ORIGINAL ARTICLE

Effects of low-intensity KAATSU resistance training on skeletal muscle size/strength and endurance capacity in patients with ischemic heart disease

T. Nakajima, M. Kurano, F. Sakagami, H. Iida, K. Fukumura, T. Fukuda, H. Takano, H. Madarame, T. Yasuda, T. Nagata, Y. Sato, T. Yamasoba, T. Morita

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KAATSU training induces muscle hypertrophy and strengthens muscle in athletes and healthy subjects through short-term and low-intensity exercise. However, it remains uninvestigated whether low-intensity KAATSU resistance training (LIKRT) induces muscle strength and hypertrophy in patients with cardiovascular diseases. We examined the effects of LIKRT on skeletal muscle size/strength and endurance capacity in patients with ischemic heart disease (IHD). Seven male patients with stable IHD performed three kinds of resistance exercises (leg press, leg curl and leg extension) with their femoral muscle blood flow restricted by KAATSU belt two times/week for three months. We measured one RM (1-RM) in each resistance exercises, and evaluated muscle cross-sectional areas (CSA) by MRI before training and after the training. We used cardiopulmonary examinations to measure endurance capacity (Peak VO_2 (VO_2peak), VO_2 at anaerobic threshold (VO_2AT)). We performed blood sampling to measure resting plasma level of insulin growth factor-1 (IGF-1) and serum high-sensitive C-reactive protein (hsCRP). LIKRT significantly increased leg press (15%), leg curl (18%) and leg extension (17%) 1-RM strength. Increases of muscle CSA in quadriceps femoris at the proximal lower leg (30%), the mid-thigh (50%), and the proximal lower leg (70%) were 5.1%, 4.6% and 10.4%, respectively. Similarly, hamstring and adductor CSA were also increased by LIKRT. LIKRT significantly increased VO_2peak and VO_2AT by 10.7% and 10.9%, respectively. IGF-1 and hsCRP were not altered before or after the training. These results suggest that LIKRT increases muscle strength/mass and endurance capacity in patients with IHD. LIKRT appears to be a promising and effective resistance method in cardiac rehabilitation.

Key words: KAATSU training, ischemic heart disease, muscle hypertrophy, aerobic capacity, blood restriction

Correspondence to:
T. Nakajima, MD: Department of Ischemic Circulatory Physiology, KAATSU Training, University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo, Japan 113-8655
masamasa@pb4.so-net.ne.jp

See end of article for authors' affiliations

INTRODUCTION

Cardiac rehabilitation is a well-established method for improving quality of life and cardiopulmonary function in patients with cardiovascular diseases. Traditionally, aerobic exercise has been generally used for cardiac rehabilitation in patients with cardiovascular diseases. This kinds of exercise improve exercise endurance capacity assessed by using parameters measured during a cardiopulmonary exercise test like peak oxygen consumption (VO_2) (VO_2peak), but has a rather minor effect on skeletal muscle weakness or mass. However, especially in patients with muscle atrophy and elderly patients, it is difficult to improve muscle endurance capacity by using only aerobic exercises. Therefore, resistance exercises combined with aerobic exercises have been recommended (Pollock et al., 2000; Leon et al., 2005). According to the American College of Sports Medicine (ACSM) guidelines, the conditions for inducing muscle hypertrophy and increasing muscle mass are as follows:

(1) More than 65～70% work load of one repetition maximum (1-RM) is needed.
(2) Three to four sets until exhaustion.
(3) Frequency is two～three times per week.

However, the adequate high-intensity loads can not be applied to patients with diseases, especially in patients with cardiovascular diseases and elderly patients.

