Effects of Low-Intensity Walk Training With Restricted Leg Blood Flow on Muscle Strength and Aerobic Capacity in Older Adults

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ABSTRACT

Purpose: Slow-walk training combined with restricted leg muscular blood flow (KAATSU) produces muscle hypertrophy and strength gains in young men, which may lead to increased aerobic capacity and functional fitness. The purpose of this study was to investigate the effects of walk training combined with KAATSU on muscle size, strength, and functional ability, as well as aerobic capacity, in older participants.

Methods: A total of 19 active men and women, aged 60 to 78 years, were randomized into either a KAATSU-walk training group (n = 11, K-walk) or a nonexercising control group (n = 8, control). The K-walk group performed 20-minute treadmill walking (67 m/min), 5 days/wk for 6 weeks.

Results: Isometric (11%) and isokinetic (7%-16%) knee extension and flexion torques, muscle-bone cross-sectional area (5.8% and 5.1% for thigh and lower leg, respectively), as well as ultrasound-estimated skeletal muscle mass (6.0% and 10.7% for total and thigh, respectively) increased ($P < .05$) in the K-walk group but not in the control group. Functional ability also increased significantly only in the K-walk group ($P < .05$); however, there was no change in the estimated peak oxygen uptake(absolute and relative to body mass) for either group.

Conclusion: The results of the current study indicate that 6 weeks of KAATSU-walk training did not simultaneously improve cardiovascular and muscular fitness of older participants. However, it significantly increased muscular size and strength as well as functional ability of active older men and women.

Key Words: KAATSU walking, isometric and isokinetic strength, muscle hypertrophy

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INTRODUCTION

Age-related decline in cardiovascular fitness (eg, peak oxygen uptake, $\dot{V}O_{2peak}$) has been attributed to changes in body composition, especially a loss of skeletal muscle (SM) mass referred to as *senile sarcopenia*. A recent study reported that thigh SM mass is closely associated with $\dot{V}O_{2peak}$ (men, r = 0.63 [n = 755], and women, r = 0.46 [n = 620]) and ventilatory threshold (men, r = 0.58, and women, r = 0.47) in healthy men and women aged 20 to 80 years.[1] A loss of SM mass leads to an increased risk for development of insulin resistance and type 2 diabetes,[2] as well as reduced levels of daily activity and physical function. In addition, it has been reported that an age-related low $\dot{V}O_{2peak}$ level is a risk factor for both cardiovascular and all-cause mortality in middle-aged and aging adult populations.[3]

To improve and maintain cardiovascular fitness, as well as muscular strength and endurance in healthy adults, the American College of Sports Medicine (ACSM) guidelines for exercise training recommend a training frequency of 3 to 5 days per week for aerobic training and 2 to 3 days per week for resistance training.[4] Because the recommended duration for aerobic and resistance training sessions, including warm-up and cool-down, would be approximately 60 minutes, a total training time of approximately 5 to 8 hours per week would be needed to complete the recommended training program for improving both types of physical fitness and to meet the ACSM guidelines. It would therefore be advantageous to develop a training method that can effectively improve both cardiovascular and muscular function within a single, short bout of training.

A newly discovered method of restricting muscular blood flow during resistance training, termed *KAATSU training*,[5] has been shown to elicit significant increases in SM size and strength even though this technique uses only low-intensity training (20% of 1 repetition maximum, 1-RM).[6,7] Perhaps even more astounding and intriguing are the significant improvements that have been reported in muscle hypertrophy and increased strength of the knee extensors and flexors following low-intensity treadmill walking with KAATSU (five 2-minute bouts of walking at 50 m/min, with 1 minute rest between bouts).[8] This may be relevant especially for aging adults because previous studies[9,10] have reported that high-intensity resistance training (HI-RT) is most appropriate to improve the maximal strength for older participants. However, whether walk exercise with KAATSU would improve muscular fitness and functional ability in aging adults is unknown.

