EFFECTS OF WHOLE-BODY LOW-INTENSITY RESISTANCE TRAINING WITH SLOW MOVEMENT AND TONIC FORCE GENERATION ON MUSCULAR SIZE AND STRENGTH IN YOUNG MEN

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ABSTRACT

Tanimoto, M, Sanada, K, Yamamoto, K, Kawano, H, Gando, Y, Tabata, I, Ishii, N, and Miyachi, M. Effects of whole-body low-intensity resistance training with slow movement and tonic force generation on muscular size and strength in young men. *J Strength Cond Res* 22(6): 1926–1938, 2008—Our previous study showed that relatively low-intensity (~50% one-repetition maximum [1RM]) resistance training (knee extension) with slow movement and tonic force generation (LST) caused as significant an increase in muscular size and strength as high-intensity (~80% 1RM) resistance training with normal speed (HN). However, that study examined only local effects of one type of exercise (knee extension) on knee extensor muscles. The present study was performed to examine whether a whole-body LST resistance training regimen is as effective on muscular hypertrophy and strength gain as HN resistance training. Thirty-six healthy young men without experience of regular resistance training were assigned into three groups (each $n = 12$) and performed whole-body resistance training regimens comprising five types of exercise (vertical squat, chest press, latissimus dorsi pull-down, abdominal bend, and back extension: three sets each) with LST (~55–60% 1RM, 3 seconds for eccentric and concentric actions, and no relaxing phase); HN (~80–90% 1RM, 1 second for concentric and eccentric actions, 1 second for relaxing); and a sedentary control group (CON). The mean repetition maximum was eight-repetition maximum in LST and HN. The training session was performed twice a week for 13 weeks. The LST training caused significant ($p < 0.05$) increases in whole-body muscle thickness (6.8 ± 3.4% in a sum of six sites) and 1RM strength (33.0 ± 8.8% in a sum of five exercises) comparable with those induced by HN training (9.1 ± 4.2%, 41.2 ± 7.6% in each measurement item). There were no such changes in the CON group. The results suggest that a whole-body LST resistance training regimen is as effective for muscular hypertrophy and strength gain as HN resistance training.

KEY WORDS resistance training regimens, muscular hypertrophy, continuous muscular activity, intramuscular hypoxic environment

INTRODUCTION

Resistance training at medium-to-high intensity (~80% one-repetition maximum [1RM]) is generally regarded as optimal for increasing muscular size and strength (21,23,32). It has been reported that resistance training at intensities lower than 65% 1RM is virtually ineffective for increasing muscular size and strength (6). Therefore, large mechanical stress has often been considered essential for increasing muscular size and strength. However, the concept of enhancing exercise movement variation was not explored in these studies. When exercise movement is devised to place muscles under continuous tension throughout the exercise movement, resistance training, even with low-intensity loads of less than 65% 1RM, may cause muscular hypertrophy and increase strength.

The results of our previous study indicated that a 12-week program of relatively low intensity (~50% 1RM) resistance training with slow movement and tonic force generation (3 seconds for eccentric and concentric actions, 1-second pause and no relaxing phase; designated as LST) for knee extensor muscles caused significant increases in muscular size (~5% gain in cross-sectional area) and strength (~10% gain in

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maximum voluntary contraction [MVC], 30% gain in 1RM) in young men. The effects of muscular size and strength gains in LST were comparable with those seen in traditional high-intensity (~80% 1RM) resistance training with normal speed (1 second for concentric and eccentric actions, and 1 second for relaxing: HN) (37). The LST exercise movement was configured to achieve continuous force generation throughout the exercise movement. Continuous force generation at > 40% MVC has been shown to suppress both blood inflow to and outflow from the muscle because of an increase in intramuscular pressure (5,19). Therefore, LST training is expected to restrict muscular blood flow during exercise movement. Resistance training regimens with restricted muscular blood flow were considered to induce increases in muscular size and strength likely mediated by the following processes attributable to oxygen insufficiency in muscle: (a) stimulated secretion of growth hormone (GH) by intramuscular accumulation of metabolic byproducts, such as lactate (33); (b) moderate production of reactive oxygen species (ROS) promoting tissue growth (18,35); and (c) additional recruitment of fast-twitch fibers in a hypoxic condition (30,36).

However, our previous study examined only local effects (in knee extensor muscles) in one type of exercise (knee extension) training using LST. We had no information regarding the systemic effects of whole-body resistance training using LST. Single-joint exercises with exercise machines, such as knee extension and biceps curl, are considered more appropriate for LST to place specific muscles under continuous tension throughout the exercise movement than multijoint exercises, such as squat and chest press. Most single-joint exercise machines are designed to maintain almost-constant joint torque at any joint position. Therefore, we adopted knee extension exercise with a knee extension machine for the experimental exercise in our previous study (37). However, a whole-body resistance training program consisting of only single-joint exercises may not be realistic or appropriate. Multijoint exercises usually recruit one or more large muscle area as agonist muscles and some other muscles as coacting muscles, whereas single-joint exercises usually isolate a specific muscle or muscle group. Also, most sport and daily performance movements consist of multijoint movements. The more similar the training activity is to the actual sport and daily performance movements, the greater the likelihood that there will be a positive transfer to these movements (i.e., the specificity concept) (9,24). Therefore, multijoint exercises are considered more important for improving sport and daily performance than single-joint exercise.

In the present study, we investigated systemic effects, including changes in whole-body fat-free mass (FFTM) and percent body fat, of a long-term (13 weeks) whole-body LST training program consisting mainly of multijoint exercises on muscular size and strength. The results show that a whole-body LST training program caused increases in muscular size and strength as effectively as normal high-intensity training.

METHODS

Experimental Approach to the Problem

This study was designed to examine whether a whole-body resistance training regimen with the LST method (using a relatively low-intensity load with slow movement and tonic force generation–3 seconds for concentric and eccentric actions and no relaxing phase), as a training prescription program for the real field, is as effective on muscular hypertrophy and strength gain as resistance training with the HN method (a traditional method using a relatively high-intensity load with normal speed–1 second for concentric and eccentric actions and 1 second for relaxing). After providing informed consent, subjects were assigned to three experimental groups (LST training group, HN training group, and CON [no-training control group], $n = 12$ for each group) for this study. Subjects in the training groups (LST and HN) performed whole-body resistance training regimens consisting of five types of exercise by each resistance training method. Subjects performed each type of exercise with eight-repetition maximum (8RM) intensity. Exercise intensities on LST and HN were adjusted to the 8RM intensity. Mechanical load in LST training was much lower than that in HN training (~55–60% 1RM in LST vs. ~80–90% 1RM in HN).The difference of mechanical load between the two groups with the same 8RM intensities may be attributable to the difference in the type of movement. The training sessions were performed twice a week for 13 weeks.

We compared measurements of acute and chronic changes in LST and HN to investigate the physiological characteristics and evaluate the effects of muscular hypertrophy and strength gain of whole-body resistance training with the LST method. As acute changes in physiological parameters during exercise, we measured electromyographic (EMG) signals, peripheral muscle oxygenation level, blood lactate concentration, and blood pressure. As chronic changes after the training, we measured muscle thickness (MT) and subcutaneous fat thickness (SFT) using B-mode ultrasound, lean soft-tissue mass (LSTM: body mass minus bone mass minus fat mass), fat mass, and bone mineral density (BMD) using dual-energy X-ray absorptiometry (DXA), and 1RM strength in the five types of exercise used in the training regimen. These were measured before and after the training period.

Subjects

Thirty-six healthy young men who did not have experience of regular resistance training volunteered as subjects. The subjects were randomly assigned into three experimental groups ($n = 12$ for each group: LST, HN, and CON, described below), which were matched for physical parameters, such as height, weight, and age (Table 1). All subjects were advised to maintain their usual dietary habits and not to make any intentional changes such as protein

Table 1. Physical characteristics of the subjects.

	LST		HN		CON	
	Pretraining	Posttraining	Pretraining	Posttraining	Pretraining	Posttraining
Age (y)	19.0 ± 0.6		19.5 ± 0.5		19.8 ± 0.7	
Height (cm)	174.1 ± 5.5		174.8 ± 4.3		174.3 ± 7.2	
Body mass (kg)	62.5 ± 4.8	64.1 ± 5.2	63.8 ± 4.0	65.3 ± 4.3	64.2 ± 4.0	64.7 ± 3.9

Values are mean ± *SD*; $n = 12$ for each group.

LST = low-intensity resistance training with slow movement and tonic force generation; HN = high-intensity resistance training with normal speed; CON = sedentary controls.

supplement intake or increasing the amount of intake or number of meals a day, to avoid nutritional influence. All subjects were fully informed about the experimental procedures to be used as well as the purpose of the study, and they gave their written informed consent before participating in the study. The study was approved by the ethics committee for human experiments at the National Institute of Health and Nutrition.

Resistance Training Regimens

The subjects in each training group performed whole-body resistance training regimens consisting of five types of exercise: vertical squat, chest press, latissimus dorsi pull-down, abdominal bend, and back extension. All of these exercises were performed using resistance exercise machines (Cybex Corp. USA for vertical squat; Nautilus Corp. USA for chest press, abdominal bend, and back extension; and Senoh Corp. Japan for latissimus dorsi pull-down); these machine exercises were considered easier to perform than free weight resistance exercises because of balance and coordination recruitment. The subjects performed their whole-body resistance training according to the following training regimens.

