arm cuff was inflated to 40 mmHg for 5 s in each 15-s cycle to occlude venous outflow from the arm using a rapid cuff inflator (EC-20, DE Hokanson Inc.). The forearm blood flow output signal was recorded on a personal computer via an A/D converter (PowerLab, AD Instruments). Forearm blood flow was expressed in milliliters per minute per 100 ml of forearm tissue volume.

To obtain measures of flow-mediated vasodilation, arm blood flow was occluded for 5 min by inflating a blood pressure cuff over the upper arm to a pressure 100 mmHg above systolic blood pressure. Following rapid release of the inflation pressure, changes in forearm volume were measured for 3 min by strain-gauge plethysmography, following the above-mentioned 15-s cycle method [5, 22]. The day-to-day coefficient of variation for RH in our laboratory is 9 ± 5%.

Blood pressure following RH

Radial blood pressure waveforms were determined using arterial tonometry (JENTOW-7700; Colin Medical Technology). Arterial blood pressure waveforms were sampled at 1,000 samples per second by connecting each device to a computer using an A/D converter (PowerLab; AD Instruments). The principle of arterial tonometry is that blood pressure at the radial artery can be obtained by measuring the reaction forces produced by flattening the radial [artery]. A tonometric sensor was attached to the left wrist that was placed on a padded platform at the level of the heart. The oscillometric calibrations were carried out for accurate tonometric measurement before RH [23, 24].

Exercise training intervention

In the 4 months of the study period, all participants underwent three supervised resistance training sessions per week. During each training session, participants in the HIR and the COMBO groups completed three sets of 8–12 exercises at 80% of 1RM, and subjects in the MIR group completed three sets of 14–16 exercises at 50% of 1RM, in the following order: leg extension, seated chest press, leg curls, lateral row, squat and sit-ups. The resistance of each exercise was increased progressively throughout the resistance training period. The recovery time between exercise bouts was controlled at 2-min intervals. Each resistance training session lasted approximately 45 min. Subjects in the COMBO group performed a cycle exercise at 60% of the maximal heart rate for 30 min immediately after each resistance training session. Training assistants verbally encouraged the subjects and ensured proper form and technique at each exercise session. Participants were instructed to refrain from any other regular exercise during the entire study period.

Statistical analysis

Results are presented as the mean ± SE. Values of $P < 0.05$ were considered significant. One-way ANOVA was used to evaluate differences among HIR, MIR and COMBO groups concerning parameters before exercise training intervention. Comparisons of time course curves of forearm blood flow and blood pressure during RH were analyzed by two-way ANOVA (time point × period) with repeated measures for each group. Changes in other parameters were also assessed by two-way ANOVA (group × period) 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.

Results

Before exercise training, there were no significant differences in any of the characteristics of subjects among the three groups (Table 1). In all groups, there were no changes in height, weight or body mass index throughout this study period.

All groups increased 1RM strength significantly in all muscle groups tested ($P < 0.05$–$P < 0.0001$). Percentages of increases in 1RM strength for the HIR, MIR and COMBO groups were 47, 6 and 25% for leg extension; 26, 13 and 14% for leg curl; 30, 10 and 25% for squat; 25, 8 and 17% for lateral row; 20, 6 and 21% for bench press; and 32%, 12% and 21% for abdominal bend, respectively.

There were no significant differences in baseline brachial blood pressure and resting heart rate, although forearm blood flow was lower in the COMBO group compared to the MIR group in the pre-training period (Table 2). Brachial blood pressure, resting heart rate and forearm

Table 1 Characteristics of selected subjects at the baseline

Variables	HIR	MIR	COMBO
N	14	14	11
Age, years	22 ± 1	20 ± 1	21 ± 1
Height, cm	173 ± 2	170 ± 2	171 ± 2
Body weight, kg	66 ± 3	65 ± 3	66 ± 2
Body mass index, kg/m^2	22 ± 1	22 ± 1	23 ± 1
Body fat, %	18 ± 2	20 ± 2	21 ± 1
Peak oxygen consumption, ml/min per kg	51 ± 2	52 ± 2	49 ± 2

Data are mean ± SEM

HIR high-intensity resistance training group, *MIR* moderate-intensity resistance training group, *COMBO* combined high-intensity resistance training and moderate-intensity aerobic exercise training group