Furthermore, significantly greater oxygen uptakes (17%) and heart rates (HRs, 20%) are observed during low-intensity treadmill walking with KAATSU than during walking without blood flow restriction.[8] The novelty of KAATSU appears to be the unique combination of venous blood volume pooling and restricted arterial blood inflow, which can result in a decreased stroke volume and increased HR while maintaining cardiac output.[11,12] Consequently, increases in HR at the same systolic blood pressure (SBP) during exercise with blood flow restriction may produce high mechanical stress on the heart, as indicated by a greater rate-pressure product ([HR × SBP]/100).[13] Increased oxygen uptake ($\dot{V}O_2$) observed during KAATSU-walking may be the result of increased arterial and mixed venous blood oxygen difference because cardiac output is not different between walking with and without KAATSU.[14]

We hypothesized that the potential benefits of KAATSU-walking could not only include an anabolic response on muscular system[8] but may also involve improvements in cardiovascular fitness. The training-induced increases in muscle mass may also positively affect aerobic capacity. Thus, the purpose of the present study was to investigate the effects of walk training combined with KAATSU on muscle size, strength, and functional ability, as well as aerobic capacity, in aging adult participants.

METHODS

Participants

Nineteen men and women, aged 60 to 78 years, volunteered to participate in the study. Participants were randomized into either a KAATSU-walk training group (2 men and 9 women; n = 11) or a nonexercising control group (2 men and 6 women; n = 8). All participants in this study were physically active and most of them performed daily walking exercise (average 8000-20 000 steps/d as assessed by pedometer). Participants in the control group continued their daily physical activity but no additional exercise routine was imposed by the investigators. Potential participants were required to fill out a medical history questionnaire and had health interview by a physician before acceptance to ensure that there were no existing health risks. Volunteers who suffered from a chronic disease such as cardiovascular disease, diabetes, cancer, orthopedic disorders, deep venous thrombosis, or peripheral vascular disease were excluded from the study. None of the participants had participated in strengthening or resistance-type training for a minimum of 2 years prior to the start of the study. All participants were informed of the methods, procedures, and risks, and they signed an informed consent document before participation. 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.

Training Protocol

Training was conducted once a day, 5 days per week, for 6 weeks. Following measurement of body weight, blood pressure, and limb girth, the participants walked on a motor-driven treadmill at 67 m/min for 20 minutes. This treadmill speed was similar to their usual walking speed for these participants, and it provided with slow rhythmic muscular contraction during the walk training. This speed also ensured that exercise intensity does not exceed the habitual walk exercise performed by the control participants. The walking speed and duration remained constant throughout the training period.

Participants in the KAATSU-walk group wore pressure belts (Kaatsu-Master, Sato Sports Plaza, Tokyo, Japan) on both legs during walk training. Before the KAATSU-walk training, the participants were seated on a chair and the belt air pressure was set at 100 mm Hg (the approximate mean blood pressure at heart level for each participant) for 30 seconds, and the air pressure was released. The air pressure was increased by 20 mm Hg and held for 30 seconds, and then it was released for 10 seconds between occlusive stimulations. This process was repeated until a final occlusion pressure for each training day. We believe that peripheral as well as central circulation of arterial/venous blood may be stimulated during this warm-up process.

On the first day of the training, the final belt pressure (training pressure) was 160 mm Hg. This training pressure was increased by 10 mm Hg each week until a final belt pressure of 200 mm Hg was reached, although the final belt pressure of 180 mm Hg was kept for 2 older participants because of significant muscle fatigue perceived by these subjects during KAATSU-walk. A restriction pressure of 160 to 200 mm Hg was selected for the restriction stimulus on the basis of our previous study in young men[8] and clinical experience for older subjects. HR during KAATSU-walk training was measured by using a pulse oximetry (Onyx, Nonin Medical, Plymouth, Minnesota). On average, HR and estimated exercise intensity during KAATSU-walk were 104 (11) beats/min and 45 (9%) of HR maximum reserve (maximum HR, 220 − age), respectively. Blood flow to the leg muscles was restricted for a total time of about 23 minutes (20 minutes walking and 3 minutes of preparation process) during each training session for each participant, and the belt pressure was released immediately upon the completion of the session.

