

Muscle size and strength are increased following walk training with restricted venous blood flow from the leg muscle, KAATSU-walk training

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Running Head: Increases in muscle size and strength by KAATSU-walk training

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ABSTRACT

Previous studies have shown that low-intensity resistance training with restricted muscular venous blood flow (KAATSU) causes muscle hypertrophy and strength gain. To investigate the effects of daily physical activity combined with KAATSU, we examined the acute and chronic effects of walk training with and without KAATSU on MRI-measured muscle size and maximum dynamic (1-RM) and isometric strength, along with blood hormonal parameters. Nine men performed KAATSU-walk training and 9 men performed walk training alone (Control-walk). Training was conducted 2 times/day, 6 days/week for 3 weeks using 5 sets of 2-min bout (treadmill speed at 50 m/min), with a 1-min rest between bouts. Mean oxygen uptake (VO_2) during KAATSU-walk and Control-walk exercise were $19.5 \pm 3.6\%$ and $17.2 \pm 3.1\%$ of treadmill-determined VO_2 max, respectively. Serum growth hormone was elevated ($P < 0.01$) after acute KAATSU-walk exercise, but not in Control-walk exercise. MRI-measured thigh muscle cross-sectional area and muscle volume increased 4~7%, and 1-RM and maximum isometric strength increased 8~10% in the KAATSU-walk group. There was no change in muscle size and dynamic and isometric strength in the Control-walk group. Indicators of muscle damage (creatinine kinase and myoglobin) and resting anabolic hormones did not change in both groups. The results suggest that the combination of leg muscle blood flow restriction with slow-walk training

induces muscle hypertrophy and strength gain despite the minimal level of exercise intensity. KAATSU-walk training may be a potentially useful method for promoting muscle hypertrophy covering in a wide range of the population, including the frail and elderly.

Key words: muscle hypertrophy, dynamic and isometric strength, anabolic hormones, ischemia

INTRODUCTION

To develop and maintain muscular fitness, several societies, including the American College of Sports Medicine and the National Strength and Conditioning Association, have published their guidelines, which recommend combining training intensity, volume, and frequency for optimizing muscle hypertrophy and strength gains [3, 17]. In general, the magnitude of the acquired training adaptation is proportional to the training stimulus, although it depends on the individual's training experience and/or 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 [7, 15]. Training below an intensity of 65% of 1-RM, on the other hand, rarely produces substantial muscle hypertrophy or strength gains [14]. However, high-intensity (HIT; >65% of 1-RM) resistance training can increase the risk of injury, especially for frail and elderly populations [11, 16]. It would therefore be advantageous to develop more safe and effective methods of promoting muscle hypertrophy for a wider range of people, including the frail and elderly.

Low-intensity (20-50% of 1-RM) resistance training combined with restricted venous blood flow from the working muscle (KAATSU-resistance training) may provide an alternative training method to the

traditional HIT resistance training programs currently being used. In recent years, a number of publications have reported that KAATSU-resistance training can result in significant and rapid increases in muscle hypertrophy [2, 21, 23]. Although it is not fully understood how KAATSU training can achieve such rapid results, it is well established that KAATSU-resistance training produces changes in muscle hypertrophy similar to those produced by current HIT resistance training regimens, when training volume and frequency are similar [2, 21]. A unique characteristic of KAATSU-training is that substantial muscle hypertrophy can occur using a training intensity as low as 20% of 1-RM [2, 23]. Training at 20% of 1-RM is considered equivalent to the physical activities of daily life (10-30% of maximal work capacity) as evaluated by electromyography (EMG) and metabolic cost measurements [4, 19]. Therefore, we hypothesized that substantial muscle hypertrophy and strength gain could be achieved by combining KAATSU with an activity of daily life, such as walking. Thus, the purpose of this study was to investigate the acute and chronic effects of walk-training combined with KAATSU (KAATSU-walk) on muscle size and strength, along with blood hormonal parameters.

METHODS

Subjects

Eighteen healthy young men volunteered to participate in the study (Table 1). All subjects led active lives, with 8 of 18 participating in regular aerobic exercise. However, none of the subjects had participated in a regular resistance exercise program for at least 1 year prior to the start of the study. The subjects were randomly divided into two training groups: walk-training with restricted venous leg muscle blood flow (KAATSU-walk, $n = 9$), and walk-training without restricted leg muscle blood flow (Control-walk, $n = 9$). One month prior to the start of the chronic training study, 11 of the 18 subjects participated in an acute study to examine the hormonal responses to a single bout of KAATSU-walking (described below). All subjects were informed of the procedures, risks, and benefits, and signed an informed consent document before participation. The Tokyo Metropolitan University Ethics Committee for Human Experiments approved the study.

