resistance exercise at relative intensities were lower in middle-aged than in young men, suggesting that the BP response to dynamic resistance exercise may be attenuated with advancing age despite age-associated arterial stiffening.

From the relative intensities, it is reasonable to hypothesize that the attenuated BP response to resistance exercise in middle-aged men may be induced by the age-related reduction in maximal muscular strength, because of the exercise intensity-associated increase in BP response to resistance exercise in both groups. In the present study, the 1RM estimated by the leg press exercise was lower in middle-aged than in young men, suggesting that the absolute intensities during exercise at individual relative intensities were lower in the former than in the latter. Accordingly, we determined BP response during the dynamic leg press exercise at individual absolute intensity (145 kgw) in the middle-aged and young men. The results indicated that the amount of change in BP response to resistance exercise was lower in middle-aged than in young men. These results suggest that age-associated reduction in muscle strength did not contribute to the attenuated pressor response to dynamic resistance exercise in middle-aged as compared with young men.

It is unclear what physiological mechanisms explain the attenuated BP responses during dynamic resistance exercise using large muscle groups in middle-aged as compared with young men. However, we speculate that the mechanism may be as follows. In middle-aged men, the muscle sympathetic nerve activity is higher at rest than in young men (*16*), whereas during exercise it is lower in the former than the latter (*16*). This results in attenuation of the increases in cardiac output and peripheral vasoconstriction induced by sympathoexcitation during exercise with advancing age (*34–36*). The ratio of high-glycolytic muscle fiber type II in skeletal muscle falls from 59% to 48% between the third and sixth decades of life (*37*), and the transformation to oxidative skeletal muscle fibers results in a lower pressor response evoked by static contraction as compared with glycolytic fibers (*38*). Therefore, alterations in sympathetic nerve activity and/or skeletal muscle fiber type with advancing age may contribute to the attenuated BP response to resistance exercise in middle-aged as compared with young men.

Sarcopenia and osteoporosis with advancing age are social problems in developed countries with aging populations. The leg press exercise used in this study, as a form of dynamic resistance exercise using predominantly the lower body, is widely accepted in exercise prescription for the prevention and rehabilitation of sarcopenia and osteoporosis, which can lead to falls and femur bone fracture, and may even result in patients becoming bedridden. However, BP rises rapidly and remarkably during high-intensity leg press exercise (*10*). Indeed, it has been reported the accidents, such as artery dissociation and subarachnoid hemorrhage, occur during resistance exercise (*39–42*). Therefore, care should be taken regarding the rapid and marked increases in BP response to resistance exercise, particularly in middle-aged and older men. In contrast to our expectations, the results of the present study indicated that pressor responses during dynamic resistance exercise at individual relative and absolute intensities were not higher in middle-aged men with stiffening arteries than in young men with compliant arteries. These results may contribute to our understanding of the cardiovascular responses to resistance exercise at appropriate intensities recommended by the major health organizations in middle-aged men who have developed arterial stiffening.

As it is the simplest parameter of arterial buffering function, pulse pressure was evaluated along with systolic and diastolic BP responses to resistance exercise in the present study. The results indicated that the amounts of change in pulse pressure response to resistance exercise at either relative or absolute intensities were lower in middle-aged men than in young men despite age-related increases in arterial stiffness. The attenuation of pulse pressure response to resistance exercise with advancing age may be affected by systolic function in the left ventricle. Of course, this function is greater in young than in middle-aged men during exercise as well as at rest. Thus, lower pulse pressure response to resistance exercise in middle-aged men may be appropriate. Pulse pressure at rest was also lower in middle-aged than in young men. As pulse pressure at rest increases progressively in normotensive subjects from the fifth decade (*43*), further studies are needed to determine BP response to resistance exercise in older men with augmented pulse pressure.

The present study had several limitations. Although there have been several reports on BP responses to isometric or aerobic exercise, we did not attempt to compare the BP responses to isometric resistance or aerobic exercise with those to dynamic resistance exercise. Compared to isometric or aerobic exercise, dynamic resistance exercise is more often used for health promotion, strength conditioning and prevention of sarcopenia or osteoporosis in middle-aged and older individuals. Therefore, as a primary approach, it was necessary to clarify the differences in BP response to dynamic resistance training using large muscle groups between young and middle-aged men. Although increases in central arterial BP during exercise may be more important than those in peripheral arterial BP from the standpoint of cardioprotection, we performed noninvasive assessment of only the radial arterial BP response to resistance exercise. Therefore, the results of the present study must be confirmed in future prospective studies focusing on central arterial BP responses to resistance exercise. Finally, the muscular strength maximum was evaluated with a leg press machine using air pressure. The value of muscular strength assessed by this machine may be different from that of muscular strength evaluated using real weights. Although the muscular strength maximum of subjects in the present study was relatively high, our results may not have been affected by this difference.