Safety of KAATSU Exercise

Severely restricting blood flow or complete occlusion to muscle tissue may draw some concerns as traditional knowledge suggests that it may cause necrosis, blood coagulation, and reduced endothelial function.[15] However, our previous studies demonstrated that low-intensity exercise combined with moderate blood flow restriction has no impact on blood clotting function as assessed by the changes in fibrin D-dimer and fibrin degradation products after exercise.[16] Furthermore, unlike complete blood flow occlusion and reperfusion, moderate restriction of blood flow while performing low-intensity exercise does not affect production of reactive oxygen species, as assessed by the plasma lipid peroxide,[7] blood glutathione status, and plasma protein carbonyls,[17] as well as plasma marker of muscle damage (creatine phosphokinase activity) following the exercise. In addition, a survey to determine the safety of KAATSU exercise has been conducted, and approximately 13 000 people, including those older than 70 years, have participated (45.4% men and 54.6% women). The study indicated that there were no crucial side effects associated with KAATSU training among healthy participants.[18] These findings together support the notion that low-intensity KAATSU training does not pose any immediate health concerns among the aging adult population.

Estimation of Muscle-Bone Cross-sectional Area

Muscle-bone cross-sectional area (CSA) for the mid-thigh and 30% proximal lower leg (between the lateral malleolus of the fibula and the lateral condyle of the tibia) was estimated by using the following anthropometric equation: Muscle-bone CSA = $\pi\ [r - (Q - \mathrm{AT} + H - \mathrm{AT})/2]^2$, where r is the radius of the thigh calculated from limb girth of the right leg, and Ant-AT and Pos-AT are ultrasound (Aloka SSD-500, Tokyo, Japan)-measured anterior and posterior thigh or lower leg adipose tissue thickness, respectively. The estimated coefficient of variation of repeated measure of this measurement was 1.2%.[8] Muscle-bone CSA for the 30% proximal lower leg was also estimated in the same manner as for the mid-thigh.

Ultrasound-Measured Muscle Thickness

Ultrasound evaluation of muscle thickness (MTH) was performed by using a real-time linear electronic scanner with a 5-MHz scanning head (SSD-500, Aloka, Tokyo, Japan). The scanning head with water-soluble transmission gel, which provided acoustic contact without depression of the skin surface, was placed perpendicular to the tissue interface at the marked sites. MTHs were measured directly from the screen, with electronic calipers, and were determined as the distance from the adipose tissue-muscle interface to the muscle-bone interface for the following areas: anterior and posterior thigh, midway between the lateral condyle of the femur and greater trochanter; anterior and posterior lower leg, at 30% proximal between the lateral malleolus of the fibula and the lateral condyle of the tibia; anterior and posterior upper arm, at 60% distal between the lateral epicondyle of the humerus and the acromial process of the radius; abdomen, 2 to 3 cm to the right of the umbilicus; and subscapula, 5 cm directly below the inferior angle of the scapula, as described previously.[19] The reliability of the image reconstruction and distance measurements were confirmed by comparing the ultrasonic and manual measurements of tissue thickness in human cadavers, resulting in a coefficient of variation of 1% for the MTH measurement.[20] This measurement was completed at baseline and 3 days after the final training.

Estimation of SM Mass

Total and regional SM mass were estimated by using the equations of Sanada and coworkers.[21] The MTHs were converted to mass units in kilograms by ultrasound-derived prediction equations using site-matched MTH × height, which were then used to calculate segmental (arm, trunk, thigh, and lower leg) SM mass. Strong correlations, ranging from $r = 0.83$ to $r = 0.96$, were observed between the magnetic resonance imaging–measured and predicted SM mass for total and all regional segments of the SM mass. The standard error of estimates for the various predicted SM masses ranged from 0.6 kg to 1.8 kg.[21] This measurement was completed at baseline and 3 days after the final training.

Maximum Isometric and Isokinetic Strength

Maximum voluntary isometric and isokinetic strength of the knee extensors and flexors was determined by using a Biodex System-3 dynamometer. Participants were carefully familiarized with the testing procedures of voluntary force production of the thigh muscles during several submaximal and maximal performances about 1 week before testing. The participants were seated on a chair with their hip joint angle positioned at 85°. The center of rotation of the knee joint was visually aligned with the axis of the lever arm of the dynamometer and the ankle of the right leg was firmly attached to the lever arm of the dynamometer 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, between 0° and 90° range of motion for the knee at 3 different testing speeds (30°/s, 90°/s, and 180°/s). A knee joint angle of 0° corresponded to full extension of the knee. The test was assessed at baseline and 3 days after the final walk-training session (posttesting).