Table 2 Cardiovascular indices

Variables/group	0 month	2 month	4 month	Interaction
Brachial systolic BP, mmHg				
HIR	116 ± 3	118 ± 3	116 ± 3	$F = 1.986$
MIR	121 ± 3	117 ± 3	119 ± 3	$P = 0.1058$
COMBO	115 ± 2	115 ± 2	116 ± 3	
Brachial diastolic BP, mmHg				
HIR	68 ± 1	69 ± 2	66 ± 2	$F = 1.806$
MIR	71 ± 2	67 ± 2	67 ± 2	$P = 0.1371$
COMBO	67 ± 1	66 ± 2	67 ± 2	
Brachial pulse pressure, mmHg				
HIR	68 ± 1	69 ± 2	66 ± 2	$F = 0.208$
MIR	71 ± 2	67 ± 2	67 ± 2	$P = 0.9333$
COMBO	67 ± 1	66 ± 2	67 ± 2	
Heart rate at rest, bpm				
HIR	56 ± 2	56 ± 2	54 ± 1	$F = 0.472$
MIR	55 ± 3	53 ± 2	54 ± 2	$P = 0.6273$
COMBO	52 ± 3	50 ± 1	49 ± 1	
FBF at baseline, ml/min per 100 mL tissue				
HIR	12.7 ± 1.2	13.2 ± 1.2	13.6 ± 1.9	$F = 2.435$
MIR	15.2 ± 1.9	14.4 ± 0.4	15.8 ± 2.4	$P = 0.0517$
COMBO	9.1 ± 1.5*	18.2 ± 2.6	19.8 ± 2.9	

Data are mean ± SEM

HIR high-intensity resistance training group, *MIR* moderate-intensity resistance training group, *COMBO* combined high-intensity resistance training and moderate-intensity aerobic exercise training group. *BP* blood pressure, *FBF* forearm blood flow

* $P < 0.05$ vs. MIR

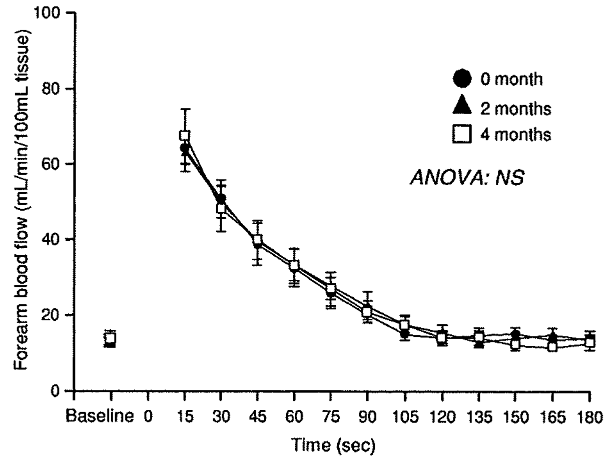

Fig. 1 Forearm blood flow during reactive hyperemia at before (*filled circle* 0 month), middle (*filled triangle* 2 months) and after (*open square* 4 months) resistance training at high intensity. Data presented as the mean ± SEM

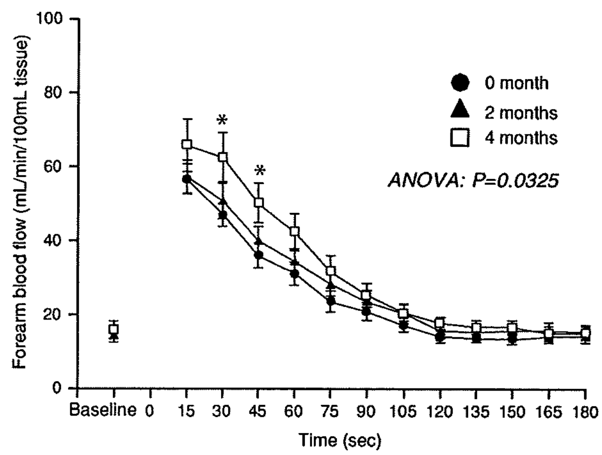

Fig. 2 Forearm blood flow during reactive hyperemia at before (*filled circle* 0 month), middle (*filled triangle* 2 months) and after (*open square* 4 months) resistance training at moderate intensity. Data presented as the mean ± SEM. *$P < 0.05$; 0 versus 4 months

blood flow in all groups did not change after exercise training intervention.

After 4 months of training, the forearm blood flow during RH did not change in the HIR groups (Fig. 1), but increased significantly in both the MIR and COMBO groups, from 57 ± 4 to 66 ± 7 ml/min per 100 ml tissue and from 59 ± 6 to 74 ± 8 ml/min per 100 ml tissue, respectively (Figs. 2, 3, both $P < 0.05$). In the COMBO group, baseline forearm blood flow increased at the 2-month and post-training periods compared with pre-training (Fig. 1), but not in the HIR and MIR groups. In the three groups, there was no change in blood pressure during RH after 4 months of training (Figs. 4, 5, 6).