Acute hormonal responses to KAATSU-walking

Eleven young men (6 KAATSU-walk and 5 Control-walk) performed treadmill walking with and without KAATSU on two separate days (1-week interval). The exercise consisted of walking at 50 m/min for five

2-min bouts, with a 1-min rest between bouts (total time, 14 min). A specially designed elastic belt (50 mm wide) was placed around the most proximal portion of each leg during the KAATSU-walk exercise. The belt contained a pneumatic bag along its inner surface that was connected to an electronic air pressure control system that monitored the restriction pressure (Kaatsu-Mater, Soto Sports Plaza Ltd., Tokyo, Japan). Prior to the KAATSU-walk test, the subjects were seated on a chair, the belt air pressure was set at 120 mmHg (the approximate resting systolic blood pressure at heart level for each subjects) for 30 s, and the air pressure was released. The air pressure was increased by 20 mmHg and held for 30 s, then released for 10 s between occlusive stimulations. This process was repeated until a final occlusion pressure of 200 mmHg was reached. This pressure was used for the occlusive stimulus during the KAATSU-walk test. . We believe that peripheral as well as central circulation of arterial/venous blood may be stimulated during this warm-up process; therefore pressure was gradually increased instead of setting the initial pressure to the final testing pressure of 200 mmHg.

The acute exercise tests began at 0900 and venous blood samples were obtained from an antecubital vein prior to the start of exercise and immediately following (immediately, 15- and 60-min after

exercise). Serum growth hormone (GH) and cortisol concentrations were determined using a commercially available radioimmunoassay. Hematocrit was measured in duplicate by microcentrifugation of each blood sample. Oxygen uptake (VO_2) during the KAATSU-walk test was measured using an automated breath-by-breath mass spectrometry system (Aeromonitor AE-280S, Minato Medical Science). Maximum oxygen uptake (VO_2 max) during treadmill running was measured on separate days. The subjects warmed up at 180 m/min at a fixed 0° grade for 5 min. The treadmill speed increased at a rate of 10 m/min for each successive 1 min of running until the subject became fatigued. VO_2 and respiratory gas exchange ratio were measured every 30 s during treadmill running. Heart rate was also measured every 30 s during exercise using a heart rate monitor (Vantage XL, Polar Electro).

Training protocol and blood sampling

The subjects in both the KAATSU-walk and Control-walk groups participated in 3 weeks of supervised walk-training. Training was conducted twice per day (morning and afternoon sessions, with at least 4 h between sessions), 6 days per week for 3 weeks. Following a warm-up, the subjects performed walking (50 m/min for five 2-min bouts, with a 1-min rest between bouts) on a motor-driven treadmill (Figure

1). The walking speed and duration remained constant throughout the training period.

Subjects in the KAATSU-walk group wore pressure belts on both legs during training. Prior to the KAATSU-walk training, the subjects were seated on a chair and the belt air pressure was repeatedly set (30 s) and then released (10 s) from initial (120 mmHg) to final (160 mmHg) pressure (described as acute KAATSU-walk). On the first day of the training (day 1), the final belt pressure (training pressure) was 160 mmHg. The pressure was increased 10 mmHg each day until a final belt pressure of 230 mmHg (day 8) was reached because the belt air pressure during training was one of the exercise intensity variables and the subjects were adapted to the occlusion stimulus during early phase of the training. The restriction pressure of 160-230 mmHg was selected for the occlusive stimulus as this pressure has been suggested to restrict venous blood flow and cause pooling of blood in capacitance vessels distal to the belt, as well as restricting arterial blood flow [6, 21]. The estimated coefficient of variation (CV) of this pressure measurement was 2.2%. Restriction of leg muscle blood flow was maintained for the entire exercise session, including the 1-min rest periods (14 min). Therefore, Leg muscle blood flow was occluded for a total time of about 17 min for each subject including the preparation process (~3 min) before start of training session. The belt pressure was released immediately upon completion of the session.

The Control-walk group performed the same exercises at the same treadmill speed but without KAATSU. Resting venous blood was drawn from each subject at baseline (pre-testing) and 3 days after the final training (post-testing). All blood samples were obtained at the same time of day (9:00-10:00 AM) following an overnight fast (12-13 h). The subjects were counseled to refrain from ingesting alcohol and caffeine for 24 h prior to blood collection and not to perform any strenuous exercise

One-RM strength measurements

One week prior to training, the subjects were familiarized with the strength-testing equipment. Two types of lower body strength tests were performed: unilateral (right leg) leg press and bilateral leg curl (Nippon, Tokyo, Japan). Proper lifting technique was demonstrated for the leg press and leg curl exercises, and all subjects performed practice lifts prior to attempting maximal effort lifts. Maximum dynamic strength (1-RM) was assessed prior to (baseline) and 3 days after the final training (post-testing) for each exercise. After warming up, the load was set at 80% of the predicted 1-RM. Following each successful lift, the load was increased by ~5% until the subject failed to lift the load through the entire range of motion. A test was considered valid only when the subject used proper form and completed the entire lift in a controlled manner

without assistance. On average, five trials were required to complete a 1-RM test. Approximately 2-3 min of rest was allotted between each attempt to ensure recovery.

Maximum isometric strength measurements

Maximum voluntary isometric strength (maximum voluntary contraction, MVC) of the knee extensors and flexors was determined using an isokinetic dynamometer (Biodex System 3). Subjects 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. The ankle of the right leg was firmly attached to the lever arm of the dynamometer with a strap. After a warm-up consisting of submaximal contractions, the subjects were instructed to perform maximal isometric knee extension at knee joint angles of 75° and maximal isometric knee flexion at knee joint angle of 60° . A knee joint angle of zero corresponded to full extension of the knee. Each effort was held for approximately 4-5 s. The test was assessed at baseline and 4 days after the final training (post-testing).