The KAATSU training is a novel exercise that restricts muscle blood flow, by binding the proximal portion of lower or upper extremities with a specially-designed belt. It has been reported to induce muscle hypertrophy and strengthen muscle in athletes and healthy subjects through short-term low-intensity exercises (Takarada et al. 2000a; b; c; Takarada et al., 2002a,b; Abe et al. 2006; Fujita et al., 2007; Karabulut et al., 2007, Wernbom et al., 2008; Karabulut et al., 2010). Thus, KAATSU training appears to be a useful muscle training method for promotion of healthy subjects and muscle strength in fields of sport. To date, 200,000 people have performed KAATSU training, and serious side effects have not been reported (Nakajima et al., 2006), suggesting that it is safe under the supervision of the instructors. However, it remains uninvestigated whether low-intensity KAATSU resistance training strengthens muscle and induces muscle hypertrophy in patients with cardiovascular diseases.

Therefore, we investigated the effects of low-intensity KAATSU resistance exercise on skeletal muscle size/strength and endurance capacity and its safety in patients with stable ischemic heart disease.

MATERIALS AND METHODS

Subjects

Seven stable male patients with ischemic heart disease (post-coronary artery bypass grafting (p-CABG) 2, post-percutaneous coronary intervention (p-PCI) 5, 52 ± 4 years old) participated in this study. These patients had no organic stenosis after CABG or PCI, and had no symptoms at the start of this study. This study was approved by the Ethics Committee of the University of Tokyo. All subjects were informed of the methods, procedures and risks, and signed an informed consent document before participation. None of the subjects had participated in strength/resistance-type training before the start of the study. During the study, they did not receive any strength/resistance-type training other than KAATSU training.

Training Protocol

Patients performed three kinds of leg resistance exercises (leg press, leg extension, and leg curl) for three months. The sets consisted of the following repetition pattern: 30 repetitions, 15 repetitions, 15 repetitions, 15 repetitions. There was a one-minute rest interval between sets. Contraction intensity was 20-30% of predetermined 1-RM (leg press 30% 1-RM, leg extension 20% 1-RM, and leg curl 20% 1-RM). Individual contraction duration was 3.0 seconds with a 1.5:1.5 sec shortening-lengthening contraction duty cycle as controlled by a metronome (40 beats per minute). Training was conducted two times per week by the KAATSU method, which restricts muscle blood flow. We monitored the symptom score (Borg scale), blood pressure, and heart rate during the training.

Reduction of Femoral Muscle Blood Flow by KAATSU

This method for inducing the reduction of muscle blood flow is similar to those described in previous papers (Takarada et al. 2000a; b; c; Takarada et al., 2002a,b; Takano et al., 2005; Abe et al. 2006; Fujita et al., 2007; Iida et al., 2007; Nakajima et al., 2008). A specially-designed KAATSU belt applies pressure at the proximal ends of both sides of the thighs, to restrict venous blood flow. The cuff pressure was first set at a low-pressure of 100 mmHg, and gradually increased to 160-250 mmHg within two to three weeks, depending on the subjects and Borg scale during the training. The training was performed within Borg scale of 16. The cuff pressure can be controlled by a KAATSU apparatus.

Estimation of Muscle Cross-Sectional Area

Muscle cross-sectional area (CSA) was estimated using magnetic resonance imaging, (MRI) technology before KAATSU training and three months after KAATSU training ("Pre" and "Pst" in the Figures, respectively). They were evaluated at the proximal lower leg (30%), the mid-thigh (50%), and the proximal lower leg (70%). The % change in CSA was calculated at the quadriceps femoris, hamstring and adductor, separately. The total CSA (cm^2) was also measured at the proximal lower leg (30%), the mid-thigh (50%), and the proximal lower leg (70%).

Measurement of 1-RM and VO_2

We measured 1-RM voluntary force, before the training and three months after the training. We measured per-breath gas exchange and determined VO_2, using a standard increment cycle ergometer protocol, with a ramp pulse (20 watt increase/min) with AE 300S (Minato Medical Science CO., LTD., Tokyo, Japan). We measured VO_2 at the anaerobic threshold (AT) and VO_2peak as well as the work load at the AT level and the peak exercise. The VO_2peak value in this study was 1463 ± 93 ml/min (n=7). One RM evaluated by 8-10 RM was measured at three different stations of a resistance exercise circuit (leg press, leg curl, and leg extension).