Estimation of Peak Oxygen Uptake

Oxygen uptake during a treadmill walk test was measured before training and following the training program by using an automated breath-by-breath mass spectrometry system (Aeromonitor AE-300S, Minato Medical Science, Tokyo, Japan). Participants warmed up at 60 m/min on a 0% grade for 3 minutes. Then, the treadmill speed was held constant while the grade was increased by 1.8% every 2 minutes until participants reached approximately 80% of their age-predicted maximum HR (220 − age). Each participant's electrocardiogram was monitored constantly during the exercise session and was used to measure HR at intervals of 60 seconds. Ratings of perceived exertion were also recorded every 2 minutes during exercise. $\dot{V}O_{2peak}$ was estimated by fitting the age-predicted maximum HR value into the linear regression equation computed from the individual $\dot{V}O_2$ and HR values during graded exercise.

Functional Ability Tests

Two tests were used to assess functional abilities for each participant before the training program and following the walking program.[22] The Timed Up and Go test required the time to be measured for the participants to stand from a chair without the use of their arms, walk 2.4 m (8 ft), turn around, walk back to the chair, and return to the seated position. The second functional test required the participants to stand up from a seated position, as many times as possible, in 30 seconds.

Statistical Analyses

StatView, version 4.5, was used to compute the data and the results are expressed as mean and standard deviation for all variables. Statistical analyses were performed by a 2-way analysis of variance (ANOVA) with repeated measures (Group [KAATSU-walk and control] × time [pre- and posttesting]) on primary outcomes including anthropometric variables, muscle-bone CSA, SM mass, muscular strength, and estimated $\dot{V}O_{2peak}$. If the data failed the normality test, they were transformed prior to ANOVA. Post hoc testing was performed by using the Tukey-Kramer test. If baseline values were significantly different or tended to be different ($P < .10$), we performed an ANCOVA test by using the baseline value as covariate. All baseline characteristics and percentage changes in anthropometric variables, muscle-bone CSA, SM mass, muscular strength, functional ability tests, and estimated $\dot{V}O_{2peak}$ between participants in KAATSU-walk and control groups were evaluated with the Student *t* test. Statistical significance was set at $P < .05$.

RESULTS

At baseline, before training, there were no significant differences between the 2 groups (KAATSU-walk and control) for age, standing height, body mass, body mass index, and limb girth (Table 1). There were no significant ($P > .05$) changes in body mass and body mass index for either group following the training program; however, mid-thigh and lower leg girths increased significantly in the KAATSU-walk group but not in the control group (Table 1). Muscle-bone CSA increased by 5.8% ($P < .05$) for the thigh and by 5.1% ($P < .01$) for the lower leg in the KAATSU-walk group. Total and thigh SM mass increased by 6.0% and 10.7%, respectively ($P < .01$), but was unaltered for the trunk and lower leg (1.8% and 2.6%, respectively) for the KAATSU-walk group. Both muscle-bone CSA and the total and segmental SM mass did not change ($P > .05$) for the control group (Table 1).

Maximal isometric knee extension strength was increased ($P < .05$) in the KAATSU-walk group (11.8%) but not in the control group (−2.2%). Maximal isokinetic knee extension and knee flexion strength increased for the KAATSU-walk group ($P < .05$) at each testing speed, with the only exception at 180°/s for knee flexion ($P = .08$). Improvements in isokinetic knee extension strength ranged from 7.1% to 12.2% and in isokinetic knee flexion strength from 13.4% to 16.1%. There were no changes ($P > .05$) in any isokinetic strength measure for the control group (Table 2).

There was no change in the estimated $\dot{V}O_{2peak}$ (absolute and relative to body mass) for either group (KAATSU-walk and control) (Table 3); however, the KAATSU-walk group significantly improved in both the functional fitness tests ($P < .05$), whereas the control group did not change (Fig 1).