Discussion

The primary findings of this study are twofold. First, resistance training performed at a moderate intensity increased changes in forearm blood flow response to RH, but not when performed at a high intensity. Second, the combined resistance and aerobic training augmented forearm blood flow response to RH for the 4-month intervention. These results suggest that although performing only moderate-intensity resistance training slightly improves vasoreactivity during RH in the microvasculature, regular combined resistance and endurance exercise training greatly and favorably impacts vasoreactivity to response to RH in the microvasculature.

It is necessary to perform habitual endurance exercise [7] for the enhancement and/or maintenance of aerobic capacity, leading to the prevention and reversal of cardiovascular disease [7] via improvements in arterial function [4, 19, 25], including endothelium-dependent dilation in the microvasculature [4]. Additionally, the current recommendation has demonstrated that resistance training should

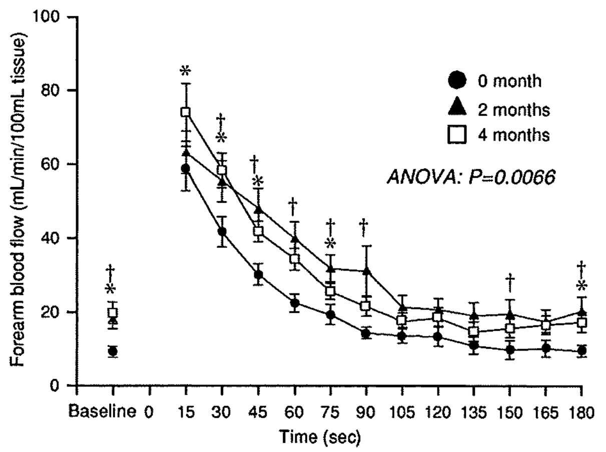

Fig. 3 Forearm blood flow during reactive hyperemia at before (*filled circle* 0 month), middle (*filled triangle* 2 months) and after (*open square* 4 months) combined resistance and aerobic training. Data presented as the mean ± SEM. $^{\dagger}P < 0.05$; 0 versus 2 months, $^{*}P < 0.05$; 0 versus 4 months

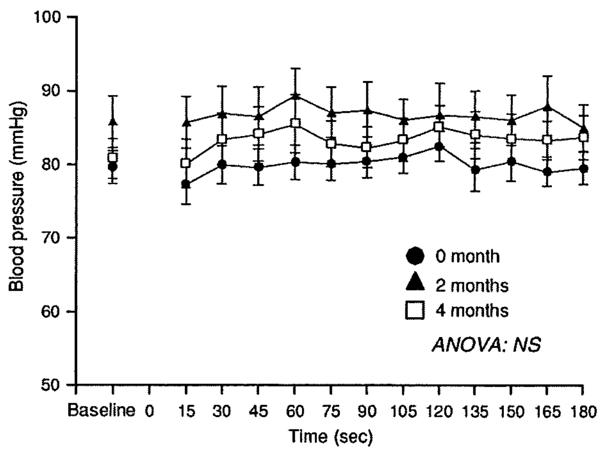

Fig. 4 Blood pressure during reactive hyperemia at before (*filled circle* 0 month), middle (*filled triangle* 2 months) and after (*open square* 4 months) resistance training at high intensity. Data presented as the mean ± SEM

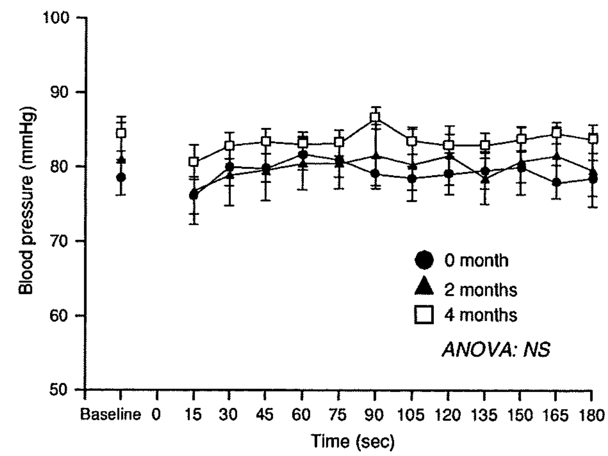

Fig. 5 Blood pressure during reactive hyperemia at before (*filled circle* 0 month), middle (*filled triangle* 2 months) and after (*open square* 4 months) resistance training at moderate intensity. Data presented as the mean ± SEM

