Original Article

Attenuated Increases in Blood Pressure by Dynamic Resistance Exercise in Middle-Aged Men

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The present study was performed to test the hypothesis that the blood pressure (BP) response to resistance exercise in middle-aged men with stiffening arteries is greater than that in young men with compliant arteries. The BP responses to acute dynamic resistance exercise (leg press) at individual relative (low, moderate and high) and absolute intensities were investigated in both young and middle-aged men. A total of 21 sedentary healthy normotensive men, 21–25 years of age (young) and 41–59 years of age (middle-aged), were included in the study. At rest, the arterial compliance (simultaneous ultrasound and applanation tonometry) and muscle strength (leg press) were lower, and indices of arterial stiffness and BP were higher in the middle-aged men than in the young men ($p<0.05$). There were no significant differences in height, body mass, or heart rate between the two groups. During exercise, the systolic BP of the middle-aged men at 80% one-repetition maximum (1RM) was significantly lower than that of the young men for the last half of the exercise period ($p<0.05$). The amounts of change in systolic and diastolic BP from baseline to the end of resistance exercise were lower in the middle-aged men than in the young men at individual relative intensities ($p<0.05$) and at individual absolute intensity. In contrast to our hypothesis, these findings indicated that the BP response during dynamic resistance exercise using large muscle groups may be attenuated in middle-aged men relative to young men. (*Hypertens Res* 2008; 31: 1045–1053)

***Key Words*: aging, resistance exercise, blood pressure, pressor, arterial stiffening**

Introduction

Regular physical activity is regarded as an important component of prevention and treatment of age-related increases in cardiovascular disease (*1*, *2*). Aerobic exercise in particular is recommended by major health organizations, including the American Heart Association and American College of Sports Medicine (*3*, *4*), because it shows favorable effects on cardiovascular functions in young, middle-aged, and older men (*5*–*8*). In recent years, resistance exercise, another common exercise modality, has gained widespread acceptance in exercise prescription and cardiopulmonary rehabilitation programs and has become an integral component of comprehensive health programs endorsed by the major health organizations (*3*, *9*). However, there is very little information on the potential influence of resistance training on non-musculoskeletal components, in particular the cardiovascular system. Systolic and diastolic blood pressures (BPs) rise rapidly to extremely high values during heavy weight-lifting exercise (*10*), and BPs are extreme even when exercise is performed with a relatively small muscle mass (*11*, *12*). Most previous studies

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have focused on the BP responses to resistance exercise in young adults (*13–15*), and thus have provided little information regarding BP responses in middle-aged and older individuals (*12*, *16*). Furthermore, the interaction between age and BP response for dynamic resistance exercise using large muscle groups has not been reported in middle-aged men with stiffening arteries or young men with compliant arteries.

The stiffness of the large central arteries in the cardiothoracic region increases with advancing age in sedentary humans (*6*, *17*, *18*). This physiological alteration reduces the buffering capacity of the arteries, leading to increased pulse pressure, peripheral vessel resistance, and left ventricular wall tension (*19*, *20*), all of which augment the workload of the heart. Generally, it can be assumed that middle-aged and older men with advanced arteriosclerosis would show attenuated pressor buffering function during resistance exercise. Accordingly, we hypothesized that the BP response to dynamic resistance exercise in middle-aged men with stiffening arteries would be larger than that in young men with compliant arteries. The present study was performed to clarify the differences in BP response to acute dynamic resistance exercise at individual relative or absolute intensities between young and middle-aged men.

Methods

Subjects

Twelve young (21–25 years) and nine middle-aged men (41–58 years) were recruited through various forms of advertisement or by posting on bulletin boards at our university, and had not participated in a regular exercise program for at least the previous 2 years. Only male subjects were included in the study to ensure that the interpretation of differences between the two age groups would not be confounded by the possible influence of sex. All subjects were normotensive ($<$140/90 mmHg), non-obese (body mass index $<$30 kg/m^2), and free of overt chronic diseases as assessed by medical history and physical examination. Subjects taking cardiovascular-acting medications, such as anabolic steroids, or with significant intima-media thickening, plaque formation, and/or other characteristics of atherosclerosis (*e.g.*, ankle-brachial index [ABI]$<$0.9) were excluded from the study. All subjects gave their written informed consent to participation in the study, and all procedures were reviewed and approved by the Institutional Review Board.