DISCUSSION

This study demonstrates 2 novel and important findings for participants aged 60 to 78 years: (1) isometric and isokinetic muscle strength and leg muscle size increased

Table 1. Changes in Antrhropometric Variables and Skeletal Muscle Size Following 6-Week KAATSU-Walk Training or Control Period

	KAATSU-walk group (n = 11)			Control group (n = 8)		
	Pre[a]	Post[a]	% Change	Pre[a]	Post[a]	% Change
Anthropometric variables						
Standing height, m	1.52 (0.1)	1.52 (0.1)	0.0	1.55 (0.1)	1.55 (0.1)	0.0
Body mass, kg	54.4 (9.4)	53.8 (9.2)	−1.1	54.4 (7.3)	54.1 (7.5)	−0.6
BMI, kg/m^2	23.4 (2.8)	23.1 (2.8)	−1.3	22.4 (1.4)	22.3 (1.5)	−0.7
Mid-thigh girth, cm	46.8 (3.8)	47.6 (3.9)[b]	1.7[b]	47.0 (1.6)	46.7 (1.9)	−0.6
Lower leg girth, cm	33.6 (2.3)	34.0 (2.3)[b]	1.2[b]	34.0 (2.5)	33.7 (2.6)	–0.9
Muscle-bone CSA, cm^2						
Mid thigh	129.3 (22.9)	136.8 (23.7)[b]	5.8[b]	131.4 (20.9)	131.3 (19.7)	−0.1
Lower leg	70.6 (10.2)	74.2 (10.8)[c]	5.1[b]	74.6 (15.8)	73.5 (15.9)	−1.5
Skeletal muscle mass, kg						
Trunk	6.1 (1.9)	6.2 (2.0)	1.8	5.6 (1.2)	5.6 (1.2)	0.0
Thigh	5.3 (1.6)	5.9 (1.7)[c]	10.7[c]	5.5 (1.3)	5.3 (1.3)	−2.9
Lower leg	1.5 (0.3)	1.6 (0.4)	2.6[b]	1.8 (0.6)	1.7 (0.6)	−2.3
Total	13.6 (4.0)	14.4 (4.2)[c]	6.0[c]	14.4 (4.1)	14.1 (4.2)	−2.1

[a] Values are expressed as *M* (SD).
[b] $P < .05$.
[c] $P < .01$.

Table 2. Changes in Maximum Isometric and Isokinetic Knee Extension and Flexion Torques Following 6-Week KAATSU-Walk Training or Control Period

	KAATSU-walk group (n = 11)			Control group (n = 8)		
	Pre[a]	Post[a]	%Δ	Pre[a]	Post[a]	%Δ
Knee extension torque, Nm						
Isometric	10 (25)	123 (27)[b]	11.8[b]	137 (25)	134 (21)	−2.2
30°/s	90 (19)	100 (22)[c]	12.2[c]	113 (23)	110 (22)	−2.7
90°/s	76 (16)	85 (18)[b]	11.4[b]	94 (24)	89 (18)	−5.1
180°/s	63 (14)	68 (15)[b]	7.1[b]	73 (16)	69 (15)	−4.1
Knee flexion torque, Nm						
30°/s	47 (9)	53 (11)[b]	13.4[c]	58 (12)	56 (12)	−2.3
90°/s	37 (8)	42 (7)[b]	16.1[c]	5 (8)	43 (8)	−3.4
180°/s	32 (7)	36 (8)	12.9	37 (7)	35 (5)	–5.4

[a]Values are expressed as *M* (SD).
[b]$P < .05$.
[c]$P < .01$.

following 6 weeks of low-intensity (walking speed at 67 m/min) KAATSU-walk training; however, (2) estimated $\dot{V}O_{2peak}$ did not improve by this low-intensity KAATSU-walk training.