In conclusion, this study demonstrated that, at either individual relative or absolute intensity, the BP response during dynamic resistance exercise using large muscle groups was attenuated in middle-aged men as compared with young men despite age-related stiffening of the arteries. These findings may contribute to our understanding of the BP response during dynamic resistance exercise and aid in the safe performance of exercise prescription for prevention and rehabilitation of sarcopenia and osteoporosis in middle-aged and older men.

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Research article

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Required muscle mass for preventing lifestyle-related diseases in Japanese women

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Abstract

Background: Since it is essential to maintain a high level of cardiorespiratory fitness to prevent life-style related disease, the Ministry of Health, Labour and Welfare of Japan in 2006 proposed to determine the maximal oxygen uptake (Vo_2max: $mL \cdot kg^{-1} \cdot min^{-1}$) reference values to prevent life-style related diseases (LSRD). Since muscle mass is one of the determinant factors of Vo_2max, it could be used as the reference parameter for preventing LSRD. The aim of this study was to determine and quantify the muscle mass required to maintain the Vo_2max reference values in Japanese women.

Methods: A total of 403 Japanese women aged 20–69 years were randomly allocated to either a validation or a cross-validation group. In the validation group, a multiple regression equation, which used a set of age and the percentage of muscle mass (%MM, percentage of appendicular lean soft tissue mass to body weight), as independent variables, was derived to estimate the Vo_2max. After the equation was cross-validated, data from the two groups were pooled together to establish the final equation. The required %MM for each subject was recalculated by substituting the Vo_2max reference values and her age in the final equation.

Results: The mean value of required %MM was identified as (28.5 ± 0.35%). Thus, the present study proposed the required muscle mass (28.5% per body weight) in Japanese women to maintain the Vo_2max reference values determined by the Japanese Ministry of Health Labour and Welfare.

Conclusion: The estimated required %MM (28.5% per body weight) can be used as one of the reference parameters of fitness level in Japanese women.

Background

Previous epidemiologic and clinical evidence indicate that a poor cardiorespiratory fitness is a major risk factor for life-style related diseases (LSRD) such as obesity, hypertension, hypercholesterolaemia, arteriosclerosis and diabetes [1-4]. Moreover, low cardiorespiratory fitness has been found to be a predictor of cardiovascular disease (CVD) mortality, and all-cause mortality [5-8]. Thus, it is essential to maintain a high level of cardiorespiratory fitness to prevent LSRD.

Cardiovascular fitness is usually evaluated as the maximal oxygen uptake per body mass (Vo_2max, mL · kg^{-1} · min^{-1}). The Japanese Ministry of Health Labour and Welfare in 2006 proposed Vo_2max reference values for each age group to prevent LSRD [9]. These Vo_2max reference values were determined by the "Committee for the Determination of the Recommended Exercise Allowance and Exercise Guide" established in August 2005, and were referenced in the "Exercise and Physical Activity Reference Quantity for Health Promotion 2006 (EPAR2006)". Originally, the "Recommended Quantity of Exercise for Health Promotion (1989)" had been formulated to mainly target the prevention of coronary artery disease. With the passage of more than 15 years following the establishment of this standard, the morbidity pattern of people has worsened and LSRD have increased in prevalence. In order to face this situation, the EPAR2006 was made based on the latest scientific evidence, and was designed to maintain and promote the health of people and prevent LSRD by improving their capacity for physical activity and exercise. These Vo_2max reference values proposed in the EPAR2006 were determined by experts through the systematic review of literature regarding the relationship between Vo_2max and LSRD such as obesity, hypertension, hypercholesterolemia, diabetes, cerebrovascular disease, CVD mortality and all-cause mortality.