Blood Sampling and Hormonal Analyses

We collected venous blood samples before the training and three months after the training. We obtained blood samples by venipuncture from the antecubital vein. High-sensitive C-reactive protein (hsCRP) was measured at SRL, Inc. (Tokyo, Japan) in 500 μl serum samples, using a method of latex turbidimetric immuno assay (LTIA). The limit of detection of hsCRP was 50 ng/ml. Plasma level of insulin-like growth factor-1 (IGF-1) was determined using immunoradiometric assays (IRMA) specific for the human peptides at SRL, Inc..

Data Analysis

All values are expressed as means ± S.E.M. Student's paired t-test and one-way ANOVA for repeated measures were used, and differences were considered significant if $P<0.05$.

RESULTS

All participating patients had no side effects and completed the study. None of them had any complaints, chest pain. There were no hospitalizations, or no exacerbations of ischemic heart disease during the study period.

Fig. 1 shows the effects of KAATSU training on resting plasma IGF-1 (Fig. 1A), and serum hsCRP, an inflammatory marker (Fig. 1B). There were no significant changes (P>0.05) in resting IGF-1 and hsCRP between control (Pre) and three months after the training (Post).

During the KAATSU training, muscle CSA increased significantly for quadriceps femoris (QF, Fig. 2). Increases of muscle CSA in quadriceps femoris at the proximal lower leg (30%), the mid-thigh (50%), and the proximal lower leg (70%) were 5.1%, 4.6% and 10.4%, respectively. Similarly, CSA of hamstring (HAM) and adductor (ADD) CSA were increased by the KAATSU training. A representative MRI finding is shown in Fig. 3.

Fig. 4 shows the effects of KAATSU training on total muscle CSA for the proximal lower leg (30%), the mid-thigh (50%), and the proximal lower leg (70%). After KAATSU training, muscle CSA at 30%, 50% and 70% position of femur length increased significantly to 4.2%, 3.0% and 7.5%, respectively.

The KAATSU training significantly increased 1-RM strength for leg press (15%), leg curl (18%) and leg extension (17%) (Fig. 5).

Fig. 6 shows the effects of KAATSU training on aerobic capacity in cardiopulmonary examination. KAATSU resistance training significantly increased the work load of the peak and AT exercise (Fig. 6A), and significantly increased VO_2 peak and VO_2 AT by 10.7% and 10.9% significantly (Fig. 6A). However, resting HR and systolic blood pressure (sBP) were not significantly changed (Fig. 6B).

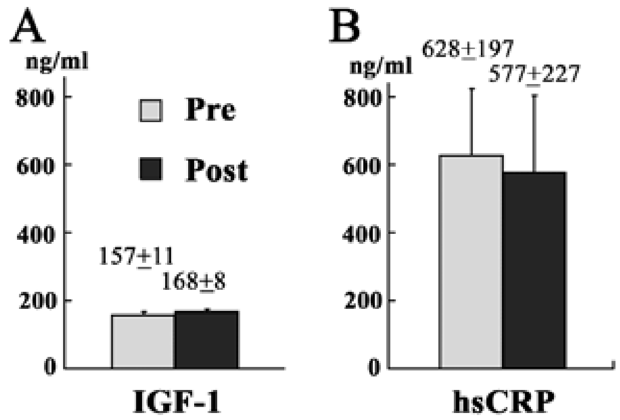

Figure 1. Changes in serum IGF-1 (A) and high-sensitive CRP (hsCRP) (B) concentration following 3 months KAATSU resistance training. Mean ± S.E.M. value is shown. Pre: Pre-training Post: Post-training