Muscle-bone cross-sectional area estimation

Muscle-bone cross-sectional area (CSA) for the mid-thigh was estimated using the following anthropometric equation:

$$\text{Muscle-bone CSA} = \pi [r - (Q\text{-AT} + H\text{-AT}) / 2]^2$$

where r was the radius of the thigh calculated from mid-thigh girth of the right leg, and Q-AT and H-AT were ultrasound (Aloka SSD-500, Tokyo, Japan) -measured anterior and posterior thigh adipose tissue thickness, respectively. The estimated CV of this measurement was 1.2 %. This measurement was carried out each morning prior to the training session and prior to post-testing.

MRI-measured muscle CSA and volume

Magnetic resonance imaging (MRI) images were prepared using a General Electric Signa 1.5 Tesla scanner (Milwaukee, Wisconsin, USA). A T1-weighted, spin-echo, axial plane sequence was performed with a 1500-millisecond repetition time and a 17-millisecond echo time. Subjects rested quietly in the magnet bore in a supine position with their legs extended. The intervertebral space between the fourth and fifth lumbar vertebrae was used as the origin point, and contiguous transverse images with 1.0-cm slice thickness (0 cm interslice gap) were obtained from the fifth lumbar vertebrae to the ankle joints for each subject. All

MRI scans were segmented into four components (skeletal muscle, subcutaneous adipose tissue, bone, and residual tissue) by a highly trained analyst, and then traced. For each slice, the skeletal muscle tissue 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 an individual muscle was defined as the summation of the slices of muscle. We have previously determined that the CV of this measurement was 2.1% [1]. An average value of the right and left sides of the body was used. This measurement was completed at baseline and 3 days after the final training (post-testing).

Hormonal analyses

Serum GH, total-T, free-T, cortisol, and IGF-1 concentrations were measured at S.R.L. Inc. (Tokyo, Japan) by commercially available radioimmunoassay kits (Daiichi Radioisotope Laboratory, Chiba, Japan). Radioactivity was measured using an automated gamma counter (ARC-950, Aloka, Tokyo, Japan). Plasma activity of creatine phosphokinase (CPK) was measured with spectrophotometry for NADPH formed by a hexokinase and D-glucose-6-phosphate-dehydrogenase-coupled enzymic system. Plasma concentration of myoglobin was measured using a commercially available radioimmunoassay (Daiichi Radioisotope

Laboratory, Chiba, Japan).

Statistical Analyses

Results are expressed as means \pm standard deviations (SD) for all variables. Statistical analyses were performed by a two-way analysis of variance (ANOVA) with repeated measures [Group (Kaatsu-walk and Control-walk) \times Time (pre- and post-testing)]. Serum hormones were analyzed with a 2 \times 4 [Group (Kaatsu-walk and Control-walk) \times Time (pre-exercise, immediately post-, 15-min, and 60-min post-exercise)] ANOVA with repeated measures. Post-hoc testing was performed by a Fisher's least significant differences test. Baseline differences between KAATSU-walk and Control-walk, and percentage changes between baseline and post-testing were evaluated with a one-way ANOVA. Statistical significance was set at $P < 0.05$.

RESULTS

Effect of acute KAATSU-walking

Serum GH concentration was elevated ($P < 0.01$) from prior to the start of exercise to immediately and 15-min after exercise in the KAATSU-walk group. The serum GH peaked to an average

level 13 ng/ml as high as that of pre-exercise level at 15 min after acute walking in the KAATSU-walk group but not in the Control-walk group (Figure 2). Serum cortisol showed no change ($P > 0.05$) during the experiments in both the KAATSU-walk and Control-walk groups. Hematocrit increased by 10% from prior to the start of exercise to immediately after exercise in the KAATSU-walk group. There was no effect of acute exercise on hematocrit in the Control-walk group. Mean oxygen uptake (VO_2) was higher ($P < 0.05$) at the latter half of the walking session in the KAATSU-walk group (708 ± 96 ml/min) than in the Control-walk group (623 ± 77 ml/min) (Figure 3). The percent change in VO_2 between the KAATSU-walk and Control-walk groups was 14%. The mean VO_2 during KAATSU-walk and Control-walk were 19.5 ± 3.6 % and 17.2 ± 3.1 % of treadmill-determined VO_2 max, respectively.

Effect of chronic KAATSU-walk training

Muscle-bone CSA gradually increased ($P < 0.01$) over time, reaching significance by day 4 in the KAATSU-walk group, but did not change in the Control-walk group (Figure 4). The muscle-bone CSA increased 2.3%, 5.0%, and 6.0% at the end of first, second and third week, respectively, in the KAATSU-walk group. By post-testing, the muscle-bone CSA had increased 5.3% in the KAATSU-walk group. In the

Control-walk group, the muscle-bone CSA did not change during the training period. MRI-measured mid-thigh quadriceps and hamstrings (biceps femoris, semitendinosus, and semimembranosus) muscle CSA increased by 5.7% and 7.6%, respectively, in the KAATSU-walk group ($P < 0.01$, Figure 5) but did not change (1.5% and -1.7%) in the Control-walk group. Also, quadriceps, hamstrings, and adductors muscle volumes increased 4.1%, 6.4% and 6.1%, respectively, in the KAATSU-walk group ($P < 0.01$). There was no change in thigh muscle volume in the Control-walk group ($P > 0.05$) (Table 2).

