

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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Abe, Takashi, Charles F. Kearns, and Yoshiaki Sato. Muscle size and strength are increased following walk training with restricted venous blood flow from the leg muscle, Kaatsu-walk training. *J Appl Physiol* 100: 1460–1466, 2006. First published December 8, 2005; doi:10.1152/jappphysiol.01267.2005.—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 (one repetition maximum) and isometric strength, along with blood hormonal parameters. Nine men performed Kaatsu-walk training, and nine men performed walk training alone (control-walk). Training was conducted two times a day, 6 days/wk, for 3 wk using five sets of 2-min bouts (treadmill speed at 50 m/min), with a 1-min rest between bouts. Mean oxygen uptake during Kaatsu-walk and control-walk exercise was 19.5 (SD 3.6) and 17.2% (SD 3.1) of treadmill-determined maximum oxygen uptake, 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 by 4–7%, and one repetition maximum and maximum isometric strength increased by 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 a wide range of the population, including the frail and elderly.

muscle hypertrophy; dynamic and isometric strength; anabolic hormones; ischemia

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). How-

ever, 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 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 yr before 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 before 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.

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Table 1. Descriptive characteristics of subjects

	Kaatsu-Walk	Control-Walk
<i>n</i>	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)
Midhigh girth, cm	51.0 (3.4)	52.1 (1.6)
Muscle-bone CSA, cm ²	174.5 (17.8)	176.9 (10.3)

Values are means (SD); *N*, no. of subjects. BMI, body mass index; CSA, cross-sectional area.

Acute hormonal responses to Kaatsu-walking. Eleven young men (6 Kaatsu-walk and 5 control-walk) performed treadmill walking with and without Kaatsu on 2 separate days (1-wk 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, Sato Sports Plaza, Tokyo, Japan). Before 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 subject) for 30 s, and the air pressure was released. The air pressure was increased by 20 mmHg and held for 30 s, and then it was 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 9:00 AM, and venous blood samples were obtained from an antecubital vein before the start of exercise and immediately following (immediately, 15- and 60-min after exercise). Serum growth hormone (GH) and cortisol concentrations were determined by using a commercially available radioimmunoassay. Hematocrit was measured in duplicate by microcentrifugation of each blood sample. Oxygen uptake ($\dot{V}O_2$) during the Kaatsu-walk test was measured with the use of an automated breath-by-breath mass spectrometry system (Aeromonitor AE-280S, Minato Medical Science). Maximum $\dot{V}O_2$ ($\dot{V}O_{2\max}$) 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. $\dot{V}O_2$ 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 wk of supervised walk training. Training was conducted twice per day (morning and afternoon sessions, with at least 4 h between sessions), 6 days/wk for 3 wk. 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 (Fig. 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. Before 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 the 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 ~17 min for each subject, including the preparation process (~3 min) before the start of the training session. The belt pressure was released immediately on 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 (pretesting) and 3 days after the final training (posttesting). 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 before blood collection and not to perform any strenuous exercise.

1-RM strength measurements. One week before 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 before attempting maximal effort lifts. Maximum dynamic strength (1 RM) was assessed before (baseline) and 3 days after the final training (posttesting) for each



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

exercise. After warm 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 were allotted between each attempt to ensure recovery.

Maximum isometric strength measurements. Maximum voluntary isometric strength (maximum voluntary contraction) of the knee extensors and flexors was determined by 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 ~4–5 s. The test was assessed at baseline and 4 days after the final training (posttesting).

Muscle-bone cross-sectional area estimation. Muscle-bone cross-sectional area (CSA) for the midthigh was estimated by 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 midthigh girth of the right leg, and Q-AT and H-AT were ultrasound-measured (Aloka SSD-500, Tokyo, Japan) anterior and posterior thigh adipose tissue thickness, respectively. The estimated CV of this measurement was 1.2%. This measurement was carried out each morning before the training session and before posttesting.