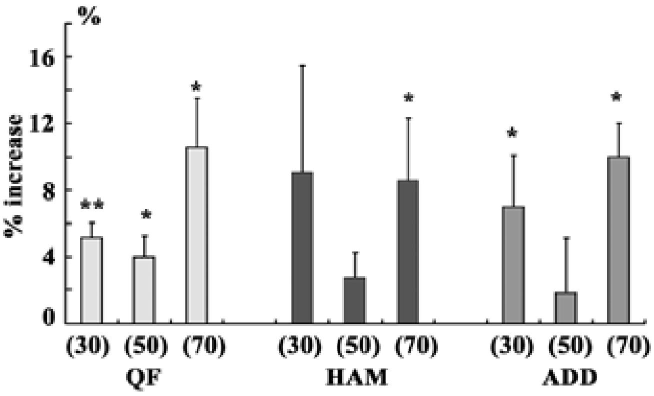

Figure 2. Changes in skeletal muscle size following three months KAATSU training. Muscle cross sectional area (CSA) was evaluated at the proximal lower leg (30%), the mid-thigh (50%), and the proximal lower leg (70%). The % change in cross sectional areas (CSA) was calculated at the quadriceps femoris (QF), hamstring (HAM), and adductor (ADD), separately. Mean ± S.E.M. value is shown. *P<0.05, **P<0.01 vs. pre (before)-KAATSU training

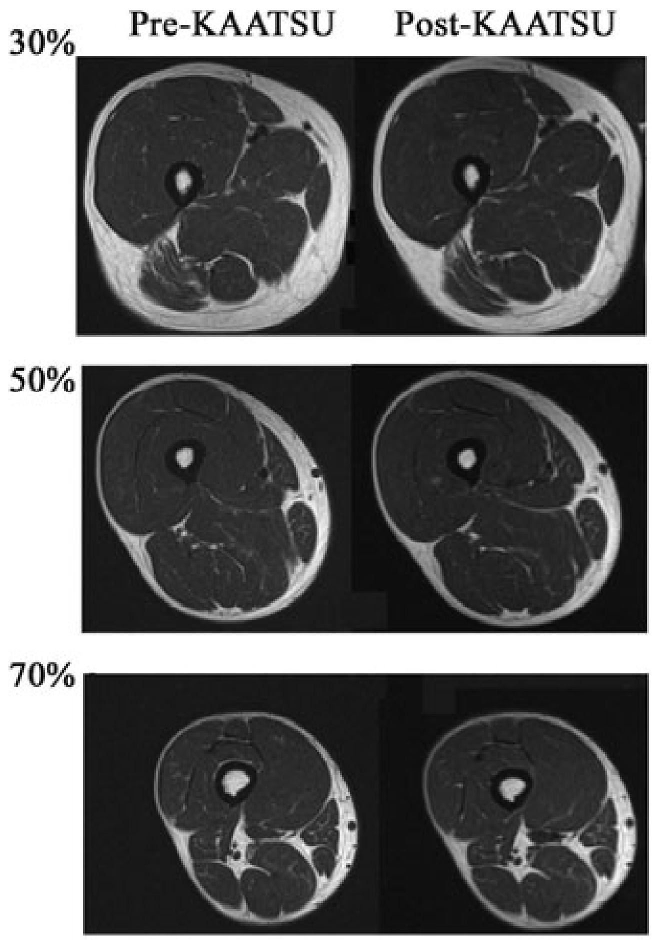

Figure 3. A typical MRI finding. The MRI finding is illustrated at the proximal lower leg (30%), the mid-thigh (50%), and the proximal lower leg (70%) before (left part) and three months after the training (right part).