Leg press and leg curl 1-RM strength increased by 7.4% and 8.3%, respectively, in the KAATSU-walk group after 3 weeks of training ($P < 0.05$), but not in the Control-walk group (1.9% and -2.9%, respectively) (Figure 6). Maximum isometric knee extension (10.4%, $P < 0.05$), but not knee flexion (9.4%, $P > 0.05$), strength was increased in the KAATSU-walk group. There was no change in maximum isometric knee extension and flexion strength in the Control-walk group (-2.0% and 4.2%, respectively). Relative isometric strength (knee extension strength per unit quadriceps muscle CSA or knee flexion strength per unit hamstrings muscle CSA) was similar at pre- and post-testing in both groups (Figure 7).

At baseline, all subjects had a normal CPK and myoglobin concentrations, and these values did not change ($P > 0.05$) following training in both the KAATSU-walk and Control-walk groups. There were

no changes ($P > 0.05$) in resting serum IGF-1, GH, total-T, free-T, and cortisol concentrations in both groups (Table 3).

DISCUSSION

The major finding of the present study was that 3 weeks of twice-daily KAATSU-walk training increased thigh muscle CSA and volume in young men. The estimated muscle-bone CSA continually increased in the KAATSU-walk group, and the resultant increase was constant throughout the training period, increasing approximately 2% per week. The estimated and MRI-measured relative percent change in mid-thigh muscle size was similar after the training. The KAATSU-walk training-induced increase in muscle size was accompanied by a significant increase in absolute but not relative strength. In addition, a previous study [25] reported that short-duration, low-intensity (20% of 1RM) KAATSU resistance training increased muscle fiber CSA. Therefore, we believe that the change in skeletal muscle volume seen in the present study was due to muscle hypertrophy and not changes in extra-cellular tissue/liquid content.

While this is the first study to demonstrate KAATSU-walk training-induced increases in skeletal muscle size, other studies [2, 21, 23] have consistently shown KAATSU-resistance training-induced muscle

hypertrophy. The mechanisms of KAATSU-induced muscle hypertrophy and strength gain are not fully understood. However, several possibilities exist. Growth hormone (GH), insulin-like growth factor-1 (IGF-1), and other myogenic regulatory factors are believed to play important roles in KAATSU-training-induced muscle hypertrophy. A single bout of KAATSU-walk exercise significantly increased serum GH concentration even though the training intensity was very low (50 m/min). These results are consistent with a previous published study [22] that demonstrated elevations in the circulating GH concentration following low-intensity (20% of 1-RM) KAATSU-resistance exercise. In contrast, a single bout of regular walking in young men does not cause an elevation in serum GH concentration [5]. Myostatin, a negative regulator of muscle hypertrophy, is up-regulated by glucocorticoids like cortisol [9]. In the present study, serum cortisol concentration was unchanged following KAATSU-walk exercise. Muscle myostatin content decreased following 14 days chronic restriction of muscular venous blood flow in a rodent model for KAATSU training [13]. In humans, interim analysis of DNA microarray data demonstrated down-regulation of myostatin in the vastus lateralis muscle following short-duration, low-intensity KAATSU-resistance training [12]. Myostatin expression was not measured in the present study. However, based on previous data and the current cortisol results, it is conceivable that myostatin may be down-regulated or unchanged following KAATSU-walk training. It was

anticipated that resting serum IGF-1 concentration would increase following KAATSU-walk training, since our previous study had reported increases in resting serum IGF-1 following KAATSU-resistance training [2].

It is not clear why serum IGF-1 did not change following 3 weeks of KAATSU-walk training, but it might be related to training intensity. KAATSU-walking may not be of sufficient intensity, as compared to KAATSU-resistance training, to alter circulating IGF-1 levels. To date, there has been no systematic study on the interactions of altering frequency, intensity, or duration of KAATSU-training. More work needs to be done to better understand how changing these variables would affect muscle adaptation to KAATSU-training.

The level of training intensity (mechanical stress) is an important factor for skeletal muscle hypertrophy and strength gain. However, the large mechanical stress associated with high-intensity resistance exercise poses a risk for injury, especially in elderly populations whose musculoskeletal system is weak. A unique characteristic of KAATSU-training is that substantial muscle hypertrophy can occur using a training intensity as low as 20% of 1-RM. In the present study, the mean value of oxygen uptake (VO_2) during KAATSU-walk exercise was 19.5% of VO_2 max, while the VO_2 during 40-70% of 1-RM resistance exercise is approximately 33-47% of VO_2 max [8]. From a metabolic perspective, the intensity of KAATSU-walk exercise is equivalent to the metabolic cost of 10-20% of 1-RM. Furthermore, blood markers for muscle

damage (CPK activity and myoglobin) were not elevated after the KAATSU-walk training. These data suggest that significant muscle hypertrophy can be achieved by low-intensity exercise that does not cause muscle damage. Therefore, KAATSU-training may be beneficial to a wider range of population, including the elderly, which may not otherwise tolerate high-intensity resistance training.