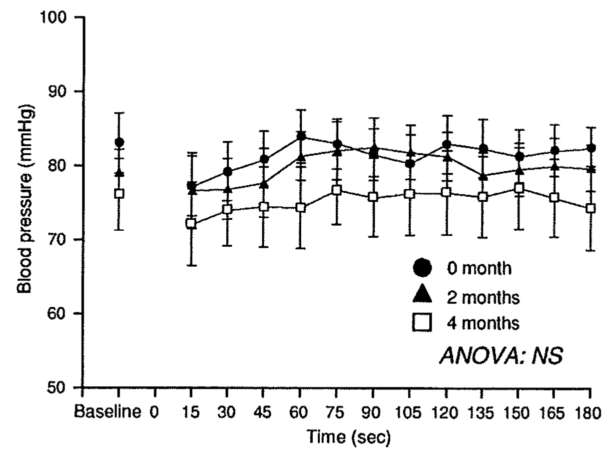

Fig. 6 Blood pressure during reactive hyperemia at before (*filled circle* 0 month), middle (*filled triangle* 2 months) and after (*open square* 4 months) combined resistance and aerobic training. Data presented as the mean ± SEM

be incorporated into exercise regimens for the prevention of sarcopenia or osteoporosis and the maintenance of functional capacity [7, 8]. Therefore, in the future, combined resistance and aerobic exercise may be endorsed as a treatment in clinical practice as well as prescribed exercise. It is, however, incompletely understood whether cardiovascular function is affected by resistance training, let alone by a combination of resistance and aerobic training. We have determined the effects of different intensities of resistance training as well as a combination of aerobic and resistance training on forearm blood flow during RH, resulting in enhanced endothelial function in the microvasculature with both moderate-intensity resistance training and combined aerobic and resistance training. Our findings may contribute to understanding the adaptation of microvascular function with exercise training, including resistance exercise, leading to the development of prescribed exercise.

In our results, moderate-intensity resistance training increased forearm blood flow response to RH, but high-intensity resistance training did not. Although the exercise volumes of the HIR and MIR groups in the present study were similar, the total time that tonic force was applied to the muscular function in the MIR group was longer compared with the HIR group in the present intervention study. Our results suggest that resistance exercise for a longer time and at a lower intensity in the MIR group might induce the enhancement of endothelial function in the microvasculature of the forearm assessed by RH. Previous studies have demonstrated that low-intensity resistance exercise with slow movement and the generation of tonic force on muscular function induces hypertrophy through the hypoxic intramuscular environment [26], and this may lead to the activation of angiogenesis. One possibility is therefore that intramuscular hypoxia induced by moderate-intensity resistance training in the present study increased the forearm blood flow during RH via angiogenesis. On the other hand, we previously demonstrated that performing resistance training not only at high-intensity but also at moderate-intensity decreased central arterial compliance [9, 10], suggesting an increase in the risk of cardiovascular disease. Previous and present findings indicate that resistance training has an unfavorable effect on the elastic properties of the central artery, but the reverse effect on the endothelial function in the peripheral microvasculature. We propose that, given these unfavorable and favorable effects on central and peripheral cardiovascular function, resistance training should be carefully prescribed, taking into account the clinical characteristics of the clients or patients.

In the present study, forearm blood flow during RH was increased by a combination of high-intensity resistance and moderate-intensity aerobic training, but not by high-intensity resistance training alone. These results suggest that aerobic training performed concurrently with resistance training may enhance the endothelial function in the microvasculature, even if high-intensity resistance training does not favorably affect the function. We have recently demonstrated that high- and moderate-intensity resistance training is associated with a reduction in arterial compliance, an independent risk factor for cardiovascular disease [9, 10], but a combination of resistance and aerobic training is not [10]. These results suggest the importance of performing aerobic training concurrently with resistance training. Results in the present study also support the hypothesis that a combination of resistance and aerobic exercise training maintains and enhances the vascular functions, including endothelium-dependent vasodilation in the microvasculature.

Chronic and repeated increases in blood flow exert their effects on endothelial vasodilatation by modulating the expression of nitric oxide synthase [27], and regular aerobic exercise thereby improves endothelium-dependent vasorelaxation in the microvasculature and peripheral conduit arteries through an increase in the release of nitric oxide in both normotensive and hypertensive men [4, 28]. Recently, we and others have demonstrated that resistance training is not associated with the endothelial function in the carotid and brachial arteries [12, 13]. It is speculated that the enhancement of endothelial vasodilatation during RH with a combination of resistance and aerobic training was engendered by the effects of aerobic factors in the combined training, such as increased blood flow, shear stress or nitric oxide bioavailability. Indeed, considering that forearm vasoreactivity to RH was not changed by high-intensity resistance training, our speculation may be reasonable. Nonetheless, because moderate-intensity resistance training in the present study enhanced endothelium-dependent vasodilation during RH, future studies are needed to confirm the effects of a combination of moderate-intensity resistance and aerobic training, and to determine the effective intensity of resistance training needed for the enhancement of endothelial function in the microvasculature.