The LST group exercised at low intensity (~55–60% of 1RM), with slow movement and tonic force generation (3 seconds for concentric [lifting phase] and eccentric [lowering phase] actions, and no relaxing phase). In the vertical squat, chest press, and latissimus dorsi pull-down, the subjects did not extend their legs or arms fully, to maintain continuous tension in the muscles throughout the exercise movement.

The HN group exercised at high intensity (~80–90% 1RM), with normal speed (1 second for concentric and eccentric actions, and 1 second for relaxing).

The CON group served as the no-training control. The training session consisted of the five types of exercise described above, and each subject performed one warm-up set and three regular sets for each type of exercise, with an interset rest period of 60 seconds. A 3-minute rest period was taken between exercise events. The training session was performed twice a week for 13 weeks. The first 2 weeks were a preparation period, during which the subjects gradually increased the training volume and intensity, and in 2 weeks they reached regular volume and intensity. Subjects in both training groups (LST and HN) repeated the movement at approximately constant speed and frequency with the aid of a metronome. The subjects repeated the movement until exhaustion (repetition maximum [RM]) at each exercise set. The exercise intensity was determined at 8RM for each set but not at % 1RM, because the former method is more commonly used in actual exercise training. The intensity was adjusted in all training sessions based on the record of the previous training session. The intensities used in the LST and HN groups (8RM) in the first set corresponded to about 55–60% 1RM and about 85–90% 1RM, respectively (Table 2). In the HN group, the subjects performed the same RM (8RM) as in the LST group: that is, the same RM-based intensity. The difference in % 1RM intensities between the LST and HN groups may have been attributable to the difference in type of exercise movement. The exercise intensities actually used in both training groups are summarized in Table 2.

Procedures

Acute Changes in Physiological Parameters During Exercise. Electromyographic signals, peripheral muscle oxygenation level, blood lactate concentration, and blood pressure were measured during and after exercise to investigate the characteristics of these trainings. Electromyographic signals were measured to confirm muscle continuous activity in LST, because muscle continuous activity may lead to a decrease in peripheral muscle oxygenation level, and decreases in muscle oxygenation level during exercise movement may lead to increases in blood lactate concentration. Muscle oxygenation, which was the primary measurement element, could be measured only in limb muscles. Of the five types of exercise, only vertical squat limb muscles were mobilized as agonist muscles. Blood pressure was measured from the radial artery with the upper-body muscles kept relaxed. Of the five types of exercise, only vertical squat was performed with the upper-body muscles kept relaxed. Thus, EMG signal, muscle oxygenation, and blood pressure were measured during and after vertical squats, and the results were used as

TABLE 2. One-repetition maximum and exercise intensity during the experimental period.

	Pretraining	LST 7th week	13th week	Pretraining	HN 7th week	13th week	Pretraining	CON 7th week	13th week
Vertical squat									
1RM (kg)	106.5 ± 22.8	122.1 ± 22.9*	136.4 ± 20.5†‡	105.1 ± 16.1	125.2 ± 17.4*	136.5 ± 20.4†§	113.7 ± 16.3		112.9 ± 17.8
Intensity/first set (kg)		70.9 ± 22.8	82.4 ± 8.5		111.3 ± 17.4	121.9 ± 18.8			
% 1RM		59.0 ± 5.8	60.8 ± 5.8		88.7 ± 4.1	89.4 ± 4.2			
Chest press									
1RM (kg)	46.1 ± 10.4	56.1 ± 11.3*	62.0 ± 12.3†‡	41.3 ± 5.4	49.7 ± 8.5*	55.1 ± 9.1†§	46.1 ± 10.0		47.3 ± 11.1
Intensity/first set (kg)		30.8 ± 5.7	35.3 ± 6.3		40.5 ± 6.1	46.9 ± 7.3			
% 1RM		55.3 ± 5.6	57.3 ± 5.9		81.9 ± 5.4	85.2 ± 3.5			
Lat pull-down									
1RM (kg)	42.7 ± 6.7	56.3 ± 7.4*	62.0 ± 8.2†‡	39.6 ± 7.2	50.4 ± 6.9*	55.7 ± 9.0†§	47.7 ± 6.9		48.9 ± 7.3
Intensity/first set (kg)		32.9 ± 3.3	35.3 ± 6.3		41.7 ± 5.8	46.7 ± 7.3			
% 1RM		59.0 ± 5.9	57.3 ± 5.9		82.7 ± 3.9	83.9 ± 4.2			
Abdominal bend									
1RM (kg)	57.8 ± 8.1	74.5 ± 11.9*	82.0 ± 13.7†‡	59.3 ± 8.8	78.5 ± 10.6*	90.4 ± 13.4†§	66.4 ± 7.9		67.1 ± 8.5
Intensity/first set (kg)		40.1 ± 5.2	45.4 ± 5.2		69.8 ± 9.3	79.9 ± 9.8			
% 1RM		54.4 ± 5.6	56.0 ± 6.4		89.0 ± 3.4	88.8 ± 4.7			
Back extension									
1RM (kg)	63.8 ± 6.9	81.7 ± 11.1*	98.4 ± 14.1†‡	61.5 ± 10.0	94.7 ± 20.9*	113.0 ± 13.5†§‖	70.0 ± 16.4		72.4 ± 16.2
Intensity/first set (kg)		48.8 ± 7.9	58.9 ± 9.5		79.5 ± 18.9	96.6 ± 11.9			
% 1RM		59.7 ± 5.1	60.0 ± 6.8		83.7 ± 3.7	85.5 ± 1.7			

Values are mean ± *SD*; $n = 12$ for each group. One-repetition maximum in the 13th week was measured after completion of the 13-week training period (posttraining).

LST = low-intensity resistance training with slow movement and tonic force generation; HN = high-intensity resistance training with normal speed; CON = sedentary controls; 1RM = one-repetition maximum.

*Significant difference ($p < 0.05$) between pretraining and 7th week.

†Significant difference ($p < 0.05$) between 7th week and 13th week.

‡Significant increase from pretraining to 13th week in LST ($p < 0.05$) as compared with CON.

§Significant increase from pretraining to 13th week in HN ($p < 0.05$) as compared with CON.

‖Significant increase from pretraining to 13th week in HN ($p < 0.05$) as compared with LST.

representative for all five types of exercise. Each measurement was taken between weeks 7 and 9, when the participants had become sufficiently accustomed to the training routine.

Electromyographic Recording. Electromyographic signals during squat exercise were recorded from the left vastus lateralis (VL) muscle and long head of the biceps femoris (BF) muscle. Bipolar surface electrodes (Vitrode F; Nihon Kohden Corp., Japan) were placed over the belly of the muscle with a constant interelectrode distance of 30 mm. The EMG signals were amplified, fed into a full-wave rectifier through both low (30 Hz) and high (1 kHz) cut filters, and stored using a data-acquisition system (Power Lab/16SP; AD Instruments, Australia).

Measurement of Peripheral Muscle Oxygenation by a Near-Infrared Continuous-Wave Spectroscopic Monitor. A near-infrared continuous-wave spectroscopic (NIRcws) monitor (BOMLITR; Omegawave, Inc., Japan) was used to measure the peripheral muscle oxygenation in the left VL muscle during and after vertical squat exercise. The wavelengths of emission light were 780, 810, and 830 nm, and the relative concentrations of oxygenated hemoglobin/myoglobin (Oxy-Hb/Mb) in tissues were quantified according to the Beer-Lambert law (7). Because the NIRcws signals registered during exercise do not always reflect the absolute levels of oxygenation, the changes in oxygenation in working skeletal muscles are expressed as values relative to the overall changes in the signal monitored according to the arterial occlusion method (7,14). In the present study, the resting level of Oxy-Hb/Mb was defined as 100% (baseline), and the minimum plateau level of Oxy-Hb/Mb obtained by arterial occlusion was defined as 0%. A pressure cuff was placed around the proximal portion of the thigh and was inflated manually up to 300 mm Hg until the minimum plateau level of Oxy-Hb/Mb was attained (4). The distance between the incident point and the detector was 30 mm. The laser emitter and detector were fixed with tape after shielding with a rubber sheet. The NIRcws signals were stored on a personal computer.

Measurement of Blood Lactate Concentration. Blood samples were collected during the exercise sessions. Samples were collected before and immediately after each type of exercise. Blood samples of approximately 5 μl were taken from the fingertip using a needle and were analyzed immediately for blood lactate concentration using a lactate analyzer (Lactate Pro; Kyoto Primary Science, Japan).

Measurement of Blood Pressure. Blood pressure from the left radial artery was measured continuously during exercise with an arterial tonometry during the vertical squat exercise (JENTOW-7700; Colin, Japan). During measurements, the arm was supported with an adjustable board. To minimize the mechanical effects of the contraction of upper-body muscles and changes in posture, the upper body was kept relaxed and was immobilized on the machine during exercise. Blood pressure signals were stored on a personal computer.

Chronic Effects of Resistance Training. Muscle thickness and SFT using B-mode ultrasound, LSTM (body mass minus bone mass minus fat mass), fat mass, and BMD using DXA, and maximal muscular strength by 1RM test with the five types of exercise used in the training regimen were measured before and after the experimental period to evaluate the chronic effects of these training regimens.

Muscle and Subcutaneous Fat Thickness by B-Mode Ultrasound Imaging. The MT and SFT were measured by B-mode ultrasound (5-MHz scanning head) at six sites from the anterior and posterior surfaces of the body, in principle following the standard method described by Abe et al. (1). The sites were the chest, anterior and posterior upper arm, abdomen, subscapula, and anterior and posterior thigh. Six anatomic landmarks for the sites are noted below.