It is well known that Vo_2max decreases with age [10-20]. It has been suggested that the age-related decline in Vo_2max is a consequence of attenuation of central and peripheral functions such as stroke volume, heart rate max (HR_{max}), peripheral O_2 extraction, and lean body mass (LBM) or muscle mass [19,21-25]. Among these determinants, reductions in HR_{max} and LBM or muscle mass have been suggested to be primary factors [26,27]. While many studies on cardiovascular fitness have focused on cardiac measurements, it should be emphasized that muscle mass is one of the critical determinants of Vo_2max [13,14,19,24,26,28-30] since the amount of tissue available to extract oxygen during maximal exercise, i.e., muscle, can directly contribute to the value of Vo_2max. For example, Sanada et al. reported the MRI-measured lower body skeletal muscle mass was closely associated to the absolute Vo_2max during running [28,30]. Additionally, the age-related decrement in Vo_2max can be related to the age-associated muscle loss [24,19]. Further, it is important to notice that LBM or muscle mass can be maintained to some degree by exercise training, while such training cannot prevent age-related declines in HR_{max}, [26,27].

Therefore, we hypothesized that a certain level of muscle mass required to maintain sufficient cardiovascular fitness is present and that it could be a limiting factor of age-related Vo_2max attenuation. Based on this hypothesis, it is advantageous to Japanese women's health to propose such muscle mass required to maintain sufficient Vo_2max. Thus, the purpose of this study was to determine a required value of muscle mass to maintain the Vo_2max reference value determined by the Japanese Ministry of Health Labour and Welfare in 2006 (Ministry of Health, Labour and Welfare of Japan 2006).

Methods

Subjects

A group of 403 Japanese women aged 20 to 69 years were randomly allocated to either a validation group (V-group, n = 201) or a cross-validation group (CV-group, n = 202). The subjects were recruited from the community around the National Institute of Health and Nutrition. All subjects were active and free of overt CVD assessed using a medical history questionnaire. All assessments were conducted at the National Institute of Health and Nutrition between February 2004 and October 2006. The study was approved by the Ethics Committee of the National Institute of Health and Nutrition, and written consent was obtained from all participants.

Percentage of muscle mass

The lean soft tissue mass of legs and arms were measured with a whole-body Dual Energy X-ray Absorptiometry (DXA) scanner (Hologic QDR-4500, Hologic INC., Waltham, MA, USA). The body regions were delineated according to specific anatomical landmarks using manual DXA analysis software (version11.2.3). The appendicular lean soft tissue mass was calculated as a sum of the lean soft tissue mass of the legs and the arms. The lean soft tissue mass of extremities assessed using DXA was assumed to represent appendicular skeletal muscle mass along with a small and relatively constant amount of skin and underlying connective tissues. The percentage of muscle mass (%MM) was calculated as follows;

$$\%MM\ (\%) = (\text{Appendicular lean soft tissue mass})/\text{Body weight} \times 100.$$

Vo_{2max}

We assessed peak oxygen uptake (Vo_{2peak}, mL · kg^{-1} · min^{-1}) instead of Vo_{2max} as an index of cardiorespiratory fitness, which is defined as the highest level of oxygen uptake that is determined by the protocol of a graded exercise load. The Vo_{2peak} was measured using the incremental cycle exercise. An initial work intensity of 30 W or 60 W was selected for each patient based on the patient's fitness level. The work intensity was increased thereafter by a step of 15 W/min, until the subject was not able to maintain the required pedaling frequency of 60 rpm. The heart rate and rating of perceived exertion (RPE) were monitored throughout the exercise. The O_2 consumption and the minute ventilation were monitored during each 1-min exercise stage (two 30 sec samplings for each stage), after RPE reached 18. The expired air was collected using Douglas bags. Expired O_2 and CO_2 gas concentrations were measured using a mass spectrometer (ARCO-1000A, ARCO SYSTEM, Chiba, Japan), and gas volume was measured using a dry gas meter (DC-5C Shinagawa Seiki, Tokyo, Japan). If the subject became exhausted and was not able to keep the pedaling frequency at 60 rpm, it was decided that the maximum effort had been achieved and the test was terminated. The highest value of Vo_2 during the exercise test was designated as Vo_{2peak}. Note that the oxygen uptake obtained in this procedure is referred to as Vo_{2peak}, to discriminate this from Vo_{2max} in the strict definition. However, we equate the obtained Vo_{2peak} to Vo_{2max} in the present study since the Vo_{2max} reference value was determined using both Vo_{2max} and Vo_{2peak} as mentioned in the next section.