Measurements at Rest

Brachial-Ankle Pulse Wave Velocity and BP

The brachial-ankle pulse wave velocity (baPWV) and BP were assessed using a form PWV/ABI device (Colin Medical Technology, Komaki, Japan). Subjects were examined in the supine position after a rest of at least 5 min. The cuffs were wrapped on both sides of the brachium and ankle, and contained a plethysmographic sensor that determined the waveform data, including BP measurements by the oscillometric method. The baPWV was calculated as distance/time (cm/s) between the brachium and ankle. The time delay between the arrival of the pulse wave at the brachium and ankle was obtained automatically by gating the pulse wave to the peak of the R wave of the electrocardiogram. The distance was estimated from the subject's height as $L = L_a - L_b$ (L_a: path length from the heart to the ankle; L_b: path length from the heart to the brachium). Then, we used the mean of the right and left baPWV values for analysis. The measurements of baPWV and BP were performed three times per day, and the three values were averaged. The reproducibility of baPWV measurement has been validated in our laboratory (coefficient of covariance, 2±1%) and in other studies (*21*, *22*).

Carotid Artery Intima-Media Thickness

The right common carotid artery intima-media thickness (IMT) was measured from images obtained using an ultrasound machine equipped with a high-resolution linear-array broad-band transducer as described previously (*23*, *24*). Ultrasound images were analyzed using computerized image analysis software (NIH Image 1.63). At least 10 measurements of IMT were taken at each segment, and the mean values were used for analysis. This technique has excellent day-to-day reproducibility (coefficient of variance, 3±1%) for the carotid IMT.

Carotid Artery Compliance and Stiffness

A combination of ultrasound imaging of the pulsatile right common carotid artery with simultaneous applanation of tonometrically obtained arterial pressure from the contralateral carotid artery permits noninvasive determination of arterial compliance (*23–25*). The carotid artery diameter was measured from images obtained using an ultrasound machine equipped with a high-resolution linear-array transducer. A longitudinal image of the cephalic portion of the common carotid artery was acquired 1–2 cm distal to the carotid bulb. All image analyses were performed by the same investigator who was blinded to the group assignments.

Pressure waveforms and amplitudes were obtained from the common carotid artery with a pencil-type probe incorporating a high-fidelity strain-gauge transducer (SPT-301; Millar Instruments, Houston, USA) (*26*). As baseline levels of BP are subject to hold-down force, the pressure signal obtained by tonometry was calibrated by equating the carotid mean arterial and diastolic BP to the brachial artery value (*23–25*). In addition to arterial compliance (*27*), we also calculated the β-stiffness index, which provides an index of arterial compliance adjusted for distending pressure (*28*). Arterial compliance and the β-stiffness index were calculated using the equations $[(D_1 - D_0)/D_0]/[2(P_1 - P_0)](P_1 - P_0) \times \pi \times (D_0)^2$ and $[\ln(P_1/P_0)]/[(D_1 - D_0)/D_0]$, where D_1 and D_0 are the maximal and minimum diameters, and P_1 and P_0 are the highest and lowest BPs, respectively (*23–25*). The day-to-day coefficients of variation were 2±1%, 7±3%, and 5±2% for the carotid artery diameter, pulse pressure, and arterial compliance, respectively.

Measurements during Dynamic Resistance Exercise

Radial BP and ECG

To determine circulatory response, radial BP and ECG were recorded simultaneously in the sitting position at baseline, during exercise, and during the recovery period. ECG and radial BP waveforms were determined using arterial tonometry (JENTOW-7700; Colin Medical Technology) and standard lead electrocardiography (Life Scope 11; Nihon Kohden, Tokyo, Japan), respectively. Both ECG and arterial BP waveforms were sampled at 1,000 samples per second by connecting each device to a computer using an A/D converter (PowerLab; AD Instruments, Colorado Springs, USA). The principle of arterial tonometry is that BP at the radial artery can be obtained by measuring the reaction forces produced by flattening the radial artery. Recently, this method has become preferred over the conventional finger photoplethysmographic method (Finapres), and it has been confirmed that the accuracy and reliability of BP measured by tonometry are greater than those of BP measured by the intra-arterial method. A tonometric sensor was attached to the left wrist, and the wrist was placed on a padded platform at the level of the heart. The oscillometric calibrations were carried out for accurate tonometric measurement before, and sometimes during the main experiment (*29*).

Strength Testing

Maximal muscular strength was assessed with a leg press machine using air pressure (Keiser; Fitness Apollo Japan Co., Ltd. Tokyo, Japan). A one-repetition maximum (1RM) was determined by having the subjects perform single repetitions with progressively heavier weights, resting 2–3 min between attempts; the heaviest weight that subjects could lift once through a complete range of movement was considered their 1RM. The day-to-day coefficient of variation for 1RM strength in our laboratory is 4±2%.