Aside from its effect on muscle size and strength, KAATSU training also causes metabolic adaptation in skeletal muscle that are similar to the metabolic response of muscle to ischemia [18]. KAATSU-resistance training enhanced muscle glycogen storage and produced a greater net decrease in resting muscle ATP concentrations compared with resistance training alone [6]. It was also speculated that KAATSU training might alter GLUT-4 translocation [6]. In the present study, mean oxygen uptake (VO_2) was 14% higher in the KAATSU-walk group compared with the Control-walk group. These results are consistent with a previous study [10] that reported a 15% increase in total body VO_2 during supine exercise with restricted muscle blood flow compared with normal flow. As compared with total body VO_2 , leg muscle VO_2 is not different during supine exercise with or without local leg ischemia [20]. In the present study, however, the increase in total body VO_2 may be related to the increase in the mean integrated electromyographical activity of leg muscle during KAATSU-exercise [21] and/or a coordinated and integrated muscle chemoreflex

induced by the metabolic strain of KAATSU-exercise [6].

In conclusion, the combination of leg muscle blood flow restriction (KAATSU) with slow-walk training induces muscle hypertrophy and strength gain despite the minimal level of exercise intensity. KAATSU-walk training may be a potentially useful method for promoting muscle hypertrophy covering a wider range of the population, including the frail and elderly.

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Figure legends

Figure 1. Walk training combined with restricted muscular venous blood flow from the leg muscle (KAATSU-walk) on a motor-driven treadmill.

Figure 2. Serum growth hormone and cortisol concentrations in response to acute walk exercise combined with and without KAATSU. Significant differences from before exercise, † $P < 0.01$.

Figure 3. Oxygen uptake (VO_2) and heart rate (HR) during walk exercise with and without KAATSU. The exercise consisted of walking at 50 m/min for five 2-min bouts (from Walk 1 to Walk 5) with a 1-min rest between bouts. Significant differences between KAATSU-walk and Control-walk, * $P < 0.05$.

Figure 4. Relative percentage changes in muscle-bone cross-sectional area (CSA) for the KAATSU-walk and Control-walk groups measured before (pre), during (every morning prior to the training session), and after (post) the training period. Significant differences from pre-training, * $P < 0.05$.

Figure 5. Typical magnetic resonance images showing transverse sections of the mid-thigh taken before (baseline) and after (post-testing) the 3 weeks of walk training with KAATSU. The images show identical sections, mid-way along the femur in the same subject (YW).

Figure 6. Dynamic (1-RM) and maximum isometric strength responses following 3 weeks of walk training with and without KAATSU. Significant differences from pre-training, * $P < 0.05$.

Figure 7. Relative maximum isometric knee extension and flexion strength responses following 3 weeks of walk training with KAATSU.