Vo_{2maxk} reference values

The Japanese Ministry of Health Labour and Welfare proposed Vo_2max reference values to prevent life-style related illness for women [9]. The Vo_{2max} reference values are provided for each age group. The procedure to determine Vo_{2max} reference values was described in the EPARQ2006 [9]. In brief, these Vo_{2max} reference values were determined by experts through a systematic review of literature. The target age was 6 years and older. The target LSRD were obesity, hypertension, hyperlipemia, diabetes mellitus, cerebrovascular disorders, death due to circulatory diseases, osteoporosis, ADL and total mortality. By means of this systematic review, the threshold values of the Vo_{2max} or Vo_{2peak} at which the morbidity of LSRD statistically increases in each age group were collected from the literature. The average values of these threshold values for each age group were then calculated and designated as the Vo_{2max} reference values for preventing LSRD. The identified Vo_{2max} reference values ($mL \cdot kg^{-1} \cdot min^{-1}$) were 33 (20–29 yr), 32 (30–39 yr), 31 (40–49 yr), 29 (50–59 yr), and 28 (60–69 yr).

Analyses

First, a single regression analysis was used to test the correlation between age and Vo_2max, and between %MM and Vo_2max in V-group. Then, a multiple regression analysis was performed using Vo_2max as a dependent variable, and age and %MM as the independent variables. This analysis was based on the hypothesis that Vo_2max can be accounted for by age and %MM. In this hypothesis, we assumed that the age factor included Vo_2max determinant factors related to aging except for muscle mass, such as HR_{max}, maximal stroke volume, and peripheral O_2 extraction [21-23,25,27]. The validity of the prediction by the obtained regression equation was tested by applying the obtained regression equation to the CV-group. After the equation was cross-validated, the data from the two groups were pooled together to obtain the final prediction equation and in the subsequent analysis.

The purpose of the final prediction equation was to obtain the required %MM to maintain the reference Vo_2max value in each age group. Thus, the required %MM for each subject was recalculated by assigning the Vo_2max reference values and age in the final prediction equation. If the difference of the required %MM among the age groups was very small, the mean value of the required %MM was calculated to be used in the following analysis. To test the validity of the required %MM, the correlation between the sufficiency of Vo_2max, i.e., individual's Vo_2max as the percentage of the Vo_2max reference values (% Vo_2max reference values), and the sufficiency of the required %MM, i.e., individual's %MM as the percentage of the required %MM (%required-%MM), were tested.

All data are reported as means ± standard deviations (SD). $P < 0.05$ was used as a level of significance for all comparisons.

Results

Physiological characteristics

The physiological characteristics for each group are shown in Table 1. There were no significant physiological differences between V-group and CV-group.

Relationship between age and Vo_2max in V-group

Vo_2max in V-group was from 16.4 to 56.9 $ml.kg^{-1}min^{-1}$ (mean 33.5 ± 7.9) (Table 1). As expected, a strong nega-

Table 1: Characteristics of validation and cross-validation group

	V-group	CV-group
n	202	201
Age (yr)	41.4 ± 16.7	41.6 ± 16.9
Height (cm)	158.5 ± 6.4	157.9 ± 6.1
Body weight (kg)	54.4 ± 7.4	53.9 ± 7.3
Body mass index (kg/m^2)	21.6 ± 2.7	21.7 ± 2.9
Appendicular muscle mass (kg)	16.4 ± 2.4	16.1 ± 2.3
% MMI (%)	30.3 ± 3.2	30.0 ± 3.4
Vo_2max ($ml \cdot kg^{-1} \cdot min^{-1}$)	33.5 ± 7.9	32.7 ± 7.7

mean ± SD, V-group, Validation group; CV-group, Cross-validation group; %MM, percentage of muscle mass tive linear correlation was found between Vo_2max and age (Figure 1). The decrement was 2.58 ml.kg^{-1}min^{-1} per decade. The Vo_2max reference values for each age group in the EPAR2006 were superimposed in Figure 1. With increasing age, the proportion of subjects with Vo_2max values below the reference Vo_2max values increased.

Relationship between Vo_2max and %MM in V-group

%MM in V-group was from 18.7 to 37.3% (mean 30.3 ± 3.2%) (Table 1). There was also a strong correlation between Vo_2max and %MM, while the correlation was positive (Figure 2).

Multiple-regression analysis in V-group

Multiple regression analysis in V-group revealed that age ($R^2 = 0.286$) and %MM ($R^2 = 0.540$) were significant ($p < 0.0001$) contributors to the prediction of the measured Vo_2max. The multiple regression equation obtained in the V-group was the following: $Vo_2\text{max} = -0.135 \times \text{Age} + 1.315 \times \%\text{MM} - 0.799$. In this equation, R^2 and SEE were 0.522 and 5.4 mL · kg^{-1} · min^{-1}, respectively.