Exercise Protocol I

Subjects rested under quiet conditions before beginning the leg press exercise. After a 60-s baseline period, all subjects randomly performed 10 repetitions of the leg press exercise for 40 s at each of 40%, 60%, and 80% 1RM, followed by an 80-s recovery period. One repetition was performed for 4 s (2 s for concentric and 2 s for eccentric contraction). To measure radial BP accurately, the subject's left arm was supported on an adjustable table during measurement. Subjects were stabilized in the apparatus during exercise using their right hand to hold the support handle on the seat. The left arm was allowed to rest freely by their side to avoid interference with the recording of radial BP from this arm. The subjects were encouraged to avoid deep inhalations while performing the Valsalva maneuver during the exercise. Exercise measurements were performed randomly in a day. The interval time between exercises was controlled at 10 min.

Table 1. Subject Characteristics

	Young	Middle-aged
N	12	9
Age, years	21.4±0.5	47.8±1.9
Height, cm	170.6±1.7	170.1±2.1
Body mass, kg	65.3±2.1	67.7±2.9
Resting heart rate, bpm	52.3±1.7	60.8±4.4
Brachial systolic BP, mmHg	118±3	123±4
Brachial diastolic BP, mmHg	67±2	80±3*
Brachial mean BP, mmHg	82±4	96±4*
Brachial PP, mmHg	55±4	43±2*
Carotid systolic BP, mmHg	109±2	119±6
Carotid diastolic BP, mmHg	67±2	80±3*
Carotid PP, mmHg	42±2	38±3
Carotid diastolic diameter, mm	5.9±0.1	6.7±0.3*
Carotid intima-media thickness, mm	0.48±0.02	0.63±0.02*
Carotid arterial compliance, mm^2/mmHg	0.17±0.01	0.11±0.01*
Carotid β-stiffness index, a.u.	3.95±0.28	7.30±0.76*
Brachial-ankle PWV, cm/s	1,092±38	1,291±46*
Augmentation index, %	−6.9±5.7	19.6±5.8*
Leg press maximum, kg	350±11	286±19*

Data are mean±SEM. BP, blood pressure; PP, pulse pressure; PWV, pulse wave velocity. Leg press maximum was evaluated by air pressure machine (Keiser; Fitness Apollo Japan Instruments). *Significant at $p<0.05$ *vs*. young.

Exercise Protocol II

Eleven young men and nine middle-aged men were studied using protocol II. All subjects performed 10 repetitions of the leg press exercise at individual absolute intensity (145 kgw) 10 min after the end of protocol I. Protocol II was performed using a procedure similar to that in protocol I.

Data Analysis

In the baseline period, during the leg press exercise and recovery periods, waveforms of ECG and radial BP were recorded continuously and simultaneously on a personal computer (iBook G3; Apple Computer, Cupertino, USA). Heart rate and systolic, diastolic, and mean BP were calculated using the Chart5 software package (AD Instruments). Baseline values of BP were taken as the average of the baseline period (1 min) before exercise. Average values every 4 s for one repetition and peak values of BP were obtained during the 40-s exercise period. Eight BP values in the recovery period were averaged at 0–4, 4–8, 16–20, 36–40, 56–60, 76–80, 96–