Figure 1



Figure 2

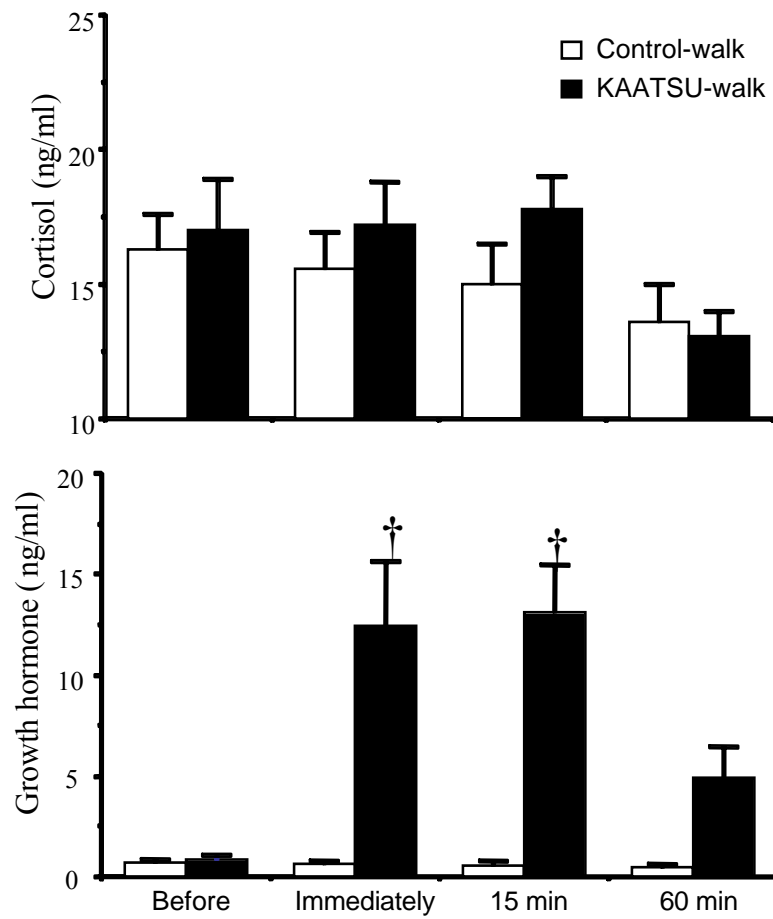


Figure 3

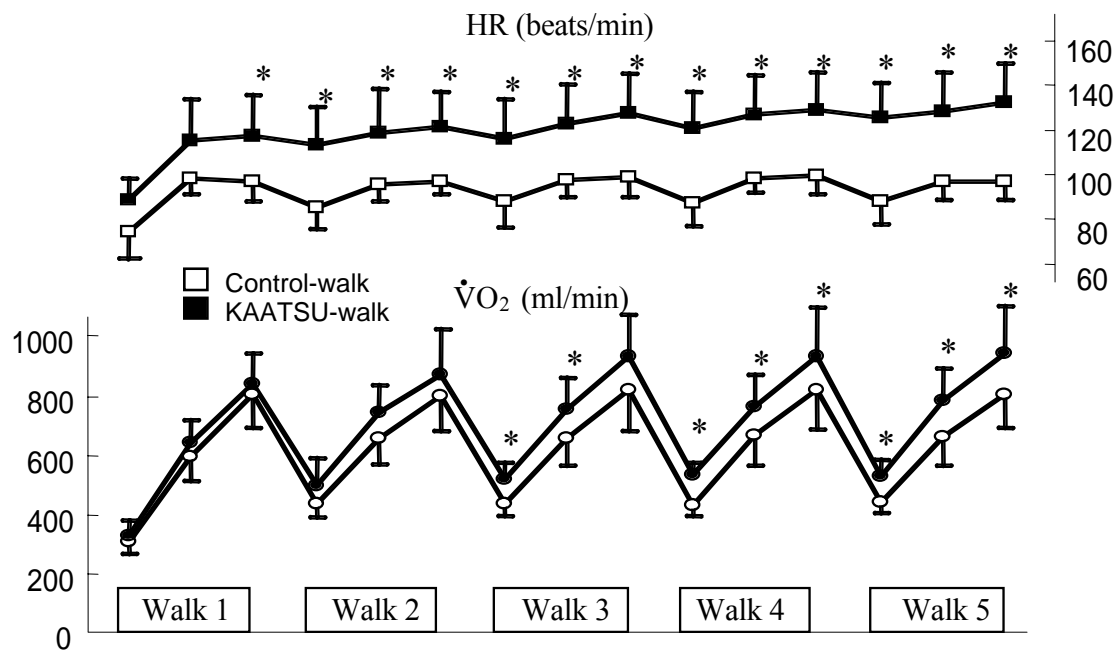