Cross-validation of the multiple regression equation

The multiple regression equation derived from the V-group was used to predict Vo_2max in the CV-group. Figure 3 shows the residual plot. There was not statistically significant correlation between the predicted Vo_2max and residual error ($p > 0.05$). Thus, the residual plot indicates that there was no bias in the prediction of Vo_2max of the CV-group using the multiple regression obtained in the V-group.

Final prediction equation

Data from the two groups were pooled to generate the final equations:

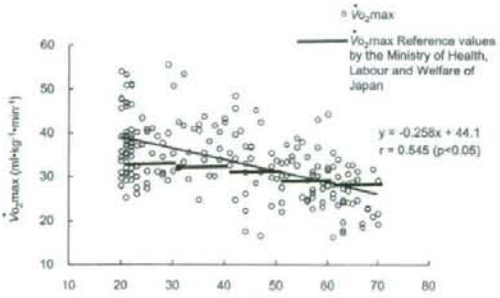

Figure 1

The relationship between age and Vo_2max in the V-group. The Vo_2max reference values by the Japanese Ministry of Health Labour and Welfare were shown for reference.

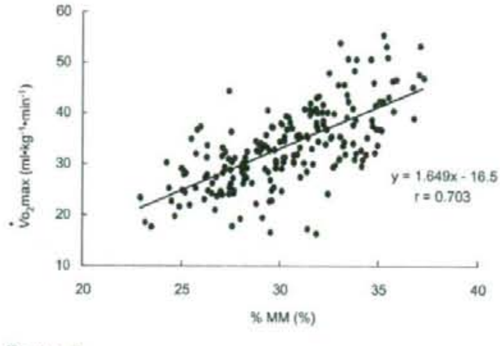

Figure 2

Relationship between percentage of muscle mass (%MM) and Vo_2max in the V-group.

$$Vo_2\text{max} = -0.131 \times \text{Age} + 1.344 \times \%\text{MM} - 2.035. \quad (1)$$

In the final equation, analysis revealed that age ($R^2 = 0.282$) and %MM ($R^2 = 0.570$) were significant ($p < 0.0001$) independent contributors to the prediction of the measured Vo_2max. Figure 4 shows the residual plot of the multiple-regression. There was no statistically significant correlation between the predicted Vo_2max and residual error ($p > 0.05$). Thus, the residual plot indicates that there was no bias in the prediction of Vo_2max.

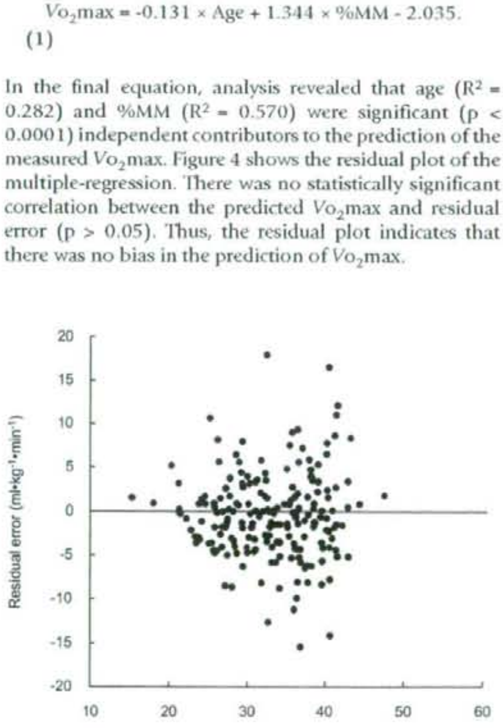

Figure 3

Relationship between estimated Vo_2max by the multiple regression equation and the residuals for the CV-group.

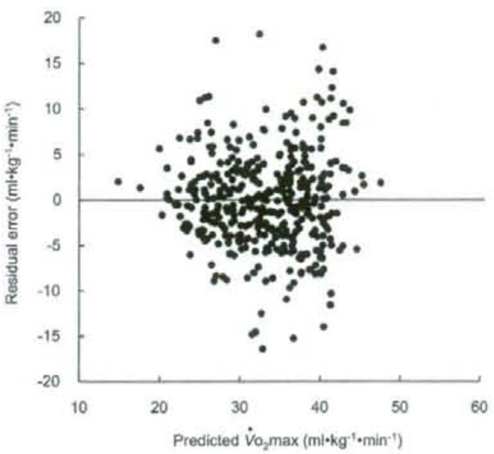

Figure 4
Relationship between estimated Vo_2max by the multiple regression equation and the residuals for both the V-group and the CV-group.