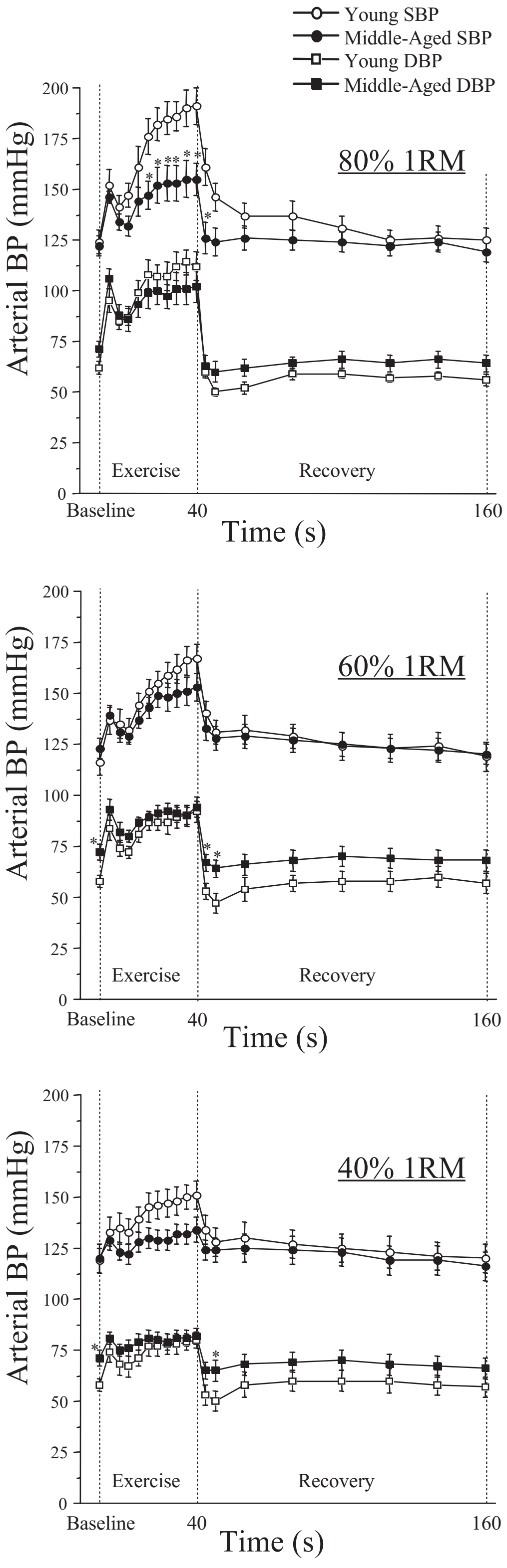

Fig. 1. *Systolic (circles) and diastolic (squares) blood pressure responses during resistance exercises and recovery periods at 40% (bottom), 60% (middle), and 80% (top) of 1RM in young (white) and middle-aged (black) men. Values are means±SEM. *p<0.05 vs. young men.*

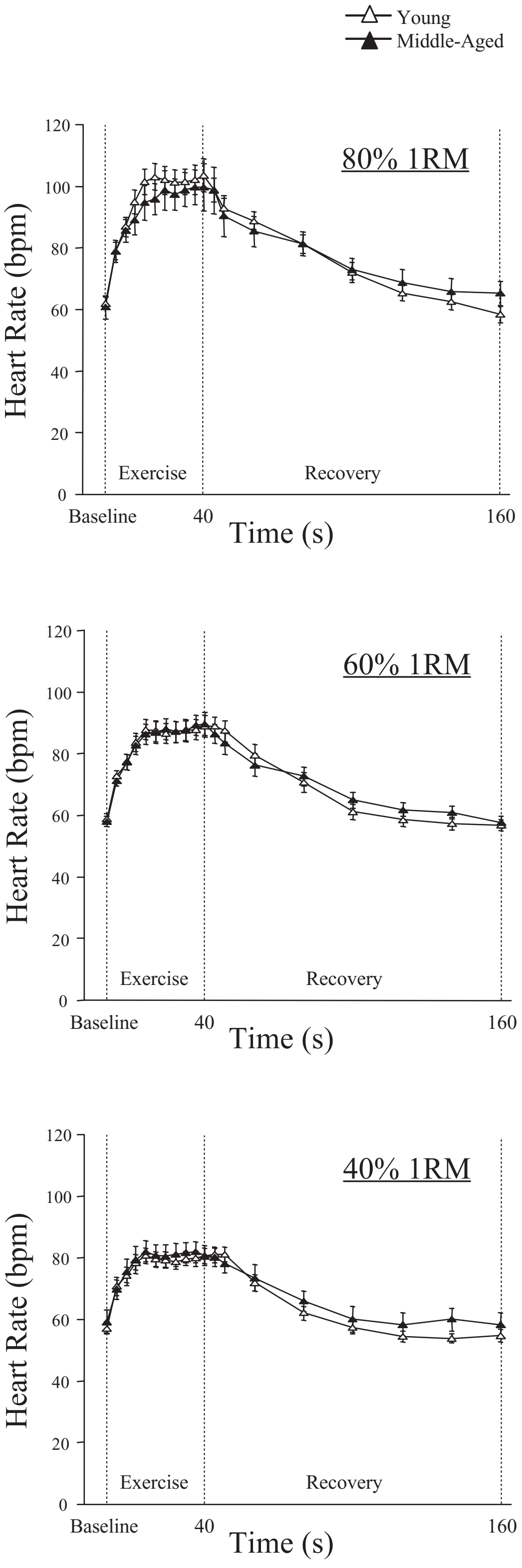

Fig. 2. *Heart rate responses during resistance exercises and recovery periods at 40% (bottom), 60% (middle), and 80% (top) of 1RM in young (white) and middle-aged (black) men. Values are means±SEM.*