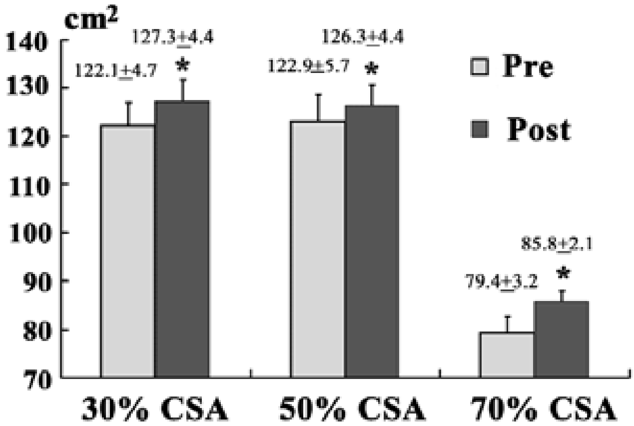

Figure 4. Effects of KAATSU resistance training on CSA of 30%, 50% and 70% position of femur length. Mean ± S.E.M. value is shown. *p<0.05 vs. pre (before)-KAATSU training

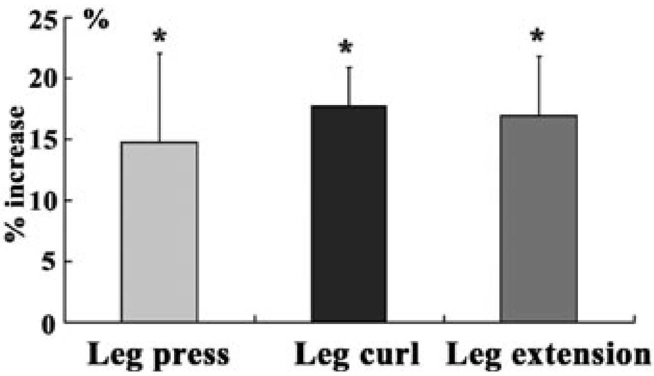

Figure 5. Effects of KAATSU resistance training on 1-RM of leg press, leg curl, and leg extension. The % change in 1-RM is shown in each exercise. Mean ± S.E.M. value is illustrated. *p<0.05 vs. pre (before)-KAATSU training

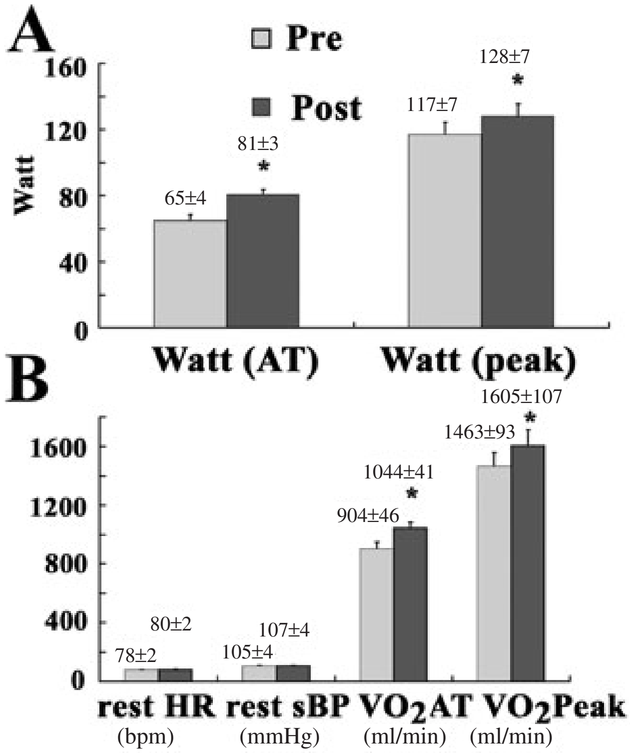

Figure 6. Effects of KAATSU training on the parameters determined by cardiopulmonary examinations. A: Change in work load (watt) at anaerobic threshold (AT) and peak exercise (peak). B: Change in resting HR, systolic blood pressure (sBP), and VO_2AT and VO_2 Peak. The resting HR (bpm), systolic blood pressure (sBP, mmHg), and VO_2AT (ml/min) and VO_2 peak (ml/min) are shown before and three months after the training. Mean ± S.E.M. value is illustrated. *P<0.05 vs. pre (before)-KAATSU training

DISCUSSION

These results suggest that low-intensity KAATSU resistance exercises safely increase muscle strength/mass and endurance capacity in patients with ischemic heart diseases. Low-intensity KAATSU resistance training using low-intensity resistance exercise appears to be a promising and useful resistance method in cardiac rehabilitation.