MRI-measured muscle CSA and volume. MRI images were prepared using a General Electric Signa 1.5-T scanner (Milwaukee, WI). A T1-weighted, spin-echo, axial plane sequence was performed with

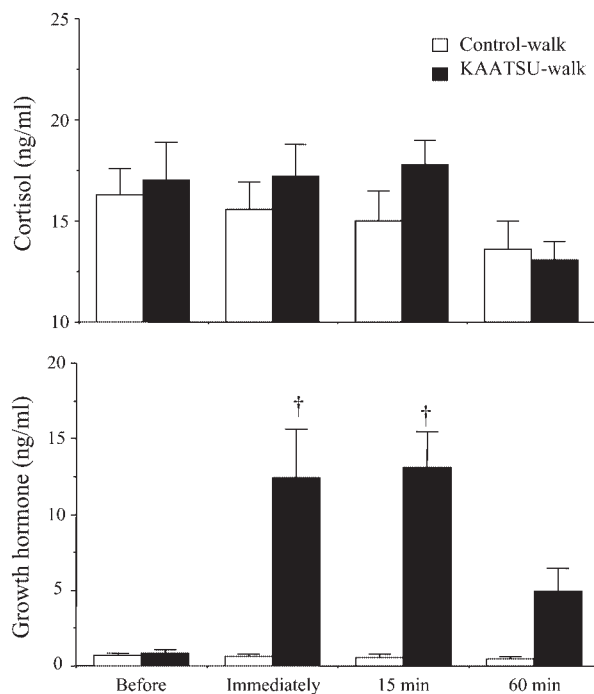


Fig. 2. Serum growth hormone and cortisol concentrations in response to acute walk exercise combined with and without Kaatsu. Significant differences from before exercise: † $P < 0.01$.

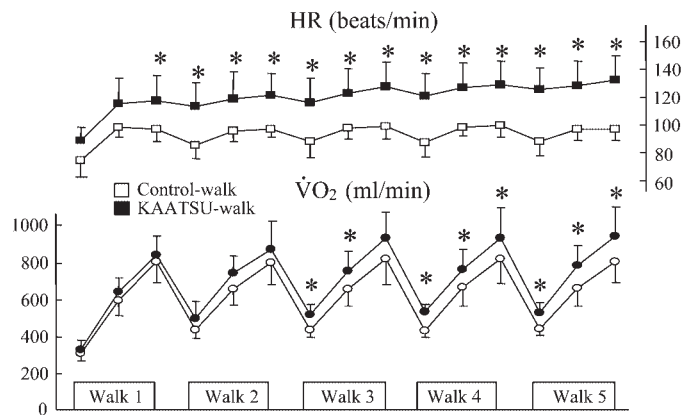


Fig. 3. Oxygen uptake ($\dot{V}O_2$) and heart rate (HR) during walk exercise with and without Kaatsu. The exercise consisted of walking at 50 m/min for five 2-min bouts (from Walk 1 to Walk 5) with a 1-min rest between bouts. Significant differences between Kaatsu-walk and control-walk: * $P < 0.05$.

a 1,500-ms repetition time and a 17-ms 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 (posttesting).

Hormonal analyses. Serum GH, total testosterone, free testosterone, cortisol, and IGF-I concentrations were measured at S.R.L. (Tokyo, Japan) by commercially available radioimmunoassay kits (Daiichi Radioisotope Laboratory, Chiba, Japan). Radioactivity was measured by 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 hexoki-

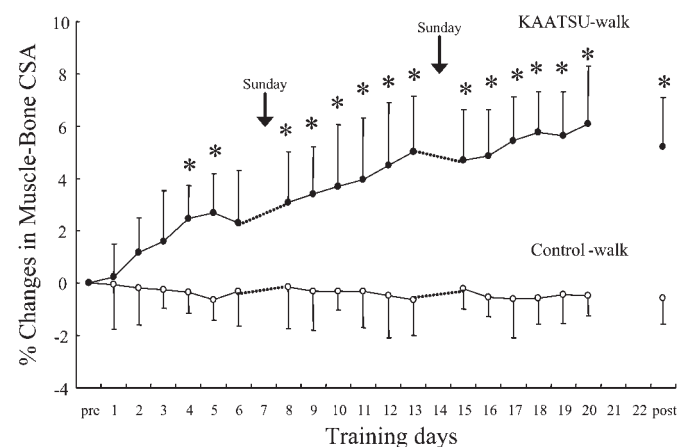
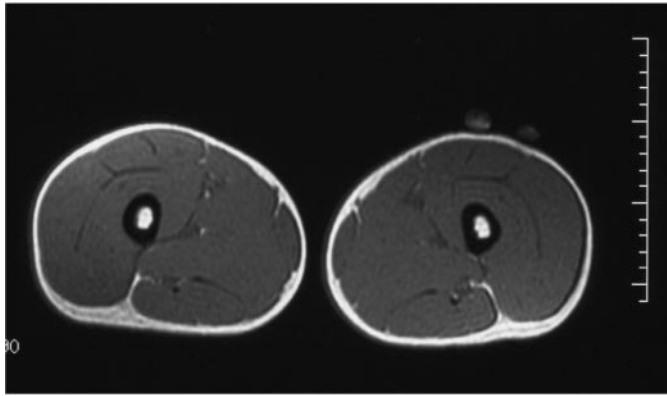