Chest: At a distance of 8 cm, directly above the mamilla.

Anterior and posterior upper arm: On the anterior and posterior surface, 60% distal between the lateral epicondyle of the humerus and the acromial process of the scapula.

Abdomen: At a distance 2–3 cm to the right of the umbilicus.

Subscapula: At a distance of 5 cm, directly below the inferior angle of the scapula.

Anterior and posterior thigh: On the anterior and posterior surface, midway between the lateral condyle of the femur and the greater trochanter.

Muscle thickness and SFT were scanned using a real-time linear electronic scanner with a 5-MHz scanning head (SSD-500; Aloka, Japan). The scanning head was prepared with water-soluble transmission gel that provided acoustic contact without depression of the skin surface. The scanner was placed perpendicular to the tissue interface at the marked sites.

Whole-Body Composition in Dual-Energy X-Ray Absorptiometry. Lean soft-tissue mass (body mass minus bone mass minus fat mass), fat mass, and BMD were determined for the whole body using DXA (Hologic QDR-4500A scanner; Hologic, USA). Subjects were positioned for whole-body scans according to the manufacturer's protocol. Participants lay in the supine position on the DXA table with the limbs close to the body. Fat-free body mass (FFM) was the sum of LSTM and bone mineral content (BMC). The bone densitometer delivers a very low dose of radiation (1.5 mR for the whole body) using quantitative digital radiography. To minimize interobserver variation, all scans and analyses were carried out by the same investigator, and the day-to-day coefficients of variation (CVs) of the observations were <0.8 whole-body BMD. The whole-body was divided into several regions: arms, legs, trunk, and head. The body compositions were analyzed using manual DXA analysis software (version 11.2.3). The arm region was defined as the region extending from the head of the humerus to the distal tip of the fingers. The reference point between the head of the humerus and the scapula was positioned at the glenoid fossa. The leg region was defined as the region extending from the inferior border of the ischial tuberosity to the distal tip of the toes. The whole body was defined as the region extending from the shoulders to the distal tip of the toes. We selected a reference point that could be visualized clearly on the DXA system terminal.

Measurements of Muscle Strength. Maximal muscular strength was tested with the five types of exercise used in the training regimen: vertical squat, chest press, latissimus dorsi pulldown, abdominal bend, and back extension. Values were obtained for 1RM according to the established guidelines (39). The 1RM strength test using resistance exercise machines was considered better suited to eliminate the influence of coordination recruitment skills than a test using free weights, such as barbells.

In this 1RM test, subjects lifted the load on a resistance exercise machine from a bottom position without preliminary (eccentric) muscle contractions, because preliminary muscle contraction enhances muscle force (41). In this study, 1RM has been underestimated compared with 1RM as tested with preliminary muscle contractions such as free weight bench press and squat lifting after eccentric movement. This means that the exercise loads (% 1RM) used in LST and HN might be overestimated.

Statistical Analyses

All values are expressed as mean ± *SD*. One-way analysis of variance (ANOVA) with a Fisher protected least significant difference test was used to determine the significance of any differences among the initial parameters of the three groups, such as body weight and muscle strength. One-way ANOVA with a Fisher protected least significant difference test was used to examine differences in peripheral muscle oxygenation and blood lactate concentration between groups. Two-way ANOVA with repeated measures (group × period) with the Newman-Keuls method was used to examine differences in changes in MT and SFT, body weight, LSTM, fat mass, percent body fat, BMD, and 1RM among groups. For all statistical tests, $p \le 0.05$ was considered significant.

Power calculations (statistical power) were performed using G*power computer software. Statistical power of >80% was obtained in the main significant changes, such as MT, LSTM, and 1RM strength after the LST and HN training terms. Intraclass correlation coefficient and CV were calculated to examine the test-retest reliability for variables in MT and SFT measured by B-mode ultrasound and 1RM strength test, because these variables may be affected by manual handling technique. Intraclass correlation coefficient and the mean CV value for measurement values by B-mode ultrasound in our laboratory were 0.999 and 3.2%, respectively. Intraclass correlation coefficient and the mean CV value for measurement values of 1RM strength test were 0.995 and 2.8%, respectively.

RESULTS

Acute Effects of Exercises

Typical Examples of Muscle Electric Activity During Exercise. Figure 1 shows typical examples of changes in EMG signals from VL during vertical squat exercise. In LST, the EMG from VL showed almost continuous activity throughout the entire movement. In HN, EMG signals from VL exhibited intermittent activity. Data from two subjects, whose 1RM values were about the same, are shown. The measurements of EMG from VL were made for all subjects in the training groups ($n = 24$). All subjects showed essentially the same patterns.

Peripheral Muscle Oxygenation

Figure 2 shows minimum and maximum oxygenation levels in the left VL during and after vertical squat exercise in

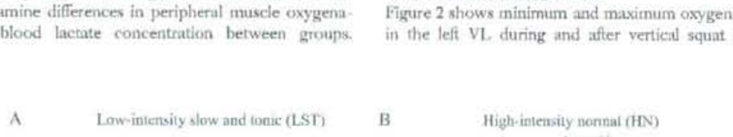

Figure 1. Typical electromyographic (EMG) signals from the vastus lateralis (VL) during vertical squat exercise. The signals were recorded during (A) low-intensity resistance training with slow movement and tonic force generation (LST) with a load of 75 kg (~57% one-repetition maximum [1RM]) and (B) high-intensity resistance training with normal speed (HN) with a load of 102 kg (~89% 1RM) in the vertical squat. Records were from the first to second lifting movements in the first set for LST and from the first to fourth lifting movements for HN. Data from two subjects, whose 1RM strengths were about the same, are shown.

LST and HN. In both LST and HN, the oxygenation level decreased immediately when the exercise repetitions started, and it recovered rapidly and was followed by a hypercompensation after the end of the exercise repetitions. The mean value of minimum oxygenation level during LST vertical squat exercise was significantly lower than that during HN exercise (Figure 2A). The large decrease in muscle oxygenation level during LST exercise was likely attributable to continuous activity of the knee extensor muscles (see Figure 1A). There were no significant differences in the mean values of maximum oxygenation level after LST and HN exercise (Figure 2B).

Blood Lactate Concentration

Figure 3 shows changes in blood lactate concentration measured at rest and immediately after each type of exercise in LST and HN. There were no significant differences in blood lactate concentration at rest between LST and HN groups. Both LST and HN exercise caused marked increases in blood lactate concentration after each type of exercise. No significant differences were observed between blood lactate concentrations after any of the exercise types in LST and HN. Changes in blood lactate concentration during exercise were similar in LST and HN, despite the much lower intensity and smaller amount of work in LST than in HN. The large increase in the concentration of blood lactate (which is an anaerobic energy metabolite) during LST exercise was likely attributable to the lower muscle oxygenation level in LST (see Figure 2A).

Blood Pressure During Exercise

Figure 4 shows peak blood diastolic pressure during LST and HN vertical squat exercise in the first set and at rest. In both LST and HN training groups, the diastolic pressure reached a peak at the last repetition or the second- or third-from-last repetition in the exercise set, and it exhibited significant increases from that at rest. The peak diastolic pressure during HN vertical squat exercise (183.4 ± 33.0 mm Hg) was significantly higher than that during LST exercise (124.4 ± 29.4 mm Hg). Peak blood systolic pressure during vertical exercise exceeded the measurement range of the equipment (300 mm Hg) in some subjects in the HN group. Therefore, we evaluated the elevation of blood pressure during vertical squat exercise with peak blood diastolic pressure during exercise.

Chronic Effects of Resistance Training

Changes in Muscle and Subcutaneous Fat Thickness. Figure 5 shows changes in total MT, defined as the sum of the values for all six measurement sites, in the three groups after the experimental period. There were no significant differences among groups in MT at each measurement site before the experimental period. In both LST and HN groups, MT increased significantly after the experimental period, whereas no such change was observed in the CON group. The percent changes in total MT after the experimental period were +6.8 ± 3.4% in LST, +9.1 ± 4.2% in HN, and +1.3 ± 2.2% in CON. These changes in LST and HN were significantly greater than those in CON, and there were no significant differences between the changes in LST and in HN (Figure 5). In LST and HN, the MT of all measurement sites except the anterior upper arm increased significantly after the experimental period. There were no changes at any of the sites in CON. Increases in MT at all measurement sites (except the anterior upper arm) in LST and in HN were significantly greater than those in CON, and there were no significant differences between the changes in LST and HN

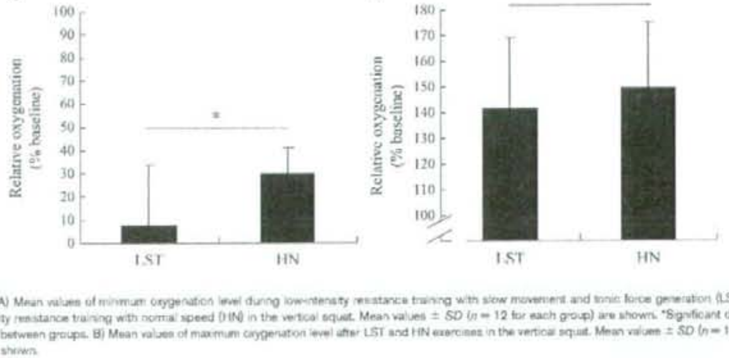

Figure 2. A) Mean values of minimum oxygenation level during low-intensity resistance training with slow movement and tonic force generation (LST) and high-intensity resistance training with normal speed (HN) in the vertical squat. Mean values ± *SD* ($n = 12$ for each group) are shown. *Significant differences ($p < 0.05$) between groups. B) Mean values of maximum oxygenation level after LST and HN exercises in the vertical squat. Mean values ± *SD* ($n = 12$ for each group) are shown.