Several studies investigate the effects of heavy resistance exercise on muscle strength in healthy subjects or patients. Hakkinen et al. (2000) showed that the increase in maximal isometric resistance strength of the knee extensor was 28% in middle healthy aged men (42 years), and 21% in elderly men (72 years) 6 months after 50-80% 1-RM resistance exercise. Brochu et al (2002) also reported that the resistance training of 50-80% (three times per week for six months) in older women with coronary heart disease improved upper body strength (18%) and lower body strength (23%). In the present study, we investigated the effects of low-intensity KAATSU resistance exercise on muscle strength in male patients with ischemic heart diseases, by using only 20-30% 1-RM. They had no organic stenosis after the therapy (CABG and PCI). The KAATSU resistance training twice a week for three months, even by using 20-30% load of 1-RM, significantly increased leg press (15%), leg curl (18%) and leg extension (17%) 1-RM strength. The magnitude of the increase in the strength was 0.17% per day (leg press), 0.2% per day (leg curl), and 0.19% per day (leg extension). These values were larger than those reported by Hakinnen et al. (2000) (0.15% per day) and Brochu et al. (2002) (0.13% per day), and similar to the previous papers using healthy subjects and athletes under the restricting muscle blood flow (see review, Karabulut et al., 2007; Wernbom et al., 2008). Thus, low-intensity KAATSU training appears to effectively increase muscle strength comparable to the high-intensity exercise, even in patients with ischemic heart disease.

In the present study, significant increase of muscle CSA in quadriceps femoris was observed. Similarly, KAATSU training also increased hamstring and adductor CSA. The estimated thigh CSA in the present study increased by approximately 4-10% ($P<0.05$) following three months of the KAATSU training (2 days per week, 32 total training sessions). Increases of muscle CSA in quadriceps femoris at 30%, 50% and 70% position of femur length were 5.1%, 4.6% and 10.4%, respectively. Therefore, the magnitude of the hypertrophic potential (percent increase in muscle CSA divided by total training sessions) in the thigh was about 0.17-0.31% per training session. Recently, Wernbom et al. (2008) reviewed the effects of high-intensity resistance exercise and low-intensity KAATSU resistance exercise (leg extension) on muscle hypertrophy of quadriceps femoris in healthy subjects. High-intensity extension exercise two to three times per week, using 80% 1-RM (three to four sets, 6-10 repetitions, interval 60-120 s), increased muscle mass by 0.03-0.26% per day and 1-7% per month (3-21% per three months). On the other hand, low-intensity KAATSU training using 20-50% 1RM (3-4 sets, 15-30 repetition, interval 30-60 s) increased it by 0.04-0.22% per day and 1.2-6.6% per month (3.6-18% per three months). Thus, low-intensity KAATSU resistance training appears to increase muscle mass in a similar way to heavy resistance exercise in healthy subjects. In the present study, increases of muscle CSA in quadriceps femoris at mid-thigh were 4.6% per three months, suggesting that even low-intensity KAATSU resistance training may be a useful method for inducing muscle hypertrophy as well as improvement of muscle strength in patients with ischemic heart diseases.

The mechanisms of the hypertrophic response and strength gain from KAATSU training are still poorly understood. It has been well known that acute bout of KAATSU training sessions significantly increase growth hormone secretion (Takarada et al., 2000a; Takano et al., 2005; Abe et al., 2006), leading to the increased secretion of IGF-1. The enhanced IGF-1/GH secretion may be involved in the hypertrophic effects of KAATSU training. However, in the presents study, IGF-1 did not increase significantly during the three-month low-intensity KAATSU resistance training. Therefore, it is unlikely that IGF-1 was mainly involved in the muscle hypertrophy induced by KAATSU training. In fact, the involvement of GH/IGF-1 on the hypertrophy induced by resistance exercise has recently been denied (West et al., 2009). The further studies are needed to clarify the basic mechanisms of the hypertrophic response and strength gain from KAATSU training.