Isometric and Isokinetic Strength

Several studies[9,10] reported that maximum isometric and isokinetic knee extension and flexion torques increased by 10%-19% following 12 to 16 weeks (3 times per week) of HI-RT in aging adults. In the present study, the increases in isometric (12%) and isokinetic (7%-16%) torques are similar to the improvements observed in some HI-RT studies[9,10,23] but are lower than those reported by Reeves et al[24] (22%-37% increases in isokinetic torque). The magnitude of increases in isometric (0.40%) and isokinetic (0.23%-0.53%) torques per training session in the present study is also similar to those reported by Frontera et al[9] (isometric torque, 0.31%; isokinetic torque at 60°/s and 240°/s; 0.28%-0.50%) and Ferri et al[10] (isokinetic torque at 60°/s, 120°/s, 180°/s, and 240°/s; 0.24%-0.41%), but lower than those reported by Reeves et al[24] (isokinetic torque, 0.52%-0.88%). The differences in mode, intensity, and duration of the exercise might have caused the variability in the training-induced strength gains. Neural drive of agonist muscles during isometric and isokinetic contractions is reduced in aging adults when compared with young participants but can improve after HI-RT.[25] Also, coactivation of antagonist muscles during muscle contraction is higher in aging adults than in young participants but can be reduced after HI-RT.[24] These neurological factors can significantly contribute to increases in strength[26]; however, neural adaptation is not the only reason for the training-induced strength gains in aging adults.[9]

Muscle Size

Previously, Fiatarone et al[27] demonstrated that HI-RT leads to significant increases in muscle strength and mid-thigh muscle CSA in aging adults, suggesting that high-intensity training can induce muscular hypertrophy in aging adults. In the present study, the estimated thigh muscle-bone CSA increased significantly by 5.8% ($P < .05$) following 6 weeks of KAATSU-walk training (5 d/wk, total 30 training sessions). Furthermore, the KAATSU-walk training produced significant increases in lower leg muscle-bone CSA (5.1%; $P < .01$) in addition to the thigh muscle, whereas lower leg SM mass did not reach a statistical significance. The magnitude of the hypertrophic potential (percentage increase in muscle-bone CSA divided by total training sessions) in the thigh is about 0.19% per training session in the aging adult participants. Our previous study[8] reported that muscle-bone CSA gradually increased over time and eventually reached 5.3% following 3 weeks of twice-daily KAATSU-walk training in young participants (6 d/wk, total 36 training sessions). In the present study, the hypertrophic potential in aging adults (0.19% per session) is similar to our previously reported value in young participants (0.15% per session) and is also comparable with the results of HI-RT for aging adults.[10,23] Therefore, similar training volume for aging adults in the present study (30 vs 36 total training sessions in the current study and the previous study, respectively) was adequate to induce a similar muscular hypertrophy as observed in the previous study.

Table 3. Change in Estimated Peak Oxygen Uptake ($\dot{V}O_{2peak}$) Following 6-Week KAATSU-Walk Training or Control Period

	KAATSU-walk group (n = 11)			Control group (n = 8)		
	Pre	Post	% Change	Pre	Post	% Change
Estimated $\dot{V}O_{2peak}$						
L/min	1.76 (0.56)	1.70 (0.55)	−2.8	1.83 (0.50)	1.79 (0.47)	−2.2
mL(kg/min	31.8 (6.3)	31.2 (6.2)	−2.2	33.3 (5.4)	32.8 (5.3)	−1.5

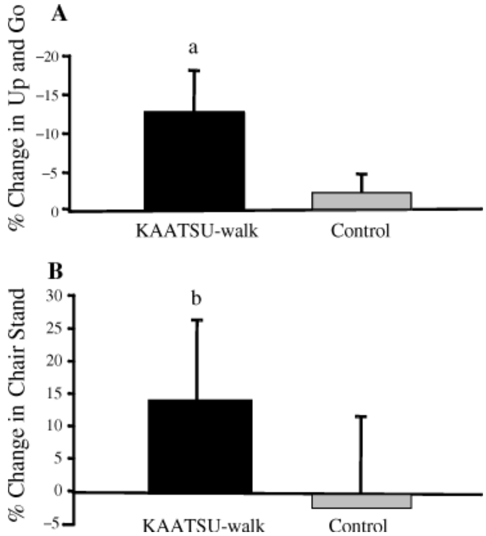

Figure 1. Percentage changes in Timed Up and Go (a) and chair stand (b) performance; Kaatsu-walk group (n = 11) vs control group (n = 5). $^{a}P < .001$. $^{b}P < .05$.