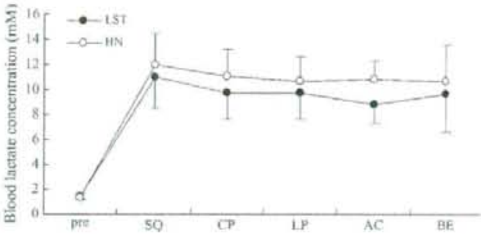

Figure 3. Changes in blood lactate concentrations before and immediately after low-intensity resistance training with slow movement and tonic force generation (LST; ●) and high-intensity resistance training with normal speed (HN; ○). Mean values ± *SD* ($n = 12$ for each group) are shown. SQ = vertical squat; CP = chest press; LP = latissimus dorsi pull-down; BE = back extension.

after the experimental period were −2.1 ± 1.22% in LST, −10.2 ± 9.4% in HN, and +1.5 ± 10.2% in CON. This decrease in HN was significantly greater than those in the LST and CON groups (Figure 6). In HN, SFT in the posterior upper arm was significantly decreased after the experimental period. In LST and CON, the SFT in the subscapula increased significantly after the experimental period. The decrease in HN in the posterior upper arm was significantly greater than that in CON. The SFT decrease in the subscapula was significantly greater in HN than in LST

at any of the measurement sites. The values of MT at each measurement site before and after the experimental period are summarized in Table 3. Figure 6 shows changes in total SFT, defined as the sum of the values for all six measurement sites, in the three groups after the experimental period. No significant differences were observed among groups in SFT at each measurement site before the experimental period. In the HN group, total SFT decreased significantly after the experimental period, whereas there were no such changes in the LST or CON groups. The percent changes in total SFT

and CON. All values of SFT at each measurement site before and after the experimental period are summarized in Table 3.

Changes in Lean Soft-Tissue Mass, Fat Mass, Percent Body Fat, and Bone Mineral Density in Dual-Energy X-Ray Absorptiometry

Table 4 shows all values measured by DXA, such as LSTM, fat mass, percent body fat, and BMD, before and after the experimental period. No significant differences were observed among groups before the experimental period. Whole-body LSTM in all groups, even in the CON group, increased significantly after the experimental period. The

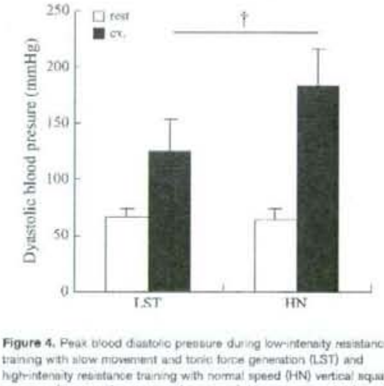

Figure 4. Peak blood diastolic pressure during low-intensity resistance training with slow movement and tonic force generation (LST) and high-intensity resistance training with normal speed (HN) vertical squat exercises (filled bars) and at rest (open bars). Mean values ± *SD* ($n = 12$ for each group) are shown. *Significant differences ($p < 0.05$) between groups. The values for both types of exercise showed significant changes as compared with the resting level ($p < 0.05$).

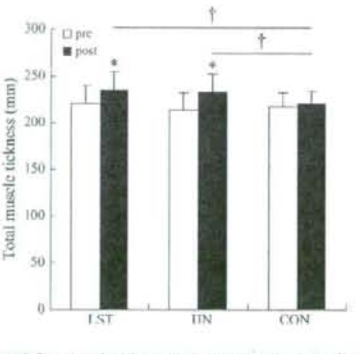

Figure 5. Sum of whole-body muscle thickness of six sites before (open bars) and after (filled bars) the experimental period. Mean values ± *SD* ($n = 12$ for each group) are shown. *Significant differences between pre- and posttraining values ($p < 0.05$). †Significant differences between groups ($p < 0.05$).

TABLE 3. Muscle and subcutaneous fat thickness before and after the experimental period.

	LST		HN		CON	
	Pretraining	Posttraining	Pretraining	Posttraining	Pretraining	Posttraining
Muscle thickness, mm						
Chest	1.75 ± 0.34	2.03 ± 0.41*†	1.67 ± 0.44	2.02 ± 0.51*‡	1.62 ± 0.22	1.64 ± 0.23
Anterior upper arm	2.70 ± 0.21	2.76 ± 0.25	2.53 ± 0.21	2.66 ± 0.22	2.69 ± 0.24	2.70 ± 0.25
Posterior upper arm	2.87 ± 0.38	3.15 ± 0.41*†	2.84 ± 0.49	3.09 ± 0.38*‡	2.95 ± 0.55	2.96 ± 0.55
Abdomen	1.44 ± 0.19	1.56 ± 0.20*†	1.29 ± 0.13	1.45 ± 0.14*‡	1.30 ± 0.23	1.28 ± 0.23
Subscapula	2.42 ± 0.41	2.58 ± 0.47*†	2.31 ± 0.33	2.61 ± 0.44*‡	2.35 ± 0.35	2.23 ± 0.28
Anterior thigh	5.12 ± 0.59	5.45 ± 0.66*†	4.94 ± 0.36	5.49 ± 0.42*‡	5.16 ± 0.55	5.29 ± 0.50
Posterior thigh	5.72 ± 0.52	5.96 ± 0.37*†	5.82 ± 0.45	6.00 ± 0.49*‡	5.69 ± 0.35	5.76 ± 0.38
Subcutaneous fat thickness, mm						
Chest	0.52 ± 0.18	0.50 ± 0.18	0.82 ± 0.51	0.62 ± 0.31	0.67 ± 0.36	0.65 ± 0.34
Anterior upper arm	0.21 ± 0.06	0.22 ± 0.06	0.25 ± 0.07	0.26 ± 0.06	0.22 ± 0.06	0.25 ± 0.07
Posterior upper arm	0.54 ± 0.18	0.52 ± 0.22	0.69 ± 0.17	0.61 ± 0.14*§	0.59 ± 0.15	0.58 ± 0.13
Abdomen	0.85 ± 0.88	0.74 ± 0.70	1.03 ± 0.43	0.90 ± 0.36	1.07 ± 0.65	1.05 ± 0.56
Subscapula	0.57 ± 0.12	0.63 ± 0.15*	0.65 ± 0.16	0.63 ± 0.12‖	0.59 ± 0.13	0.68 ± 0.12*
Anterior thigh	0.50 ± 0.12	0.48 ± 0.19	0.62 ± 0.19	0.55 ± 0.17	0.56 ± 0.11	0.53 ± 0.13
Posterior thigh	0.63 ± 0.27	0.61 ± 0.27	0.71 ± 0.20	0.64 ± 0.15	0.71 ± 0.18	0.69 ± 0.18

Values are mean ± *SD*; $n = 12$ for each group.

LST = low-intensity resistance training with slow movement and tonic force generation; HN = high-intensity resistance training with normal speed; CON = sedentary controls.

*Significant difference ($p < 0.05$) between pretraining and posttraining.

†Significant increase in muscle thickness in LST ($p < 0.05$) as compared with CON.

‡Significant increase in muscle thickness in HN ($p < 0.05$) as compared with CON.

§Significant decrease in subcutaneous fat thickness in HN ($p < 0.05$) as compared with CON.

‖Significant decrease in subcutaneous fat thickness in HN ($p < 0.05$) as compared with LST and CON.

TABLE 4. Body composition in DXA before and after the experimental period.

	LST		HN		CON	
	Pretraining	Posttraining	Pretraining	Posttraining	Pretraining	Posttraining
Whole body						
LSTM (kg)	53.86 ± 3.86	55.23 ± 3.68*†	53.74 ± 3.04	55.57 ± 3.41*‡	54.56 ± 2.71	55.19 ± 2.57*
Fat mass (kg)	8.66 ± 2.75	58.86 ± 3.11	10.08 ± 2.35	9.75 ± 2.20	9.60 ± 2.70	9.55 ± 2.68
% Fat (%)	13.75 ± 3.63	11.68 ± 3.79	15.73 ± 3.21	14.85 ± 2.89*	14.83 ± 3.56	14.63 ± 3.54
BMD ($g \cdot cm^{-3}$)	1.19 ± 0.10	1.10 ± 0.10	1.17 ± 0.10	1.17 ± 0.10	1.21 ± 0.07	1.21 ± 0.07
Arms						
LSTM (kg)	5.35 ± 0.52	5.52 ± 0.59*†	5.10 ± 0.51	5.38 ± 0.51*‡	5.18 ± 0.46	5.24 ± 0.50
Fat mass (kg)	0.84 ± 0.30	0.86 ± 0.28	1.01 ± 0.29	0.99 ± 0.26	0.99 ± 0.34	0.94 ± 0.30
Legs						
LSTM (kg)	17.80 ± 1.45	18.26 ± 1.34*†	17.73 ± 1.43	18.55 ± 1.57*‡	17.91 ± 1.07	18.22 ± 1.35
Fat mass (kg)	3.30 ± 1.17	3.36 ± 1.24	3.96 ± 1.06	3.78 ± 0.86	3.55 ± 1.04	3.52 ± 1.04

Values are mean ± *SD*; $n = 12$ for each group.