Estimation of the required %MM

The equation (1) was rearranged to predict required %MM as follow;

$$\%MM = (0.131 \times Age + 2.035 + Vo_2max)/1.344. \quad (2)$$

The required %MM was calculated by assigning the Vo_2max reference values, and age in the equation (2). The calculated required %MM was shown in Table 2. The mean value and standard deviation of required %MM was 28.5 ± 0.35%. Figure 5 shows the relationship between the measured %MM and age with the required %MM superimposed on the plot. The older people tended to have a %MM lower than the required. With increasing age, the proportion of subjects with %MM below the required %MM increased.

The validity of the required %MM

Figure 6 shows the relationship between %Vo_2max reference values and %required-%MM. The %Vo_2max reference values positively correlated with %required-%MM ($r = 0.651$, $p < 0.05$).

Discussion

The primary finding of the present study is that appendicular muscle mass of 28.5% of body weight is needed to maintain the Vo_2max reference values determined by the Japanese Ministry of Health Labour and Welfare in Japanese women. By use of the multiple-regression analysis, the regression equation of Vo_2max from age and %MM was obtained in the V-group at first. Then the validity of the regression equation was confirmed in the CV-group (Figure 3). The required %MM to maintain the Vo_2max reference values was obtained using the final regression equation using the data of V- and CV-groups (equation (2)) and the Vo_2max reference values for each age group (Table 2). There was strong correlation between percentages of the required %MM and Vo_2max reference values (Figure 6).

Required muscle mass

We propose the required %MM in Japanese women as a reference value of muscle mass for the usage of maintaining the reference value of Vo_2max proposed by the Ministry of Health Labour and Welfare of Japan. Interestingly, the calculated required %MM was not different among age groups (Table 2). Thus, we proposed the averaged required muscle mass (28.5%) as the general value for all age groups. A large portion of the subjects (68%) satisfied the required muscle mass, while with increasing age, the proportion of subjects with %MM below the required %MM increased (Figure 5). This tendency was similar to Vo_2max, i.e., with increasing age, the proportion of subjects with Vo_2max values below the reference Vo_2max values increased (Figure 1). Additionally, there was strong positive relation between percentages of Vo_2max reference values and required %MM (Figure 6). The results indicate that subjects with total muscle mass lower than 100% of the required %MM also tended to have lower Vo_2max when compared to levels of Vo_2max reference values. Thus, our result suggests that one of the reasons for insufficient Vo_2max may be insufficient %MM. Women who have %MM less than the required %MM are encouraged to increase their %MM above the required %MM to achieve the Vo_2max reference values. The required %MM can be used as an additional parameter for preventing LSRD together with the Vo_2max reference values. The

Table 2: Required %MM for Vo_2max reference values of each age group

Age roup Y	20 3 Y	0 4 Y	0 5 Y	0 6 Y	0	Total
n	143	48	55	73	84	403
Required MMI (%)	28.3 ± 0.26	28.6 ± 0.29	28.9 ± 0.27	28.4 ± 0.25	28.6 ± 0.30	28.5 ± 0.35

Mean ± SD; %MMI, percentage of muscle mass

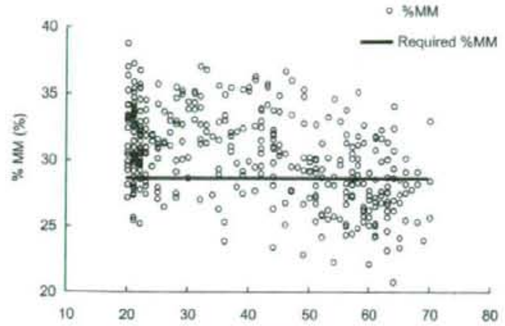

Figure 5
The relationship between age and the percentage of muscle mass (%MM) in the V-group and the CV-group. Required %MM is shown for reference.

required %MM obtained in this study is practical and appropriate for most Japanese women, because it is slightly less than the average %MM of the total number of subjects. Thus, the value is an achievable goal for most of Japanese women. Although strength training is not typically included in exercise programs targeting prevention of the age-related decline in Vo_2max or to increase Vo_2max, it would be advisable to recommend some form of strength training as well as aerobic training especially for individuals who do not achieve the required %MM.