Cellular and molecular mechanisms of the hypertrophic response and strength gain to the KAATSU-walk training are still poorly understood. In general, SM hypertrophy results from increased protein accretion and the accumulation of contractile protein, which occurs when the balance between protein synthesis and degradation shifts toward synthesis. Recently, Fujita et al[28] demonstrated that a single bout of 20% of 1 repetition maximum intensity knee extension exercise with KAATSU increased both thigh muscle protein synthesis and the Akt/mTOR signaling pathway in young men. More recently, KAATSU exercise–induced increase in muscle protein synthesis was also confirmed in aging adult participants (unpublished data). Furthermore, the thigh as well as lower leg girth increased about 2 cm immediately after a single bout of KAATSU-walk training and returned to normal size within 3 hours in young participants (unpublished data). One interesting possibility between acute muscle volume swelling and muscle hypertrophy is the relationship noted between cell swelling and reduced proteolysis.[29] A reduction in proteolysis, secondary to KAATSU-walk–induced acute cell/muscle swelling, could contribute to a net increase in protein balance and subsequently an anabolic response of SM. This may be due to activation of a signaling mechanism like h-sgk, which has been shown to be triggered by cell swelling in vitro.[30] Thus, the KAATSU exercise–induced enhancement of muscle protein metabolism appears to be the basis for the increases in muscle size observed here.

Aerobic Capacity

The KAATSU-walk group showed no significant improvement in estimated $\dot{V}O_{2peak}$ over the 6-week study period. Prior to the start of study, we hypothesized that HR during KAATSU-walk training session would reach their calculated target HR (more than 50% of HR maximum reserve) needed to improve aerobic capacity, because there is generally a 20% greater HR increase observed during the treadmill walking with KAATSU compared with that of walking without blood flow restriction.[8] Also, the age-related target HR zone needed to improve aerobic capacity in aging adults is relatively low compared with that of young adults. In fact, the average exercise intensity during KAATSU-walk training was about 45% of HR maximum reserve (average HR = 104 (11) beats/min) in the aging adult participants. Several studies have reported that HI-RT[31,32] and brisk walking training[33] resulted in essentially little or no effect on aerobic capacity (estimate $\dot{V}O_{2max}$) in aging adult participants. However, Frontera et al[34] reported a small but significant increase in leg cycle $\dot{V}O_{2max}$ in older men (increased 120 mL/min; pre, 2.07 L/min; post, 2.19 L/min) after 12 weeks of HI-RT and suggested that it may be due to adaptation in muscle oxidative capacity (increase in capillary density and citrate synthase activity) and increased mass of the strength-trained muscles. An increase of 1-kg SM mass, which corresponds to approximately a 10% gain in the lower-body SM mass, would predict an increase of about 200 mL/min in $\dot{V}O_{2max}$.[35] Therefore, it is clear that training-induced changes in muscle oxidative capacity are needed, more than increased SM mass, to improve $\dot{V}O_{2max}$. Additional research is needed to understand how different training prescriptions (higher walking speed or training duration) could simultaneously improve aerobic capacity as well as muscular function.

Functional Ability

Previous studies reported that multicomponent exercise programs, consisting of aerobic, strength, and flexibility training, can improve functional fitness performance (chair stand and up-and-go performance) in aging adult participants.[36] Our results also showed that a 6-week KAATSU-walk training significantly improved chair stand ($P < .05$) and up-and-go performance ($P < .05$). The improvement in functional fitness in the present study may be mainly due to increases in strength as measured by significant increases in maximal isometric ($P < .05$) and isokinetic ($P < .05$) torques.

CONCLUSION

The results of the present study indicate that 6 weeks of KAATSU-walk training can produce increases in muscle strength and size as well as functional ability of aging adult participants. However, there was no change in aerobic capacity over the 6-week study period. Further research is needed to determine whether combining aerobic exercise of different intensity or duration with blood flow restriction would simultaneously improve muscular and aerobic fitness.

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