DXA = dual-energy X-ray absorptiometry; LST = low-intensity resistance training with slow movement and tonic force generation; HN = high-intensity resistance training with normal speed; CON = sedentary controls; LSTM = lean soft-tissue mass; BMD = bone mass density; % fat = percent body fat.

*Significant difference ($p < 0.05$) between pretraining and posttraining.

†Significant increase in LST ($p < 0.05$) as compared with CON.

‡Significant increase in HN ($p < 0.05$) as compared with CON.

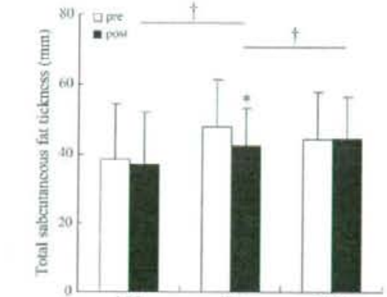

Figure 6. Sum of whole-body subcutaneous fat thickness of six sites before (open bars) and after (filled bars) the experimental period. Mean values ± *SD* ($n = 12$ for each group) are shown. *Significant differences between pre- and posttraining values ($p < 0.05$). †Significant differences between groups ($p < 0.05$).

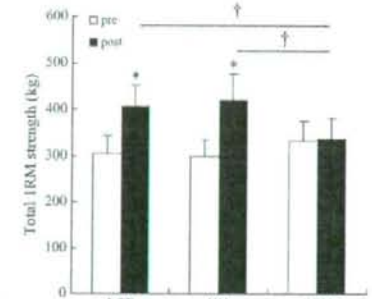

Figure 7. Sum of one-repetition maximum (1RM) strength of five exercises before (open bars) and after (filled bars) the experimental period. Mean values ± *SD* ($n = 12$ for each group) are shown. *Significant differences between pre- and posttraining values ($p < 0.05$). †Significant differences between groups ($p < 0.05$).

absolute changes in LSTM were 1.4 ± 1.4 kg in LST, 1.8 ± 1.3 kg in HN, and 0.6 ± 0.7 kg in CON. These changes in LST and in HN were significantly greater than those in CON, and there were no significant differences between the changes in LST and in HN. The LSTM increase observed in the CON group may have been attributable to weight gain associated with seasonal variations and growth. Whole-body percent body fat in the HN group decreased significantly after the experimental period. This decrease in HN was significantly greater than those in LST and CON, and there were no significant differences between the changes in LST and in CON. No significant changes occurred in body mass, fat mass, or BMD in any of the groups. All values measured by DXA before and after the experimental period are summarized in Table 4. Changes in FFM and fat mass in DXA were similar to those in MTH and SFT as determined by ultrasound imaging. Ultrasound imaging was used for direct assessment in regions involved in training, so ultrasound imaging may have higher detection sensitivity for detecting significant changes than DXA.

Changes in Muscular Strength

Figure 7 shows changes in total 1RM strength, defined as the sum of values for all five types of exercise used in the training regimen, in the three groups after the experimental period. No significant differences were observed among groups in 1RM strength in each type of training before the experimental period. In the LST group and the HN group, total 1RM strength increased significantly after the experimental period (Table 4), whereas there was no such change in the CON group (Figure 7). The percent changes in total 1RM strength were +33.0 ± 8.8% in LST, +41.2 ± 7.8% in HN, and +1.3 ± 2.4% in CON. These increases in LST and in HN after the experimental period were significantly greater than the value in CON, and there were no significant differences between the changes in LST and HN. In both LST and HN, 1RM strength in all five exercises increased significantly after the experimental period. There were no such changes in CON. The increases in LST and HN in 1RM strength in all five types of exercise were significantly larger than the values in CON, and there were no significant differences between the changes in LST and in HN except in back extension. The increase in 1RM strength on back extension in HN was significantly greater than that in LST. The values of 1RM strength in each type of exercise before and after the experimental period are summarized in Table 2.

DISCUSSION

The results of the present study indicate a significant increase in muscular size and concomitant increase in muscular strength after a 13-week whole-body LST training program consisting of the five following exercises: vertical squat, chest press, latissimus dorsi pull-down, abdominal bend, and back extension. The term *LST* refers to a low-intensity (~55–60% 1RM) resistance training program with slow movement and tonic force generation. The gains in muscular size and strength were similar to those after the same whole-body training program using a high-intensity load (~80–90% 1RM) with normal speed (HN). Previously, we reported that a 12-week LST training program with one type of exercise (knee extension) caused significant increases in muscular size and strength to the same degree as HN. This previous study investigated only local effects and provided no information about systemic effects of LST whole-body resistance training.

Single-joint exercises with exercise machines, such as knee extensions, are considered more appropriate for LST to achieve strict continuous force generation throughout the exercise movement than multijoint exercises. However, whole-body resistance training programs usually consist mainly of multijoint exercises. Multijoint exercises usually recruit more large muscle areas than single-joint exercises. In addition, the movements in most multijoint exercises are considered more similar to sport and daily performance movements. The significance of the present study lies in the demonstration that a whole-body LST training program consisting mainly of multijoint exercises, as a prescription program for actual training, was effective for muscular hypertrophy and strength gain as systemic effects.

In the previous study, the increase in muscular size after a 12-week knee extension LST training program tended to be higher than that after HN training. On the other hand, the increase in systemic muscular size after 13 weeks of whole-body LST training mainly consisting of multijoint exercises tended to be lower than that after HN in this study (no significant difference). The difference between the results in these two studies may be related to the fact that knee extension exercise, which is a single-joint exercise, is considered to be better suited for continuous muscle contraction in LST.

Multijoint LST exercise (vertical squat) has the following physiological characteristics: a) continuous muscle activity is kept constant throughout the entire exercise movement (Figure 1A); b) lowered peripheral muscle oxygenation level during exercise (Figure 2A); c) elevated peripheral muscle oxygenation level immediately after exercise (Figure 2B); and d) increased blood lactate concentration (Figure 3). These characteristics in multijoint LST exercise are similar to those of single-joint LST exercise with a knee extension exercise machine examined in the previous study (37). The lowered muscle oxygenation level and increased blood lactate concentration during LST exercise were likely attributable to the restriction of muscular blood flow by continuous muscle activity. It has been speculated that local accumulation of anaerobic energy metabolites, such as lactate, stimulates the hypophyseal secretion of GH (22,33) and the local secretion of growth factors, such as insulin-like growth factor 1 (28). It has also been shown that plasma GH stimulates synthesis and secretion of insulin-like growth factor 1 within muscle, which may then act on the muscle itself and promote growth (8,17). The production of ROS may play an important role in muscular hypertrophy. The activity of ROS within the muscle has been shown to be enhanced in hypoxic environments (20). A considerable amount of ROS could be produced when the muscle is kept hypoxic and subsequently exposed to reperfusion (31). Among the ROS, nitric oxide, which is the strongest vasodilator characterized to date, has also been shown to mediate the activation and proliferation of muscle satellite cells, which are muscle fiber stem cells (3). Therefore, both lowered and elevated muscle oxygenation levels during and after exercise may cause enhanced production of ROS, thereby stimulating muscle growth. Additional recruitment of fast-twitch fibers under a hypoxic condition is likely to mediate muscle hypertrophy (30,36). Almost all of the motor units were considered to be recruited at the final repetition in all sets in LST as well as in HN exercise, because subjects in both HN and LST repeated the movement until exhaustion (27). The physiological characteristics of LST differ significantly from those of HN using a high-intensity load. However, 13 weeks of whole-body resistance training using both LST and HN caused comparable increases in muscular size and strength.

Some recent studies have indicated that low-intensity resistance training combined with moderate vascular occlusion using artificial occlusive pressure causes marked increases in muscular size and strength (2,29,34,36). These studies suggest that large mechanical stress is not indispensable for muscular hypertrophy and strength gain. They also suggest that the muscle-trophic effect of resistance training involves not only large mechanical stress but also metabolic, hormonal, and neuronal factors. However, resistance training with vascular occlusion is so specialized that it should not be widely used without careful monitoring of occlusive pressure and blood flow. Its application is limited to upper-limb and lower-limb muscles, because it can be applied only to distal muscles from occlusive pressure belts. Usually, resistance training combined with moderate vascular occlusion is performed using occlusive pressure belts at the roots of the limbs. This is often associated with pain attributable to artificial occlusive pressure. The LST training, which sustains continuous force generation at >40% MVC to restrict muscle blood flow, would also be effective to make the intramuscular environment hypoxic even without artificial occlusive pressure. This can be applied not only to limb muscles but also to trunk muscles, and it is free from the pain associated with artificial occlusive pressure. Therefore, this represents a good alternative to resistance training with vascular occlusion.

The movement speed of LST in this study (3 seconds for concentric and eccentric actions) was configured so that all subjects could easily maintain continuous force generation throughout the exercise movement. In the exercise movement consisting of 2 seconds for concentric and eccentric actions, it seemed to be difficult for the subjects to maintain constant tension, whereas in the exercise movement consisting of 4 seconds for concentric and eccentric actions, the subjects could maintain constant tension easily, but it was almost impossible for them to perform several repetitions at sufficient intensity (>40% MVC) to restrict muscle blood flow. Thus, the movement speed of LST was determined based on the requirements described below.