Fig. 4. Relative percentage changes in muscle-bone cross-sectional area (CSA) for the Kaatsu-walk and control-walk groups measured before (pre), during (every morning before the training session), and after (post) the training period. Significant differences from pretraining: * $P < 0.05$.

Baseline



Post-testing

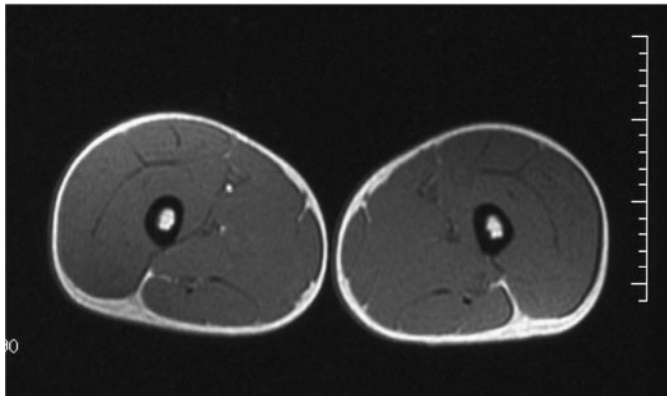


Fig. 5. Typical magnetic resonance images showing transverse sections of the midthigh taken before (baseline) and after (posttesting) the 3 wk of walk training with Kaatsu. The images show identical sections midway along the femur in the same subject (YW).

nase and D-glucose-6-phosphate dehydrogenase-coupled enzymatic system. Plasma concentration of myoglobin was measured by using a commercially available radioimmunoassay (Daiichi Radioisotope Laboratory).

Statistical analyses. Results are expressed as means (SD) for all variables. Statistical analyses were performed by a two-way ANOVA with repeated measures [group (Kaatsu-walk and control-walk) \times time (pre- and posttesting)]. Serum hormones were analyzed with a 2×4 [group (Kaatsu-walk and control-walk) \times time (preexercise, immediately post-, 15-min, and 60-min postexercise)] ANOVA with repeated measures. Post hoc testing was performed by Fisher's least significant differences test. Baseline differences between Kaatsu-walk

and control-walk and percent changes between baseline and posttesting 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 before 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 the preexercise level at 15 min after acute walking in the Kaatsu-walk group but not in the control-walk group (Fig. 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 before 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 $\dot{V}O_2$ was higher ($P < 0.05$) at the latter half of the walking session in the Kaatsu-walk group [708 ml/min (SD 96)] than in the control-walk group [623 ml/min (SD 77)] (Fig. 3). The percent change in $\dot{V}O_2$ between the Kaatsu-walk and control-walk groups was 14%. The mean $\dot{V}O_2$ during Kaatsu-walk and control-walk were 19.5% (SD 3.6) and 17.2% (SD 3.1) of treadmill-determined $\dot{V}O_{2\max}$, 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 it did not change in the control-walk group (Fig. 4). The muscle-bone CSA increased by 2.3, 5.0, and 6.0% at the end of the first, second, and third week, respectively, in the Kaatsu-walk group. By posttesting, the muscle-bone CSA had increased by 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 midthigh quadriceps and hamstrings (biceps femoris, semitendinosus, and semimembranosus) muscle CSA increased by 5.7 and 7.6%, respectively, in the Kaatsu-walk group ($P < 0.01$, Fig. 5) but did not change (1.5% and -1.7%) in the control-walk group. Also, quadriceps, hamstrings, and adductors muscle volumes increased by 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 wk of training ($P < 0.05$) but not in the control-walk group (1.9 and -2.9% , respectively) (Fig. 6). Maximum isometric knee extension (10.4%, $P < 0.05$) but not knee flexion (9.4%, $P >$