Figure 4

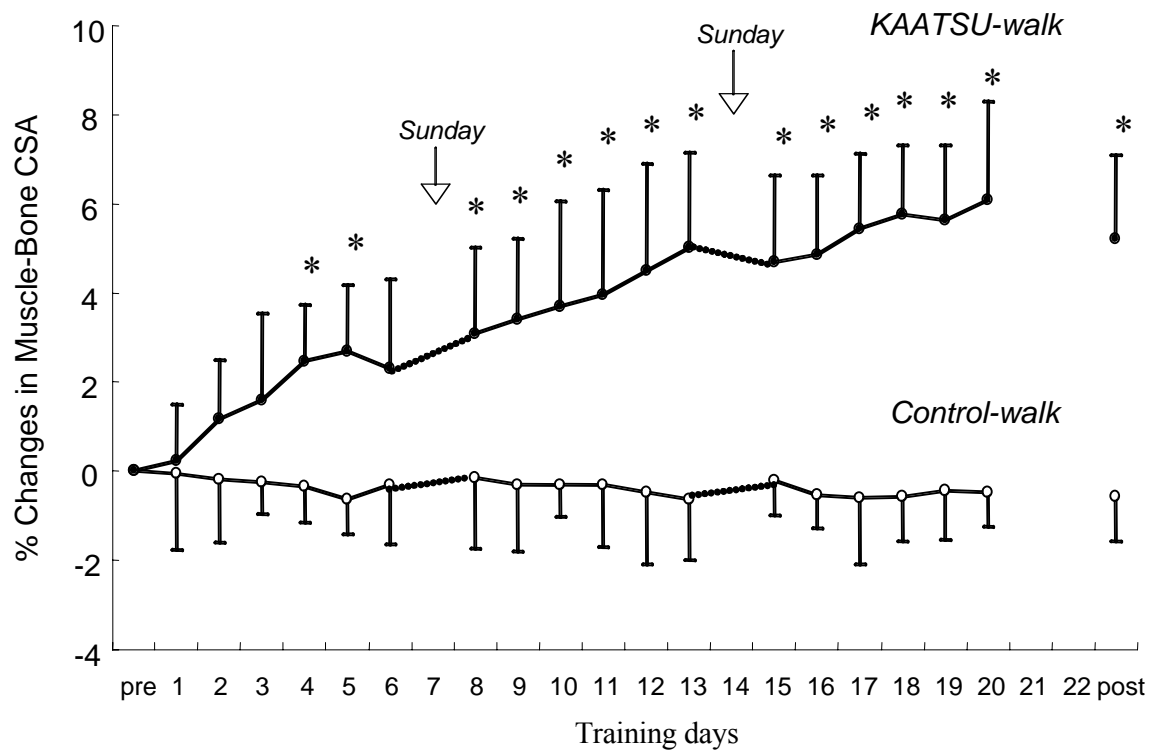
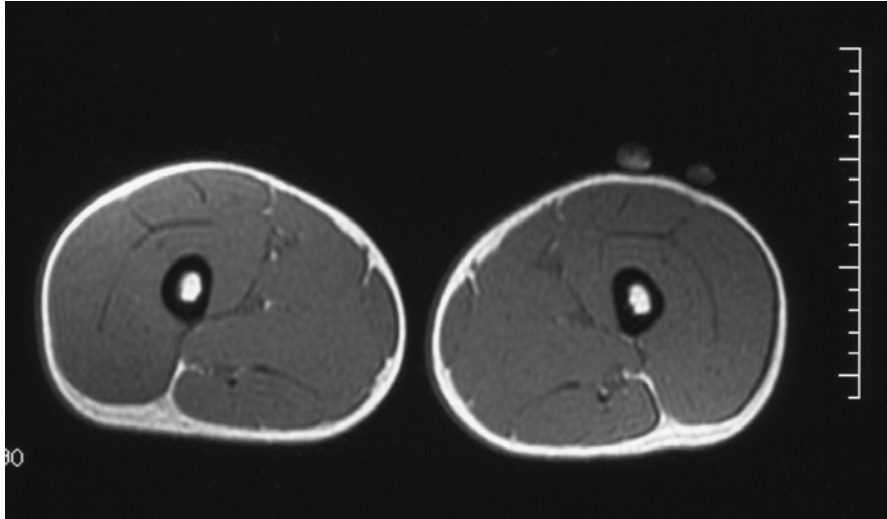