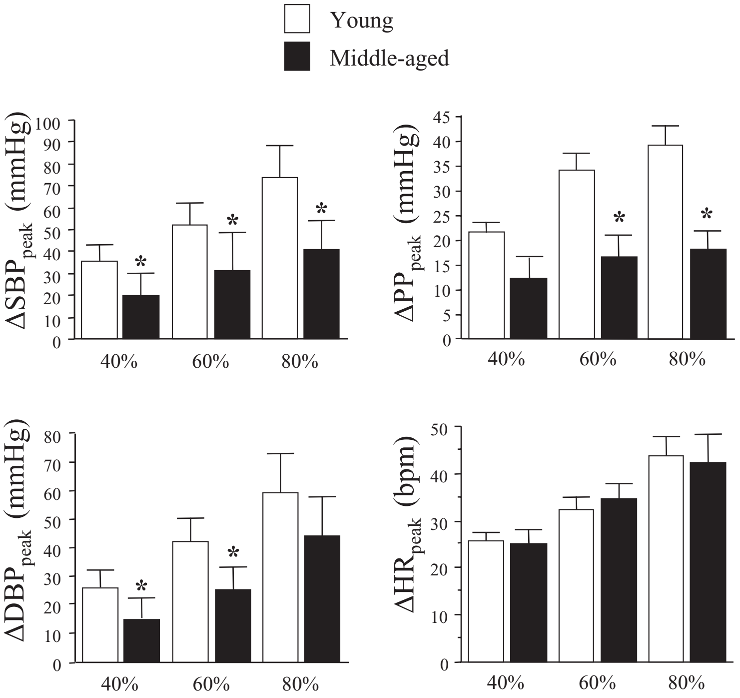

Fig. 3. *The amounts of change in systolic (SBP; top left) and diastolic (DBP; bottom left) blood pressure, pulse pressure (PP; top right) and heart rate (HR; bottom right) responses to resistance exercises at 40%, 60%, and 80% of 1RM in middle-aged (black bar) and young (white bar) men. Values are means ± SEM.* *$p < 0.05$ *vs. young men at the same intensity.*

100, and 116–120 s. Heart rate was calculated as the peak value during exercise.

Statistical Analysis

Changes during the leg press exercise were assessed by two-way analysis of variance (group × time) with repeated measures. In the case of significant F-values, a post hoc test (Newman-Keuls method) was used to identify significant differences among mean values. Peak values were analyzed using the t-test. All data are presented as the means ± SEM. Statistical significance was set at $p < 0.05$ for all comparisons.

Results

Subject Characteristics

Subjects' characteristics at rest are shown in Table 1. There were no significant differences in height, weight, heart rate, or carotid BP between young and middle-aged men in the present study. Brachial diastolic and mean BP and carotid diastolic diameter were higher in the middle-aged men than in the young group ($p < 0.05$). Brachial systolic BP and carotid pulse pressure were not significantly different between the two groups. β-Stiffness, augmentation index, and baPWV in the middle-aged men were significantly higher than those in the young group ($p < 0.05$). The carotid arterial compliance and leg press maximum of the middle-aged men were significantly lower than those of the young men ($p < 0.05$).

Exercise Protocol I

Radial systolic and diastolic BP responses during the exercise and recovery periods are shown in Fig. 1. Baseline values of radial diastolic BP under the 40% and 60% 1RM conditions were higher in middle-aged than in young men, and there were no significant differences between groups in other baseline BP values. Systolic BP for 20–40 s during exercise in the middle-aged men at only 80% 1RM was significantly lower than that in the young group ($p < 0.05$). There were no significant differences in heart rate response to resistance exercise between middle-aged and young men at any intensity examined (Fig. 2). Systolic and diastolic BP returned to the baseline values within 60 s during the recovery period. The amounts of change in systolic and diastolic BP and pulse pressure from baseline to the peak response during resistance exercise were significantly lower in the middle-aged men than in the young group at all exercise intensities examined, but there was no significant difference in Δ heart rate (Fig. 3).