Table 2. Effects of walk-training with and without Kaatsu on muscle CSA and muscle volume

	Kaatsu-Walk			Control-Walk		
	Pre	Post	% Δ	Pre	Post	% Δ
Muscle volume, cm ³						
Quadriceps	1,789 (183)	1,859 (170)*	4.1	1,903 (303)	1,900 (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
Midthigh 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

Values are means (SD). Pre, before training; Post, after training; Δ , change. * $P < 0.01$, Pre vs. Post.

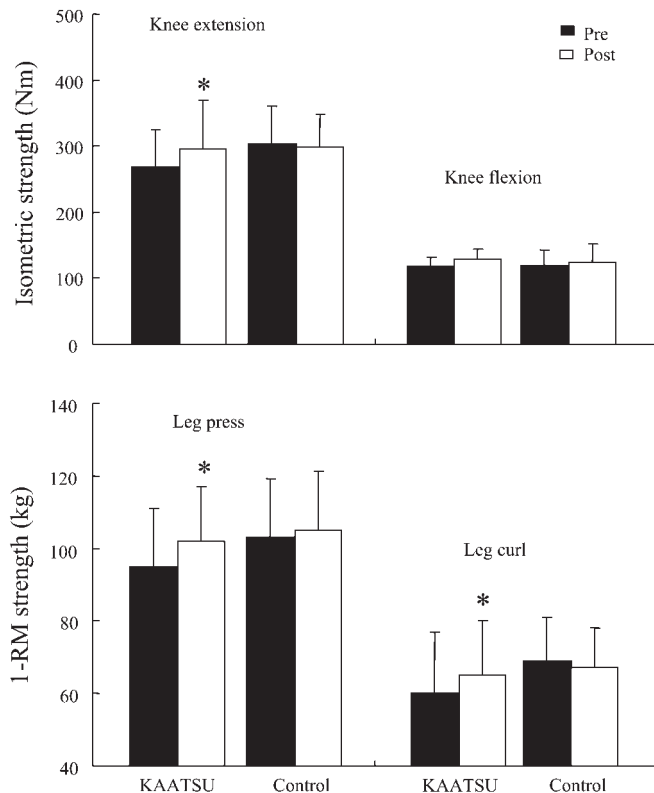


Fig. 6. Dynamic [one repetition maximum (1 RM)] and maximum isometric strength responses following 3 wk of walk training with and without Kaatsu. Significant differences from pretraining: * $P < 0.05$.

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 posttesting in both groups (Fig. 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-I, GH, total testosterone, free testosterone, and cortisol concentrations in both groups (Table 3).

DISCUSSION

The major finding of the present study was that 3 wk 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 by $\sim 2\%/wk$. The estimated and MRI-measured relative percent change in midthigh 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 1 RM) Kaatsu resistance training increased muscle-fiber CSA. Therefore, we believe that the change in skeletal muscle volume seen

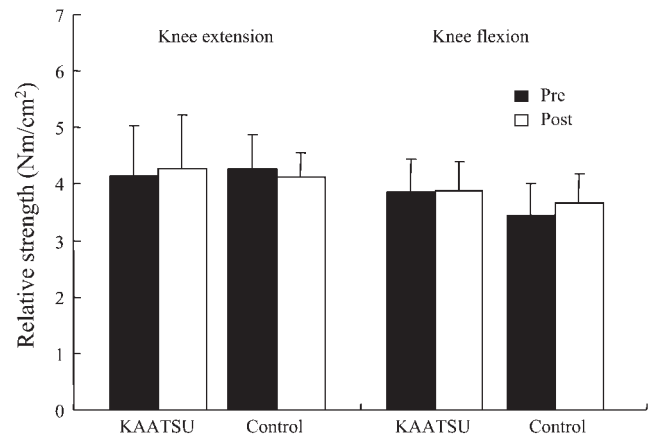


Fig. 7. Relative maximum isometric knee extension and flexion strength responses following 3 wk of walk training with Kaatsu.