1. Continuous force generation could be easily achieved even by beginners without previous experience of resistance training.

2. Continuous force generation throughout the exercise movement with more than 40% MVC load to restrict muscle blood flow.

The prime point of LST is slow movement to achieve tonic force generation, and not to slow movement itself. In this point, LST is different from SuperSlow (10-second lifting and 4-second lowering movement), a registered trademark of Ken Hutchins (42).

Fat mass measured by DXA decreased significantly, although not markedly, after HN training, whereas no significant decrease was observed after LST. Acute increase in plasma catecholamine concentration during exercise may be one of the reasons for fat loss in HN. We also have shown previously that LST and HN leg extension exercise immediately increased plasma norepinephrine concentration. The amount of increase in HN tended to be higher than that in LST (38). Acute increases in plasma catecholamine concentration during and immediately after exercise enhance fat oxidation for energy expenditure (12,25). In addition, the larger amount of mechanical work may cause fat loss in HN. The amount of work in HN was about 1.5 times that in LST.

Bone mass density (see Table 4) and bone mass component (BMC data not shown) were not increased after the experimental period in any groups. This result is perhaps related to the length of the experimental period. It is considered that the experimental period in this study was short, and therefore no changes were observed in BMD or BMC. Bone adapts to high mechanical stress by changing its size and density, and the heavier the magnitude of load, the greater the stimulus for bone growth (40). Thus, BMD and BMC increases from long-term resistance training would be more effective in HN than in LST.

High-intensity resistance training does not necessarily increase the risk of injury. High-intensity resistance training does not cause orthopedic or cardiovascular problems when performed or supervised appropriately (13). However, it has also been reported that approximately 20% of the elderly (aged 70–79 years) showed some symptoms of orthopedic injury after training at 1RM (26). In addition, a marked increase in systolic blood pressure (up to 250 mm Hg) has been reported to occur during high-intensity resistance training (~8RM) for large muscle groups (10). Some studies have reported large numbers of cases in which vascular events, such as aortic dissection, occurred during high-intensity resistance training (15,16). Thus, high-intensity resistance training can increase the risk of injury and vascular events during exercise. Therefore, the development of a resistance training regimen that can cause substantial gains in strength with much lower mechanical stress would be advantageous for the development of safer and effective methods of promoting muscle hypertrophy for a wider range of people, including older people and those with cardiovascular problems.

In conclusion, low-intensity whole-body resistance training with slow movement and tonic force generation consisting mainly of multijoint exercises was as effective for increasing muscular size and strength as high-intensity resistance training. This training method was not associated with the generation of large force or with any considerable elevation of blood pressure. Therefore, it would be useful for promoting muscular hypertrophy and strength increases in a larger population, including the elderly and those at higher risk of cardiovascular adverse events. In this regard, however, LST is anything but easy for subjects to carry out despite the use of a relatively low-intensity load. Subjects repeat movement until exhaustion in LST as in HN.

PRACTICAL APPLICATIONS

The guideline of "load and repetition assignments based on the training goal" based on Fleck and Kraemer's systematic review of resistance training (11) and other studies (39) has been widely used in the field of physical fitness. This guideline recommends resistance training with 6–12 repetitions using a 67–85% 1RM load for muscle hypertrophy. This guideline seems like an appropriate assignment in voluntary movement, but it does not include the concept of enhancing exercise movement variation. When exercise movement is devised to place muscles under continuous tension throughout the exercise movement as in the LST method, resistance training, even with low-intensity loads of less than 65% 1RM, can cause muscular hypertrophy and increase strength. The results of this study indicate that whole-body LST training is an effective method for gaining muscular size and strength in actual training. A regimen of LST training with a relatively low-intensity load can be chosen as a safe resistance training method with relatively low risk for orthopedic injury and cardiac event during exercise. The LST training should be performed with a speed that easily enables continuous force generation throughout the exercise movement. In actual training, LST does not have to be performed with the speed used in this study (3 seconds for concentric and eccentric actions). However, if the movement is too slow (e.g., more than 5 seconds for concentric and eccentric actions), it may be difficult to perform several repetitions at an intensity sufficient to restrict muscle blood (>40% MVC). Also, the mechanical work may not be sufficient to enhance local accumulation of metabolic byproducts such as lactate and proton. We recommend that the movement speed should be as fast as possible within the limits in which continuous force generation can be maintained. We regard tonic force generation rather than slow movement to be the primary point of LST training.

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研究ノート

ボディービルダーの基礎代謝量と身体活動レベルの検討

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Basal Metabolic Rate and Physical Activity Level in Bodybuilders

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We measured the basal metabolic rate (BMR), fat-free mass (FFM) and physical activity level (PAL) of well-trained bodybuilders as typical athletes with muscular development by resistance training in order to examine the standard BMR and PAL ranges for athletes. The subjects were 14 bodybuilders (mean ± SD age : 36.8 ± 9.1 y. ; height : 171.6 ± 6.2 cm ; weight : 77.1 ± 7.6 kg ; FFM : 67.6 ± 6.8 kg) who each trained for an average of 7.5 h per week. BMR was measured by using a Douglas bag, the oxygen and carbon dioxide concentrations were analyzed by mass spectrometry, and FFM was measured by dual X-ray energy absorptiometry. PAL was measured by the doubly labeled water method for 7 subjects selected from the 14 bodybuilders. BMR/FFM was 25.4 ± 2.1 kcal/kg of FFM/day. Total energy expenditure (TEE) was 3,432 ± 634 kcal, and PAL calculated as TEE divided by BMR was 2.00 ± 0.21. The FFM value needs to be considered when evaluating a standard BMR range, and both training and daily physical activity levels should be considered when evaluating a standard PAL range.

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Key words : basal metabolic rate, bodybuilder, physical activity level, fat-free mass

緒　　言

「日本人の食事摂取基準（2005年版）」1)（Dietary Recommended Intake：DRI）では推定エネルギー必要量（Estimated Energy Requirement：EER）を，基礎代謝量（Basal Metabolic Rate：BMR）と身体活動レベル（Physical Activity Level：PAL）を用いて算定している。DRIは健康な個人または集団を対象としており，極端にエネルギー消費量の多いスポーツ選手や高い身体活動量を有する者，傷病者等を含んでいないため，スポーツ選手のEER推定のためには，スポーツ選手の基礎代謝基準値及びPALの値の設定が必要となる。そのため，国立スポーツ科学センター（Japan Institute of Sports Science：JISS）は，日本人スポーツ選手を対象とした基準値策定に関するプロジェクトを立ち上げ，スポーツ選手を対象としたBMRとPALについて報告した2,3)。

BMRについては，JISSのプロジェクトではDRIに示されている基礎代謝基準値と日本人の一般的な体格から除脂肪量（Fat Free Mass：FFM）あたりのBMR（BMR/FFM）を28.5 % kcal/kgFFM/dayと設定した。これは，これまでの報告においてボート選手及びランナーと非運動群の間でFFMあたりのBMRに差が見られず，運動習慣や運動種目による差がなかったという研究報告4)を根拠としたものである。一方で，Weinsier, R. L.ら5)はBMRとFFMを測定した文献をレビューし，FFMの大きく異なる対象ではBMR/FFMが小さくなることを報告している。FFMが異なる対象でFFMあたりのBMRが異なる理由として，FFMに含まれる組織中の代謝率の高い組織と低い組織の割合の影響があると言われている5～8)。JISSが設定したBMR/FFMの値は，一般人の値からの推定値であり，一定のBMR/FFMの値が各種スポーツ選手に適用可能かについては，各種のスポーツ選手について実測したBMRの値のデータを収集したうえで，検討する必要が

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ある。そこで，本研究の第一の目的として，FFMの多い選手としてボディービルダーを対象にBMRの測定を行い，スポーツ選手における基礎代謝基準値について検討することとした。なお，BMRは，生命維持に必要な生理化学的反応を行うための覚醒安静時の最小エネルギーと定義され，実際には食後12時間以上経過した早朝空腹時に仰臥安静・覚醒状態で適正な室温において測定される[9,10]。しかし，食事摂取基準における基礎代謝基準値の算定根拠となったデータは，宿泊して起床後すぐに測定したデータと，測定当日に測定室に来室し30分程度の仰臥安静後，測定されたデータが混在している。そこで本研究においては，BMRを測定当日に測定場所へ来所した後移動し30分の仰臥安静後に空腹状態で測定した。また，引用する文献についても測定日の宿泊の有無を問わず，早朝空腹時に十分な安静後に測定した値をすべてBMRとして比較することとした。

PALについては，DRIでは二重標識水（Doubly Labeled Water：DLW）法を用いて測定したエネルギー消費量の測定値に基づいて，3段階に分類されている[1]。スポーツ選手のPALの設定にあたって，JISSのプロジェクトはスポーツ選手を対象とした先行研究におけるPALの値を基に，持久系，瞬発系，球技系，その他の種目カテゴリー別にオフトレーニング期と通常トレーニング期の期ごとにPALの値を示した[2,3]。瞬発系，球技系についてはスポーツ選手の値の平均値，持久系ではトレーニング時間が長いことと，体重が比較的軽い選手が多いことから既存研究のデータの上限値が採用されている。これまで測定されている選手のデータは，まだ限られた種目であり，特に日本人選手を対象としたものは少ない。そこで本研究の第二の目的として，レジスタンストレーニングを主として実施しているボディービルダーについてDLW法を使用してPALを測定し，スポーツ選手における身体活動レベルについて検討することとした。本研究で対象としたボディービルダーは，筋力の高度な発達を目的として，ほぼ毎日レジスタンストレーニングを実施している。トレーニング内容は他競技が筋力向上のために行っている内容とほぼ同じであるが，練習時間は他種目に比べ比較的短い対象である。

