimated. Several studies have reported that HI-RT (32,33) resulted in essentially little or no effect on aerobic capacity in aging adult populations. Conversely, aerobic exercise training is thought to stimulate improvements in aerobic capacity (VO_{2max} increased by 10%–20% after 8–12 weeks of training) in the elderly participants (34,35). Previously, we reported no significant improvement in estimated VO_{2peak} after 6 weeks of slow (67 m/min) BFR walk training in the elderly participants (12). In that study, the average exercise intensity during training sessions was about 45% of HRR (average HR = 104 beats per minute). In general, the minimal stimulus necessary to evoke change is as high as 50% of VO_{2max} (7). In the present study, exercise intensity and duration were set at 45% of HRR and 20 minutes in the BFR-Walk group. During the training sessions, however, the exercise intensity was 62% HRR on average because HR increased due to decrease in SV by leg BFR without changes in cardiac output (36). Therefore, the exercise intensity in the BFR-Walk group may be within the effective exercise intensity for improvements in VO_{2peak}.

The BFR walk training–induced increase in VO_{2peak} may be due to improvements in central cardiovascular and/or peripheral metabolic adaptations. The VO_{2max} is the product of cardiac output and arterial and mixed venous blood oxygen (a-v O_2) difference at maximal exercise intensity. However, until now, there are few studies investigating the cardiovascular hemodynamic and muscle metabolic responses to BFR exercise training. In the present study, change in VO_{2peak} estimated was correlated with change in O_2 pulse in both the BFR-Walk and CON-Walk groups. Also, Sundberg (25) found an increase in VO_{2max} by utilizing supine one-legged cycle training with 50 mm Hg chamber pressure (reduced leg blood flow by 16%) for 4 weeks (four sessions per week). In that study, oxidative muscle enzyme and capillary density were increased in the ischemically trained leg, but cardiovascular adaptations to the ischemic exercise training were not found. A recent study reported that increases in VO_{2max} and submaximal exercise SV were observed after 2 weeks of twice-daily, 6-days per week BFR walk training, whereas resting SV remain unchanged (37). Therefore, it seems that the increase in VO_{2peak} from BFR walk training may be due to adaptations in muscle oxidative capacity (a-v O_2 difference) as well as in SV. Spina (38) suggested that for older women, the increase in VO_{2peak} is solely the result of an improved a-v O_2 difference at maximal exercise, as there was no evidence of SV adaptation. In addition, the increase in lower body muscle mass may be associated with improvements in VO_{2max} in the BFR training group.

Previous cross-sectional studies (39,40) showed that Up & Go and chair-stand test results are correlated with knee extension strength in the elderly population. Our results conform to the cross-sectional studies showing that Up & Go and chair-stand performance was improved by BFR-Walk training and tended to correlate with knee joint strength. The improvements of functional fitness in the present study may be mainly due to increases in strength as measured by significant increases in maximal isometric and isokinetic knee joint torques.

In summary, low-intensity walk training with leg BFR concurrently improved thigh muscle size and knee joint strength in older women. Also, functional fitness was improved by this training, which may be mainly due to increases in strength. Further research is needed to determine the mechanism of concurrent improvement in muscular and cardiovascular adaptations by BFR walk training.

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