in the present study was due to muscle hypertrophy and not changes in extracellular 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. GH, IGF-I, 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 previously published study (2) 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 upregulated 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 of chronic restriction of muscular venous blood flow in a rodent model for Kaatsu training (13). In humans, interim analysis of DNA microarray data demonstrated downregulation 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,

Table 3. Effects of walk-training with and without Kaatsu on serum hormones, IGF-I, and markers for muscle damage

	Kaatsu-Walk		Control-Walk	
	Baseline	Posttesting	Baseline	Posttesting
CPK, IU/l	141 (30)	145 (34)	161 (40)	162 (34)
Myoglobin, ng/ml	44 (12)	47 (8)	40 (7)	42 (6)
Testosterone, ng/ml	7.4 (1.6)	7.7 (1.3)	6.5 (1.0)	7.1 (1.6)
Free testosterone, pg/ml	19.5 (4.0)	18.2 (4.7)	20.4 (3.4)	20.2 (3.9)
Cortisol, μ g/dl	19.2 (4.9)	20.5 (4.7)	20.8 (5.4)	21.5 (5.7)
IGF-I, ng/ml	292 (89)	297 (72)	288 (73)	289 (80)
IGFBP-3, μ g/ml	2.6 (0.4)	2.6 (0.4)	2.7 (0.4)	2.7 (0.3)

Values are means (SD). CPK, creatine phosphokinase; IGFBP-3, insulin-like growth factor binding protein-3.

based on previous data and the current cortisol results, it is conceivable that myostatin may be downregulated or unchanged following Kaatsu-walk training. It was anticipated that resting serum IGF-I concentration would increase following Kaatsu-walk training, since our previous study had reported increases in resting serum IGF-I following Kaatsu resistance training (2). It is not clear why serum IGF-I did not change following 3 wk of Kaatsu-walk training, but it might be related to training intensity. Kaatsu-walking may not be of sufficient intensity, compared with Kaatsu resistance training, to alter circulating IGF-I 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 HIT 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 $\dot{V}O_2$ during Kaatsu-walk exercise was 19.5% of $\dot{V}O_{2\max}$, whereas the $\dot{V}O_2$ during 40–70% of 1-RM resistance exercise is ~33–47% of $\dot{V}O_{2\max}$ (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 the population, including the elderly, who may not otherwise tolerate HIT resistance training.

Aside from its effect on muscle size and strength, Kaatsu training also causes metabolic adaptation in skeletal muscle that is 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 GLUT4 translocation (6). In the present study, mean $\dot{V}O_2$ 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 $\dot{V}O_2$ during supine exercise with restricted muscle blood flow compared with normal flow. Compared with total body $\dot{V}O_2$, leg muscle $\dot{V}O_2$ is not different during supine exercise, with or without local leg ischemia (20). In the present study, however, the increase in total body $\dot{V}O_2$ may be related to the increase in the mean integrated electromyographic 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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REFERENCES