It is generally known that aerobic exercises improve exercise endurance capacity assessed by using parameters measured during a cardiopulmonary exercise test like VO_2peak. However, especially in patients with muscle atrophy and elderly patients, it is difficult to improve muscle endurance capacity by using only aerobic exercises. Therefore, resistance exercises combined with aerobic exercises have been recommended (Pollock et al., 2000; Leon et al., 2005). In the present study, KAATSU resistance training also significantly increased VO_2peak and VO_2AT by 10.7% and 10.9% significantly. The present study showed that the KAATSU resistance exercises significantly increased skeletal muscle mass. An increase of 1 kg skeletal muscle mass in the lower-body skeletal muscle mass would predict an increase in maximal oxygen consumption (VO_2max) of about 200 ml per minute (Frontera et al., 1990). In the present study, KAATSU resistance training also significantly increased the work load of the peak and AT exercise. Thus, the increase of muscle mass and then improvement of muscle strength might play a role in the improvement of aerobic endurance capacity induced by KAATSU resistance training in patients with ischemic heart disease.

KAATSU training consists of exercises performed with restricted venous blood flow. Therefore, occlusion of blood vessels may affect the haemostasis, and cause the formation of thrombus, though serious side effects of KAATSU training such as pulmonary embolism have not been reported (Nakajima et al. 2006). During our study using patients with ischemic heart disease, no venous thrombosis had developed. This might be compatible with the previous papers showing that vascular occlusion alone stimulates the fibrinolytic activity without the coagulation activity and clot formation (Nakajima et al., 2007; Madarame et al., 2010; Clark et al., 2010). The most common side effects in KAATSU training are petechia and temporary numbness as described previously (Nakajima et al., 2006). The petechia is frequently developed during the KAATSU training of upper extremities (Nakajima et al., 2006). In the present study, all of the patients had received acetylsalicylic acid or ticlopidine hydrochloride, an antiplatelet drug. But, no petechia had occurred during the training of lower extremities. Umbel et al. (2009) reported that delayed-onset muscle soreness was induced by low-load blood flow restricted exercise in healthy subjects. But, in the present study, no serious delayed onset muscle soreness was occurred. In addition, high-sensitive CRP, an inflammatory marker (Nakajima et al., 2010), did not change during the KAATSU training. Thus, low-intensity KAATSU resistance training using low-intensity exercise appears to be a safe method for increase in muscle strength and muscle mass in patients with ischemic heart disease. However, the addition of KAATSU to resistance exercise induces a greater increase in blood pressure and noradrenaline, compared to the exercise without KAATSU (Takano et al., 2005; Abe et al., 2006; Kubota et al., 2009). Therefore, we must take this into account when the KAATSU method is applied to training in patients with cardiovascular disease.

In summary, three months of KAATSU resistance training (leg press. leg curl and leg extension, 20%-30% 1-RM) safely induces muscle hypertrophy/strength and increases aerobic capacity in patients with stable ischemic heart disease. Low-intensity KAATSU resistance training appears to be a promising and useful resistance method in cardiac rehabilitation.

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Authors' affiliations

T. Nakajima, M. Kurano, F. Sakagami, H. Iida, K. Fukumura, T. Fukuda, Takano, H. Madarame, T. Yasuda, T. Morita, Department of Ischemic Circulatory Physiology, KAATSU Training, University of Tokyo, Tokyo, Japan

T. Nagata, Sannou Hospital, Respiratory Center, Tokyo, Japan

Y. Sato, Kaatsu International University, Sri Lanka
T. Yamasoba, Department of Otolaryngology and Head and Neck Surgery, Faculty of Medicine, University of Tokyo, Tokyo, Japan