Figure 5

Baseline



Post-testing

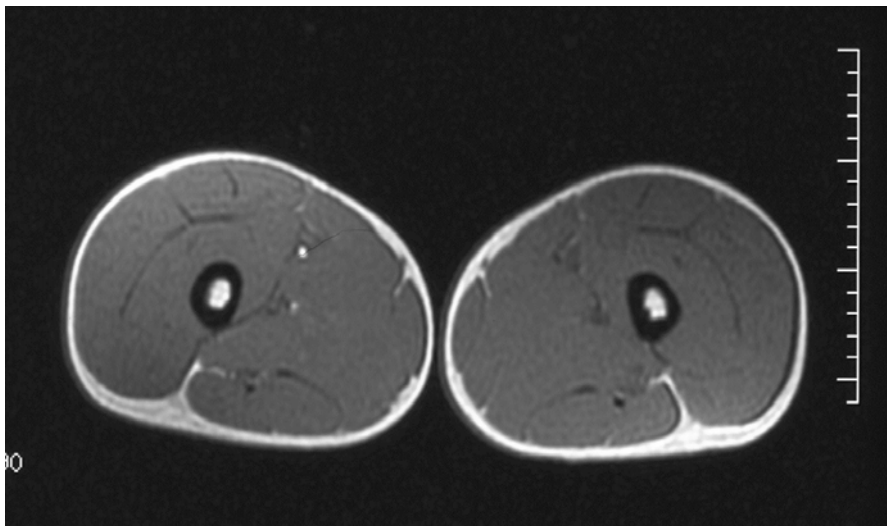


Figure 6

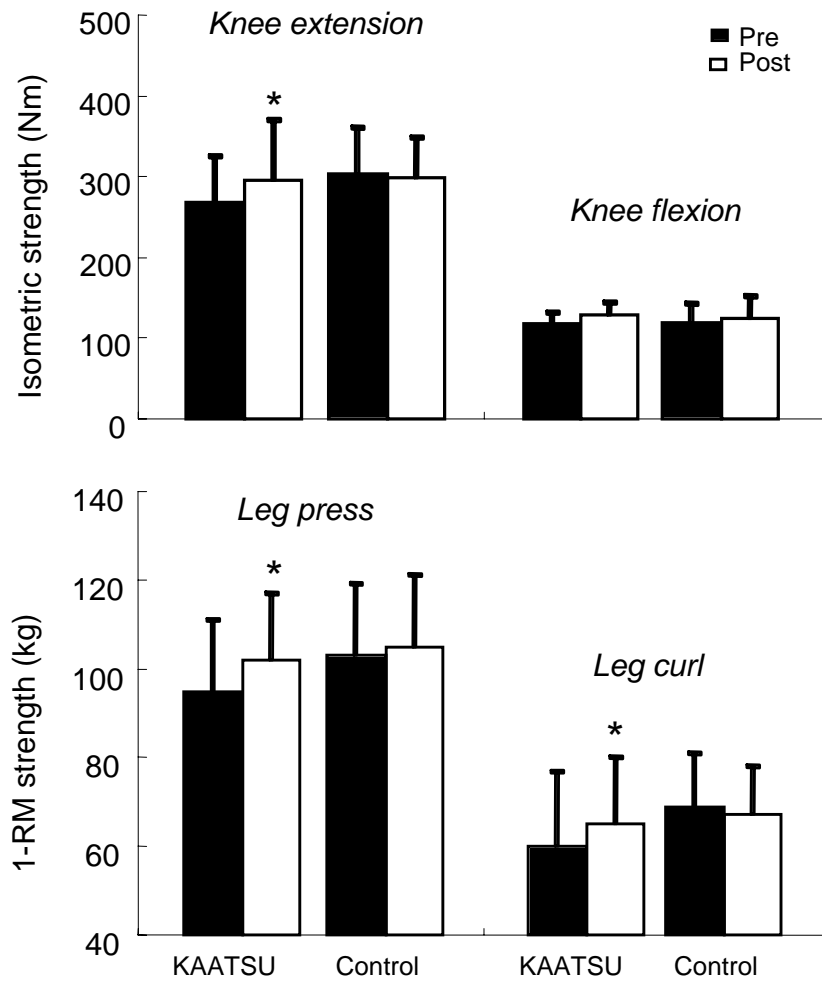


Figure 7

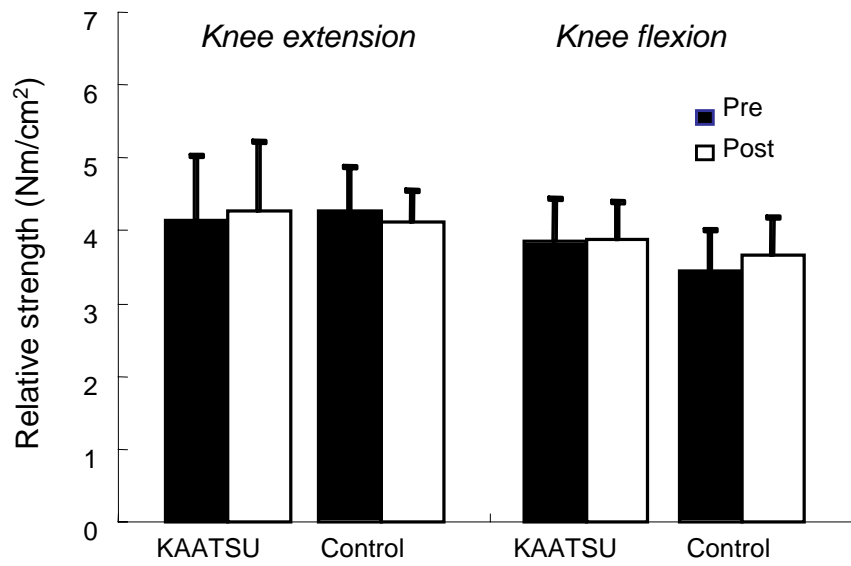


Table 1 Descriptive characteristics of subjects.

	KAATSU-walk	Control-walk
N	9	9
Age (yr)	21.2 ± 2.7	21.5 ± 2.9
Standing height (cm)	174.4 ± 5.8	173.7 ± 2.9
Body mass (kg)	64.1 ± 4.5	65.5 ± 6.1
BMI (kg/m ²)	21.1 ± 1.8	21.7 ± 1.7
Mid-thigh girth (cm)	51.0 ± 3.4	52.1 ± 1.6
Muscle-bone CSA (cm ²)	174.5 ± 17.8	176.9 ± 10.3

Table 2 Effects of walk-training with and without KAATSU on muscle cross-sectional area (CSA) and muscle volume.

	KAATSU-walk			Control-walk		
	Pre	Post	%	Pre	Post	%
Muscle volume (cm ³)						
Quadriceps	1789±183	1859±170†	4.1	1903±303	1900±296	-0.1
Hamstrings	631±99	669±90†	6.4	691±128	691±121	0.2
Adductors	804±127	852±126†	6.1	907±226	910±226	0.3
Mid-thigh muscle CSA (cm ²)						
Quadriceps	65.5±7.7	69.0±6.7†	5.7	71.2±9.0	72.1±7.8	1.5
Hamstrings	30.9±5.6	33.1±4.3†	7.6	34.8±5.7	34.1±5.2	-1.7

† p<0.01, pre vs. post

Table 3 Effects of walk-training with and without KAATSU on serum hormones, IGF-1, and makers for muscle damage.

	KAATSU-walk		Control-walk	
	Baseline	Post-testing	Baseline	Post-testing
CPK (IU/L)	141 ± 30	145 ± 34	161 ± 40	162 ± 34
Myoglobin (ng/ml)	44 ± 12	47 ± 8	40 ± 7	42 ± 6
T (ng/ml)	7.4 ± 1.6	7.7 ± 1.3	6.5 ± 1.0	7.1 ± 1.6
Free-T (pg/ml)	19.5 ± 4.0	18.2 ± 4.7	20.4 ± 3.4	20.2 ± 3.9
Cortisol (µg/dl)	19.2 ± 4.9	20.5 ± 4.7	20.8 ± 5.4	21.5 ± 5.7
IGF-1 (ng/ml)	292 ± 89	297 ± 72	288 ± 73	289 ± 80
IGFBP-3 (µg/ml)	2.6 ± 0.4	2.6 ± 0.4	2.7 ± 0.4	2.7 ± 0.3

CPK, creatine phosphokinase; T, testosterone; IGF-1, insulin-like growth factor-1; IGFBP-3, insulin-like growth factor binding protein-3