Exercise Protocol II

The amounts of change in systolic and diastolic BP and pulse pressure from baseline to the peak response during resistance

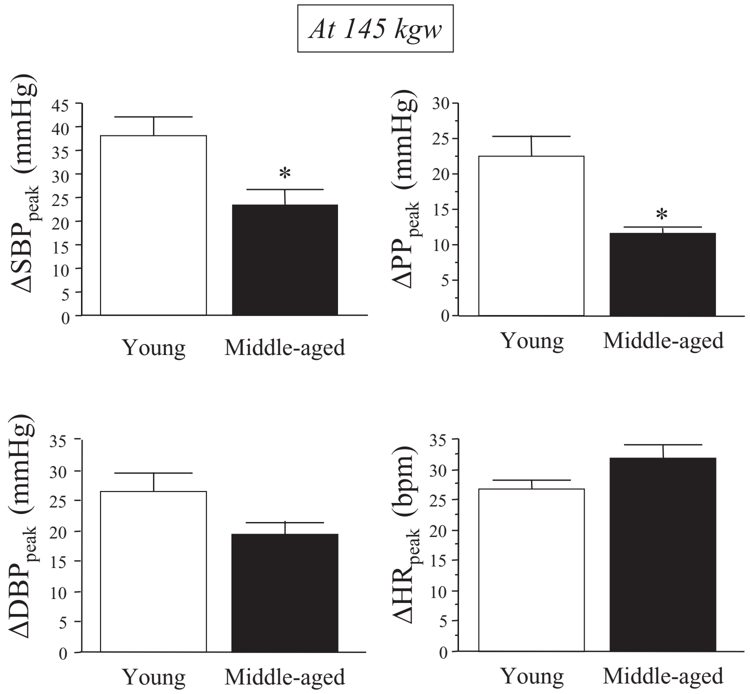

Fig. 4. *The amounts of change in systolic (SBP; top left) and diastolic (DBP; bottom left) blood pressure, pulse pressure (PP; top right) and heart rate (HR; bottom right) responses to resistance exercise at 145 kgw in middle-aged (black bar) and young (white bar) men. Values are means±SEM.* $*p < 0.05$ *vs. young men.*

exercise were lower in the middle-aged men than in the young men at individual absolute intensity, but there was no significant difference in *Δ*heart rate (systole, $p=0.019$; diastole, $p=0.091$; pulse pressure, $p=0.003$; Fig. 4).

Discussion

The major findings of the present study were as follows. 1) The absolute value of BP response to dynamic resistance exercise at 80% 1RM was lower in middle-aged men with stiffening arteries than in young men with compliant arteries. 2) At all relative intensities, the amounts of change in peak BP response to resistance exercise were lower in middle-aged than in young men. 3) At individual absolute intensity, the amounts of change in peak systolic BP response to resistance exercise were lower in middle-aged than in young men. In contrast to our hypothesis, these results suggest that BP responses during dynamic resistance exercise may be attenuated with advancing age at either individual relative or absolute intensity, despite age-related stiffening of the arteries.

Previous studies have suggested that the arteries of middle-aged men appear to be stiffer than those of young men based on measurements of carotid arterial compliance, β-stiffness, augmentation index, and baPWV (*5*, *6*, *22*, *23*, *30*). Our results also showed that arterial stiffening develops at a greater rate in middle-aged men than in young men. However, remarkable hypertrophy (>1.1 mm) of IMT, which is a characteristic of atherosclerosis, was not observed in any of the subjects in the present study. The maximal muscle strength estimated by the leg press exercise was lower in middle-aged men than in young men. These results indicate that the middle-aged men in the present study had developed arteriosclerosis without atherosclerosis and had lower maximal muscle strength than the young men. Although all BP values at rest in middle-aged men were higher than those in young men, all subjects were normotensive (<140/90 mmHg). Carotid diastolic diameter in middle-aged men was higher than that in young men. This result was consistent with the results of a previous epidemiological study (*31*). This alteration may be a physiological adaptation to suppress marked reductions in arterial compliance and vessel diameter induced by hypertrophied IMT with advancing age.

Dynamic resistance exercise is mainly used for health promotion and strength conditioning as it has greater effects on strength and volume of skeletal muscle in comparison with static (isometric) exercise (*32*). Understanding the pressor response during dynamic resistance exercise using large muscle groups is essential for exercise prescription. However, most previous studies have focused on static resistance exercise (*11*, *12*, *16*, *33*), and have provided little information regarding the cardiovascular response during dynamic resistance exercise (*10*), or the interaction between age and BP response to dynamic resistance exercise using large muscle groups. We found that pressor responses during dynamic 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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