1. Abe T, Kearns CF, and Fukunaga T. Sex differences in whole body skeletal muscle mass measured by magnetic resonance imaging and its distribution in young Japanese adults. *Br J Sports Med* 37: 436–440, 2003.
2. Abe T, Yasuda Midorikawa T T, Sato Y, Kearns CF, Inoue K, Koizumi K, and Ishii N. Skeletal muscle size and circulating IGF-I are increased after two weeks of twice daily Kaatsu resistance training. *Int J KAATSU Training Res* 1: 6–12, 2005.
3. American College of Sports Medicine. Position stand. The recommended quantity and quality of exercise for developing and maintaining cardiorespiratory and muscular fitness, and flexibility in healthy adults. *Med Sci Sports Exerc* 30: 975–991, 1998.
4. Astrand PO and Rodahl K. *Textbook of Work Physiology*. New York: McGraw-Hill, 1970.
5. Bray GA, Whipp BJ, Koyal SN, and Wasserman K. Some respiratory and metabolic effects of exercise in moderately obese men. *Metabolism* 26: 403–412, 1977.
6. Burgomaster KA, Moore DR, Schofield LM, Phillips SM, Sale DG, and Gibala MJ. Resistance training with vascular occlusion: metabolic adaptations in human muscle. *Med Sci Sports Exerc* 35: 1203–1208, 2003.
7. Campos GER, Luecke TJ, Wendeln HK, Toma K, Hagerman FC, Murray TF, Ragg KE, Ratamess NA, Kraemer WJ, and Staron RS. Muscular adaptation in response to three different resistance-training regimens: specificity of repetition maximum training zones. *Eur J Appl Physiol* 88: 50–60, 2002.
8. Collins MA, Cureton KJ, Hill DW, and Ray CA. Relationship of heart rate to oxygen uptake during weight lifting exercise. *Med Sci Sports Exerc* 23: 636–640, 1991.
9. Czerwinski S and Hickson R. Glucocorticoid receptor activation during exercise in muscle. *J Appl Physiol* 68: 1615–1620, 1990.
10. Eiken O and Bjurstedt H. Dynamic exercise in man as influenced by experimental restriction of blood flow in the working muscles. *Acta Physiol Scand* 131: 339–345, 1987.
11. Haykowsky MJ, Findlay JM, and Ignaszewski AP. Aneurysmal subarachnoid hemorrhage associated with weight training: three case reports. *Clin J Sport Med* 6: 52–55, 1996.
12. Kawada S, Waga T, Sato Y, Abe T, and Ishii N. Comprehensive analysis of gene expression after resistance training combined with vascular occlusion (Abstract). *Adv Exerc Sports Physiol* 10: 155, 2004.
13. Kawada S and Ishii N. Skeletal muscle hypertrophy after chronic restriction of venous blood flow in rats. *Med Sci Sports Exerc* 37: 1144–1150, 2005.
14. Kraemer WJ and Ratamess NA. Fundamentals of resistance training: progression and exercise prescription. *Med Sci Sports Exerc* 36: 674–688, 2004.
15. McDonagh MJ and Davies CT. Adaptive response of mammalian skeletal muscle to exercise with high loads. *Eur J Appl Physiol* 52: 139–155, 1984.
16. McDougall JD, Tuxen D, Sale DG, Moroz JR, and Sutton JR. Arterial blood pressure response to heavy resistance exercise. *J Appl Physiol* 58: 785–790, 1985.
17. National Strength and Conditioning Association. *NSCA's Essentials of Personal Training*, edited by Earle RW and Baechle TR. Champaign, IL: Human Kinetics, 2003.
18. Rowell LB, Freund PR, and Hobbs SF. Cardiovascular responses to muscle ischemia in humans. *Circ Res* 48: 137–147, 1981.
19. Sawai S, Sanematsu H, Kanehisa H, Tsunoda N, and Fukunaga T. Evaluation of muscle activity level in daily actions. *Jpn J Phys Fitness Sports Med* 53: 93–106, 2004.
20. Sundberg CJ. Exercise and training during graded ischaemia in healthy man with special reference to effects on skeletal muscle. *Acta Physiol Scand* 615, Suppl: 1–50, 1994.
21. Takarada Y, Takazawa H, Sato Y, Takenoshita S, Tanaka Y, and Ishii N. Effects of resistance exercise combined with moderate vascular occlusion.

- sion on muscular function in humans. *J Appl Physiol* 88: 2097–2106, 2000.
22. **Takarada Y, Nakamura Y, Aruga S, Onda T, Miyazaki S, and Ishii N.** Rapid increase in plasma growth hormone after low-intensity resistance exercise with vascular occlusion. *J Appl Physiol* 88: 61–65, 2000.
 23. **Takarada Y, Sato Y, and Ishii N.** Effects of resistance exercise combined with vascular occlusion on muscle function in athletes. *Eur J Appl Physiol* 86: 308–314, 2002.
 24. **Takarada Y, Tsuruta T, and Ishii N.** Cooperative effects of exercise and occlusive stimuli on muscular function in low-intensity resistance exercise with moderate vascular occlusion. *Jpn J Physiol* 54: 585–592, 2004.
 25. **Yasuda T, Abe T, Sato Y, Midorikawa T, Kearns CF, Inoue K, Ryushi T, and Ishii N.** Muscle fiber cross-sectional area is increased after two weeks of twice daily Kaatsu-resistance training. *Int J Kaatsu Training Res* 1: 65–70, 2005.