方　　法

1．対象

対象者は，22～55歳の健康な成人男性で，週3～5回のトレーニングを行い，定期的に大会に参加しているボディービルダー14名である。全員，日本ボディービルディング連盟において薬物の使用がないことが確認されている。トレーニング量は週に平均4.6 ± 0.9回，1回のトレーニング時間は平均99 ± 21分で，週あたりの平均トレーニング時間は7.5 ± 2.4時間であった。測定期間は冬季であり，通常のトレーニング期であった。調査期間中は，できるだけ体重変動のない生活をするように指示し，それ以外は，通常の食事，トレーニングをするように指示した。

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2．測定項目

(1) 身体組成

身長及び体重は早朝空腹時に測定した。体脂肪率及びFFMはDXA法（Dual Energy X-ray Absorptiometry）（QDR－4500, Hologic, USA）により測定した。

(2) 基礎代謝量（BMR）

被験者は測定前夜の午後9時までに通常通りの夕食を済ませ，測定当日に朝食をとらずに測定場所に到着した後，9時から23～25℃の快適な室温で30分以上仰臥させた。測定場所への移動はできるだけ静かに行うように指示したが，移動による活動量は把握しなかった。その後，仰臥位のまま10分間の呼気を1分の間隔を置いてダグラスバッグに2回採集した。呼気は直ちに質量分析計（ARCO－1000，アルコシステム，千葉）を用いて酸素及び二酸化炭素量の濃度を分析した。その後，乾式ガスメーター（DC－5，シナガワ，東京）にて呼気量を測定した。それらの測定値から酸素摂取量（VO_2）と二酸化炭素排出量（VCO_2）を算出し，Weir[11]の式により1分あたりのBMRを求めた。さらに1,440（分）に換算し，1日あたりのBMR（kcal/day）とした。BMRは体重（Body Weight：BW）あたり（kcal/kg BW/day）及びFFMあたり（kcal/kg FFM /day）でも算出した。

(3) 身体活動レベル（PAL）の測定

対象者のうち7名について，DLW法を用いて総エネルギー消費量（Total Energy Expenditure：TEE）を測定し，それをBMRで除してPALを算出した。DLW法は，現時点では自由生活下での身体活動量を最も精度が高く評価できる方法とされており，ヒューマンカロリーメータとの比較により検討した正確度は約±4％とされている[12]。

10％^{18}O（太陽日酸，東京）と99.9％^{2}H（Cambridge Isotope Laboratories, Inc., USA）を混合した液により，体重あたり0.14gの^{18}Oと0.06gの^{2}Hを投与した。投与前，投与後4及び5時間後，翌日（2回）と8日後（2

Table 1 Physical characteristics and basal metabolic rate among body builders

	N	Age (yr.)	Height (cm)	BW (kg)	FFM (kg)	BMR (kcal)	BMR/BW (kcal/kg)	BMR/FFM (kcal/kg)
20－29yrs	3	24.0 ± 3.5	172.3 ± 7.6	80.0 ± 11.5	70.7 ± 11.0	1,843 ± 264	23.0 ± 0.4	26.1 ± 1.2
30－39yrs	5	35.6 ± 2.6	174.8 ± 4.6	80.2 ± 6.3	69.4 ± 5.1	1,722 ± 198	21.5 ± 1.9	24.8 ± 2.1
40－49yrs	5	41.8 ± 2.5	169.5 ± 6.4	72.6 ± 6.4	65.0 ± 6.0	1,590 ± 171	21.9 ± 1.4	24.5 ± 1.7
50－59yrs	1	56	164.3	75.4	62.7	1,873	24.8	29.9
Total	14	36.8 ± 9.1	171.6 ± 6.2	77.1 ± 7.6	67.6 ± 6.8	1,712 ± 209	22.2 ± 1.6	25.4 ± 2.1

BW：body weight, FFM：fat free mass assessed by dual energy X-ray absorptiometry, BMR：basal metabolic rate per day

回）の同時刻に採尿した。サンプルは密閉した状態で，分析まで－30 ℃で保存した。^{2}H は Pt を触媒として H$_2$ ガスで，^{18}O は CO$_2$ ガスで平衡法により前処理を行った後，^{2}H，^{18}O の安定同位体比を質量比分析計（Finnigan Delta Plus，Thermo Fisher Scientific，USA）により分析した。分析の測定誤差は，^{2}H で 0.5 ‰，^{18}O で 0.03 ‰である。また，10 名のサンプルを 2 回分析した際の誤差は，1.6 ± 3.9 %であった。

身体水分量（Total Body Water：TBW）は投与後 4 及び 5 時間後の尿中の安定同位体濃度から，N=［WA（δa－δt)］/［18.02a（δs－δb)］の式により求めた。ただし，N は ^{2}H 及び ^{18}O の希釈容積（mol），W は同位体比分析の際に DLW を希釈するのに用いた飲料水の量（g），A は投与した DLW の量（g），δa は希釈した DLW における同位体比，δt は DLW の希釈に用いた飲料水の同位体比，a は同位体比分析の際に飲料水で希釈された DLW の量（g），δs は尿中の同位体比，δb はベースラインでの尿の同位体比である。TBW は，^{2}H の N を 1.041 で除したものと，^{18}O の N を 1.007 で除したものの平均値とした。

測定期間中の安定同位体の減衰率を k=［ln（δf－δb）－ln（δi－δb)］/t から求めた。δf は 8 日後の尿中の同位体比，δb はベースライン尿の同位体比，δi は投与翌日の同位体比，t は測定期間である。二酸化炭素の排出量は，rCO$_2$（mol/day）=0.4554TBW（1.007ko－1.041kh）により求めた。ko は ^{18}O の減衰率，kh は ^{2}H の減衰率である。DLW 法においては，全期間を通じた呼吸商（Respiratory Quotient：RQ）の直接測定が不可能なため，体重変動のないエネルギーバランスのとれた状態では食事調査より求めた食物商（Food Quotient：FQ）13) を使用して，TEE を求めることが最も適切とされている 14)。そこで，TEE は DLW 法による身体活動量の調査期間中の食事調査より求めた FQ を用いて，Weir11) の式により求めた。

(4) 食事調査

PAL の測定を行った 7 名については，測定期間中に 3 日間の食事記録法により食事調査を行った。食事の記録内容は，調査終了後に管理栄養士が面接により確認した。摂取栄養素量は，エクセル栄養君 ver.4.0（建帛社，東京）により計算した。補助食品については，各メーカーの資料により栄養素量を求め，追加した。

(5) 統計処理

すべてのデータは，平均値と標準偏差（mean ± SD）で表した。本研究で得られた各指標の統計処理は，SPSS13.0 J for Windows（SPSS Inc., USA）にて行った。

結　　果

1．基礎代謝量（BMR）

14 名のボディービルダーの身体特性及び BMR を Table 1 に示した。全対象における 1 日あたりの BMR は，1 日あたりでは 1,712 ± 209kcal/day，BW 1 kg あたりでは 22.2 ± 1.6kcal/kg/day，FFM あたりでは 25.4 ± 2.1kcal/kgFFM/day であった。年代別に分けると，各年代の人数は少ないものの，身体特性，BMR とも一定した傾向は認められなかった。

2．身体活動レベル（PAL）

ボディービルダー 7 名の身体特性，BMR，TEE，PAL，歩数及び 1 週間あたりのトレーニング時間（分）を Table 2 に示した。DLW 法で測定した 1 日の TEE は，3,432 ± 634kcal/day であった。TEE と BMR から計算した PAL は，2.00 ± 0.21 であった。また，総エネルギー摂取量（Total Energy Intake：TEI）は 1 日あたりでは 3,268 ± 663kcal/day，体重あたりでは 43.3 ± 6.8kcal/kg/day であった。タンパク質，脂質，炭水化物の摂取量は，161 ± 55g，79 ± 25g，429 ± 130g，FQ は 0.923 であった。TEI と BMR から求めた TEI/BMR は 1.93 ± 0.24 であった。

考　　察

本研究で，高度にトレーニングされたボディービルダー男性の BMR を測定したところ，BMR/FFM は 25.4 ± 2.1kcal/kgFFM/day であり，JISS が設定した値（28.5kcal/kgFFM/day）2, 3) より低いことをみとめた。また，週に約 8 時間のトレーニングを行っているボデ

Table 2　Physical characteristics, basal metabolic rate, and physical activity level among body builders

ID	Age (yr.)	Height (cm)	BW-pre (kg)	BW-post (kg)	BW-change (kg)	FFM (kg)	BMR (kcal)	BMR/FFM (kcal/kg)	TEE (kcal)	PAL	Walk steps (steps/day)	Time (min)	TEI (kcal)
02	41	166.0	78.2	80.1	+1.8	69.9	1,845	26.4	4,191	2.20	10,870 ± 3,190	73	4,373
03	37	173.6	75.9	73.2	−1.7	63.8	1,741	27.3	3,884	2.23	13,903 ± 5,202	62	3,359
05	46	166.5	61.5	61.1	−0.3	55.2	1,385	25.1	2,421	1.81	12,759 ± 2,897	55	2,396
06	56	164.3	75.5	77.2	+1.7	62.7	1,873	29.9	3,228	1.78	5,374 ± 2,663	55	3,350
07	33	174.3	76.2	75.1	−1.1	65.5	1,555	23.7	2,965	1.81	−[a]	−[a]	2,533
09	42	163.4	73.7	72.6	−1.1	63.3	1,610	25.4	3,324	1.95	12,949 ± 3,016	46	3,280
11	39	181.6	90.0	89.1	−0.9	74.0	1,800	24.3	4,015	2.23	11,663 ± 2,655	34	3,587

BW : body weight, FFM : fat free mass assessed by dual energy X-ray absorptiometry, BMR : basal metabolic rate per day, TEE : total energy expenditure measured by doubly labeled water method, PAL : physical activity level calculated as TEE divided by BMR, Walk steps : mean value during TEE measurement assessed by accelerometer, Time : mean training time (minutes) per day during TEE measurement, TEI : total energy intake estimated by 3-day food records

[a] Values could not be assessed.