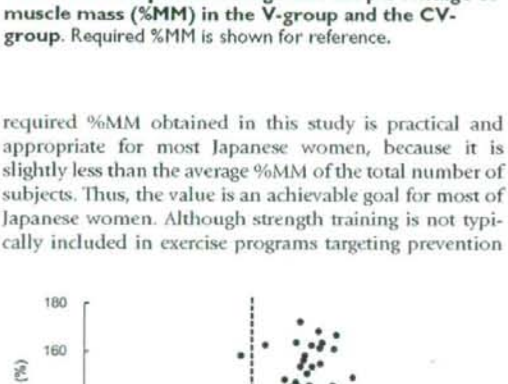

Figure 6
The relationship between the sufficiency of Vo_2max (%Vo_2max reference values) and the sufficiency of the required %MM (% required %MM) in both the V-group and the CV-group. Solid line: regression line, dashed line: lines of 100% of Required %MM and 100% of Vo_2max reference values.

Several prior studies demonstrated the significance of fat free mass, muscle mass, and/or muscle function to morbidity and mortality, although there are few researches targeting women [31-33]. The Japanese Ministry of Health Labour and Welfare also has admitted the importance of muscle mass and muscle function to prevent LSRD and/or mortality in EPAR2006. However practical target values have not been offered in the statement due to the lack of evidences compared to Vo_2max. In this present study we determined the target value of muscle mass through the Vo_2max reference values, which already has strong evidences. Although we have not confirmed the direct relation between muscle mass and LSRD morbidity and/or mortality, we believe Japanese women could aim to achieve the required %MM as one of targets for their health. Whether an increase of skeletal muscle mass would result in an improvement of exercise capacity and or reduce morbidity and mortality needs to be confirmed by future studies.

It should note that some individuals may have a large muscle mass, yet be at a high mortality risk. For example, it is well known that central obesity is one of risk factor of LSRD morbidity. Thus, it is important to remember that muscle mass is not the only important parameter but also, other risk factor should be monitored and considered together.

Prediction of Vo2max from age and muscle mass

The residuals of the multiple regression might be due to the approximation that all age-related determinant factors were included in age in the multiple regression. In the present model, we hypothesized that determinants such as HR_{max}, maximal stroke volume, and peripheral O_2 extraction were age-related, and therefore their effects were included in the factor of age. It was suggested that HR_{max} [14,22,26,29,34-39] and peripheral O_2 extraction [21,34] do decline with age, and are not influenced by exercise training. However, although maximum stroke volume was also suggested to decline with age in sedentary individuals [23], it was suggested that age-related decline of maximum stroke volume was prevented by exercise [21,34]. Thus, the simplification must be the error factor, and it is likely in future to improve the multiple regression equations using these age-related Vo_2max determinants, and to improve the estimation of the required MMI.

We studied only a statistical relationship between Vo_2max and muscle mass. Therefore, the results do not necessarily suggest a cause-effect relationship. It is possible that muscle mass and Vo_2max are physiologically unrelated but indirectly correlated, i.e., people with a high Vo_2max may be more physically active and perform activities that increase muscle mass. However, muscle mass is highly likely physiologically important determinant of Vo_2max because the amount of tissue available to extract oxygen during maximal exercise directly contribute to the value of Vo_2max.

Study limitations

The current study has limitations that require caution when interpreting and generalizing the findings reported herein. This study included only the cross-sectional design, and it did not investigate the relationship between the required %MM and the morbidity of LSRD or mortality by using a prospective design. Thus, it has not been clarified how the required %MM reflects these risks in this present study. Further investigation is required to validate the required %MM through a prospective study with the morbidity and/or mortality as an endpoint. Additionally, the potential difference between methods using %MM or absolute muscle mass (kg) as the indicator of health should be also investigated. Another limitation of this study is the results of this study are applicable to only Japanese women. The decided %MM in this study may not be able be applicable to men and/or other racial group since they may have different characteristics of the relationship between muscle mass and Vo_2max.

Conclusion

In conclusion, the present study proposed the required muscle mass (28.5% per body weight) in Japanese women to maintain the Vo_2max reference values determined by the Japanese Ministry of Health Labour and Welfare. This required muscle mass can be used as one of the reference parameters of fitness level in Japanese women.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

MM performed analysis and data interpretation as well as drafted and revised the manuscript. KM participated in the conception of this study, interpretation of the analysis and critically reviewed this manuscript, and provided comment as Statistical expertise. HK, YC, KY, MT, TO, CU and SK performed data analysis and interpretation, and provided comment and review of the manuscript. MH and IT designed the project, assisted with data interpretation and provided comment and revisions for the manuscript. MM designed the project, participated in the conception of this study, interpretation of the analysis and critically reviewed this manuscript. All authors read and give final approval of the final manuscript for publication.

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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 (BOML1TR; 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 pull-down, 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, $p \leq 0.05$ 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

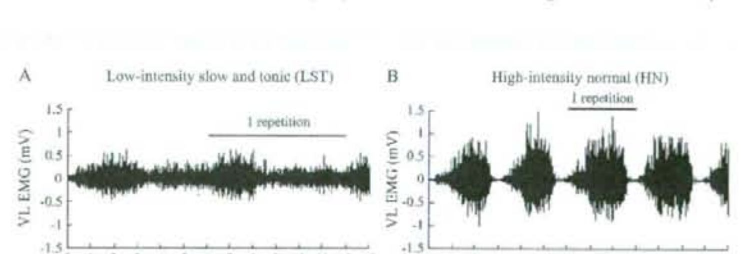

Figure 1. Typical electromyographic (EMG) signals from the vastus lateralis (VL) during vertical squat exercise. The signals were recorded during (A) low-intensity resistance training with slow movement and tonic force generation (LST) with a load of 75 kg (~57% one-repetition maximum [1RM]) and (B) 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

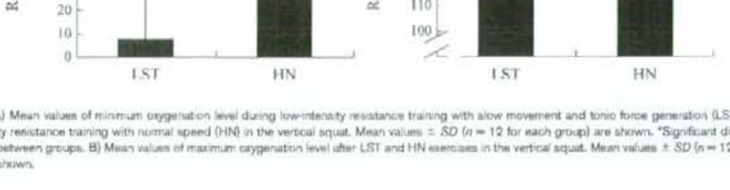

Figure 2. A) Mean values of minimum oxygenation level during low-intensity resistance training with slow movement and tonic force generation (LST) and high-intensity resistance training with normal speed (HN) in the vertical squat. Mean values ± *SD* ($n = 12$ for each group) are shown. *Significant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

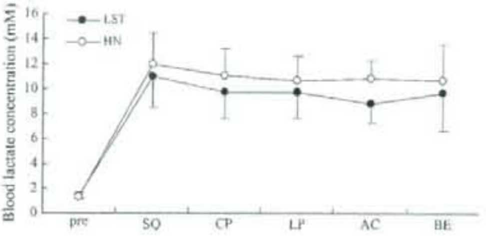

Figure 3. Changes in blood lactate concentrations before and immediately after low-intensity resistance training with slow movement and tonic force generation (LST; ●) and high-intensity resistance training with normal speed (HN; ○). Mean values ± *SD* ($n = 12$ for each group) are shown. SQ = vertical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

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 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 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

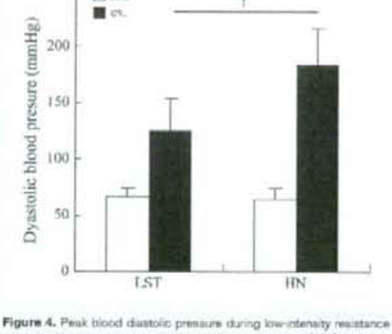

Figure 4. Peak blood diastolic pressure during low-intensity resistance training with slow movement and tonic force generation (LST) and high-intensity resistance training with normal speed (HN) vertical squat exercises (filled bars) and at rest (open bars). Mean values ± *SD* ($n = 12$ for each group) 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 ($p < 0.05$).

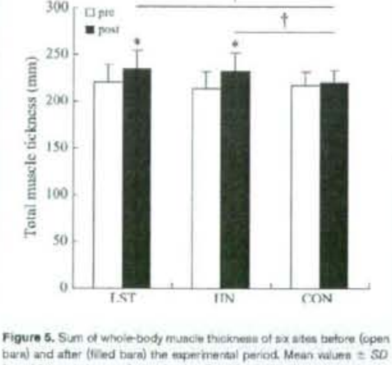

Figure 5. Sum of whole-body muscle thickness of six sites before (open bars) and after (filled bars) the experimental period. Mean values ± *SD* ($n = 12$ for each group) are shown. *Significant differences between pre- and posttraining values ($p < 0.05$). †Significant differences between groups ($p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

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.