ィービルダーのPALは約2.0であった。

今回の結果では，FFM67.6kgのボディービルダーのBMR/FFMは25.4kcal/kgFFM/dayとなった。この値は，JISSが示した28.5kcal/kgFFM/day[2, 3]や，先行研究におけるウォーキングまたはローイングをしているスポーツ愛好者男性（FFM52kg）28.5kcal/kgFFM/day[15]，水泳選手（FFM69kg）29.5kcal/kgFFM/day[16]，柔道選手（FFM67.1kg）28.1kcal/kgFFM/day[16]，空手選手（FFM64.5kg）28.2kcal/kgFFM/day[16]よりも，小さい値であった。FFMが35～45kgの者を対象とした研究[4, 15, 17]のBMR/FFMは，30～31kcal/kgFFM/dayと高い値が報告されていた。しかしながら，これらの先行研究では，FFMの測定法がBOD POD（空気置換法）[4, 15]，DXA法[16, 17]，水中体重法[17]と異なっている。また，BMRの測定条件や方法も，前日より宿泊してダグラスバッグにより測定したもの[4, 15]，当日来所しフードを使用したもの[16]，当日あるいは前日に移動しフードを使用したもの[17]と様々であり，単純な比較は困難である。本研究と同じFFM，BMRの測定法による先行研究はなく，測定法による一定の傾向もみられなかった。

Weinsier, R. L. ら[5]のレビューによると，FFMが大きい対象においてBMR/FFMが小さくなることが指摘されている。その理由は，FFMが大きくなるとFFM中で安静時の代謝活性の低い筋組織の割合が安静時の代謝活性の高い内臓組織よりも大きくなるからであると指摘されている[5～8]。ボディービルディングでは，筋肉を高度にトレーニングしている。そのため，FFM中の筋肉の割合が非運動者や他の種目に比べて大きいことが推測され，FFMあたりの代謝率に影響する可能性は高い。一方で，Bosselares, I. ら[18]はヒューマンカロリーメータを使用して，ボディービルダーと非運動者の睡眠時代謝を比較し，年齢，FFM，体脂肪量（FM）で調整した睡眠時代謝には差がないとしている。また，Midorikawaら[19]は水中体重法によりFFMを，MRIにより内臓の重量を測定し，肝臓と腎臓のFFMに占める割合は，運動群と非運動群でほぼ同じであり，FFMが大きくなってもその比率は減少しないという結果を得ている。脳・肝臓・心臓・腎臓の4器官は重量は体重の約6％しか占めないが，安静時の代謝量は約58％を占めており，そのうちでも肝臓と腎臓の代謝量は特に大きい[8]。しかし，FFMの量がBMRの違いに大きく影響していることは否定できず，選手の基礎代謝基準値としてBMR/BWよりもBMR/FFMを使用することは適切と考えられる。一方で，すべての選手に同一の値を使用できるかについては，今後，各種スポーツ選手について一定の方法でBMRとFFMを測定し，種目や体格などを考慮した基礎代謝基準値の設定が必要となるであろう。

TEEについては，齊藤らのレビュー[12]によると，スポーツ選手のPALは大学生女子水泳選手の1.71からツールドフランスのレース中の者の4.95となっている。日常的なトレーニングを行っていたスポーツ選手に限定すると，PALが2.2以内に75％の選手が分布する[20]。これまでに測定されたスポーツ選手のTEEに関する調査結果の平均値は2.03となったと報告されている[20]。本研究では7名のボディービルダーに対しDLW法による測定を行い，PALを算出したところ，2.00 ± 0.21となり，これらの報告とほぼ一致した。しかし，個人差は大きく1.78～2.23とばらついていた。この個人差の要因の1つは，個別のトレーニング内容には大きな差がないことから，1日あたりトレーニング時間が34～73分と倍以上の違いがあることによると推測される。しかしながら，Phillips, W. T. ら[21]の報告よりレジ

スタンストレーニング中の身体活動強度を3.9METs，運動時以外の平均を1.5METsとすると，30分のトレーニング時間の違いによるPALの差は（3.9－1.5）×30/1,440＝0.05となり，個人差を説明できるものではない。DLW法は自由生活下でのTEEを最も正確に評価できる方法とされているが，1～2週間の測定期間の1日の平均のTEEでしか評価できないという欠点がある。PALが2以上であった3名は，トレーニング指導員（2名）と技能職で仕事中も立位と歩行が多い作業であり，歩数も多い。一方で，最もPALの低い1名は歩数が少なく，仕事はほとんど座業でありトレーニング以外の身体活動量が極めて低かったことが推測される。ボディービルダーは特にトレーニング時間が短いが，それ以外のスポーツ選手でも合宿中などを除くと，トレーニング時間は限られている。トレーニング時間以外の生活における身体活動量による個人差を考慮しながら，どのように各種目のスポーツ選手の1日のPALを評価するか，今後，評価方法や基準となるPALの設定方法なども検討が必要であると考える。

以上より，スポーツ選手のBMRを測定した既存の資料では，FFM，BMRとも測定条件，方法などが異なり比較は困難であるが，今後，スポーツ選手の基礎代謝基準値の設定においては，種目や体格を考慮して示す必要があると考えられた。また，レジスタンストレーニングを主とするボディービルダーのPALは2.00±0.21であったが，個人差が大きく，スポーツ選手のPALの評価においては，トレーニング時間や内容の評価とそれ以外の時間の身体活動をどのように組み合わせて設定していくかが課題であると考えられた。

ま　と　め

22～55歳の高度にトレーニングを積んでいるボディービルダー14名を対象にBMR，FFM，PALを測定し，スポーツ選手のBMRとPALの基準値について検討した。

1）ボディービルダーの1日あたりのBMRは1,712±209kcal/dayであった。BMR/FFMは25.4±2.1kcal/kgFFM/dayであり，先行研究に比べると小さい傾向にあった。スポーツ選手の基礎代謝基準値の設定においては，その測定方法・条件を統一するとともに，種目や体格をどのように考慮するかを検討する必要があると考えられた。

2）DLW法で求めたボディービルダーの1日のTEEは3,432±634kcalで，PALは2.00±0.21であった。PALには個人差が大きく，PALの設定においては，トレーニング内容や時間の考慮だけでなく，それ以外の時間の身体活動量をどのように評価するか検討する必要があると考えられた。

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Reducing waist circumference by at least 3 cm is recommended for improving metabolic syndrome in obese Japanese men

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ABSTRACT

Objective: We investigated the link between a reduction in waist circumference and metabolic syndrome.

Methods: 105 obese Japanese men were enrolled in this study with a 1-year follow-up. Anthropometric and body composition parameters, *i.e.* height, body weight, body fat percentage, waist circumference and hip circumference, blood pressure, triglyceride, HDL cholesterol and blood sugar, were evaluated. Metabolic syndrome was diagnosed using criteria developed in Japan.

Results: After a 1-year follow-up, the parameters of metabolic syndrome were significantly improved. The prevalence of metabolic syndrome was significantly reduced in subjects with at least 3 cm of waist circumference reduction (Group R). However, in subjects without such reduction (Group C), the prevalence of metabolic syndrome was similar to baseline levels. The prevalence of abdominal obesity, hypertension and dyslipidemia was also significantly reduced in Group R. In addition, there were remarkable differences of delta triglyceride (delta represents positive changes in parameters) and delta HDL cholesterol between Group R and Group C.

Conclusion: At least 3 cm of waist circumference reduction may be beneficial for improving metabolic syndrome in obese Japanese men.

1. Introduction

Metabolic syndrome is a common public health challenge in Japan. We previously reported that 30.7% of men and 3.6% of women were diagnosed as having metabolic syndrome [1]. In addition, metabolic syndrome induces coronary heart disease [2], proteinuria [3] and elevation of hepatic enzymes [4]. The work of Reaven [5] is convincing in showing that visceral fat accumulation is a critical pathogenesis of metabolic syndrome.

In 2006, the Japan society for the study of obesity recommended a 3 cm reduction in waist circumference and 3 kg of body weight for preventing and improving metabolic syndrome (http://wwwsoc.nii.ac.jp/jasso/index.html, accessed on Mar 5, 2007). A reduction in waist size is one important approach to prevent and improve metabolic syndrome. However, whether at least a 3 cm reduction is beneficial for improving metabolic syndrome and what effects this will have on metabolic remain to be investigated.

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