There was a more pronounced trend toward an increase in forearm blood flow during RH after 2 months than after 4 months in the COMBO group, but the difference was not significant. We speculate that adaptation of forearm blood flow during RH response to combined training had already been completed during the training period (i.e., 2 months), and increased forearm blood flow during RH due to combined training was gradually beginning to return to baseline. On the other hand, in the MIR group, the increase in forearm blood flow lasted for as long as that in the COMBO groups. Although it seems that increases in forearm blood flow during RH in the MIR and COMBO groups are the same adaptations, we feel that there are different mechanisms in increased forearm blood flow during RH between the MIR and COMBO groups. We hypothesize that an increase in forearm blood flow during RH in the COMBO group may be induced by the aerobic training component in the combined training. On the other hand, subjects in the MIR group performed resistance training at moderate intensity without aerobic exercise training. Moderate intensity resistance training may induce an hypoxic intramuscular environment [26]. As previously described in this discussion, this may induce the activation of angiogenesis, resulting in increased forearm blood flow during RH with moderate intensity resistance training. Generally, improvements in endothelial function may be induced by a number of stimuli (i.e., aerobic training) rather than by angiogenesis. At 2 months in the present study, forearm blood flow during RH in the COMBO group increased, but was unchanged in the MIR group. These results suggest that there may be differences in mechanisms between the MIR and COMBO groups.

We continuously measured radial blood pressure using a tonometric sensor before and during RH. Radial blood pressure during RH was not affected by exercise training in the three groups. Therefore, this result supports the hypothesis that increased forearm blood flow in the MIR and COMBO groups may be induced by enhanced endothelial-dependent vasodilation.

Previous studies have demonstrated that a combination of resistance and aerobic training (including circuit training) improved endothelial dysfunction in patients with cardiovascular disease or type 2 diabetes [14, 18]. Although there are differences in subjects, and the intensity and duration of the combined training, the results of the present study—enhanced endothelial function with a combination of resistance and aerobic training—are consistent with previous studies. Overall, it is considered that aerobic training performed concurrently with resistance training may improve endothelial function, not only in patients with cardiovascular disease or type 2 diabetes mellitus, but in healthy young adults as well.

Using one-way ANOVA, baseline forearm blood flow in the COMBO group significantly increased at the middle- and end-point training period compared with pre-training (Fig. 3). Although previous studies, focused on blood flow response to RH, have not paid attention to baseline blood flow [5, 22, 29–34], we should emphasize that the increased RH in the COMBO group may be partly associated with an increase in baseline blood flow. The increase in baseline blood flow and RH may be induced by angiogenesis, muscular hypertrophy and improvements of endothelial and autonomic functions [5, 35, 36], but further study is warranted to clarify the mechanisms.

We have not examined the change in maximal oxygen consumption over the 4-month study period. Considering the effect of aerobic training on aerobic capacity, changes in maximal oxygen uptake induced by exercise training should have been determined, and the result would have provided supportive evidence that subjects performed exercise training properly during time of the intervention study. As an alternative to this approach, we monitored all training sessions performed by subjects.

Conclusion

The findings of this study demonstrate that a combination of resistance and aerobic training increases the blood flow response to RH and resting blood flow in the forearm, whereas resistance training alone does not. However, performing resistance training at moderate intensity may also induce increase of blood flow during RH. These results suggest that aerobic training performed concurrently with resistance training enhances the vasoreactivity response to RH via partly improvint the endothelial function in the forearm. In addition, future studies should determine the synergic effects of combining moderate intensity resistance with aerobic training on endothelial function in the microvasculature.

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Differences in body composition and risk of lifestyle-related diseases between young and older male rowers and sedentary controls

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Abstract

The aim of this cross-sectional study was to compare body composition and risk factors of lifestyle-related diseases between young and older male rowers and sedentary controls. Healthy males aged 19–73 years participated in the study, and were divided into four groups: 26 young rowers, 24 senior rowers, 23 young sedentary controls, and 22 senior sedentary controls. Total and regional lean soft tissue, fat mass, and bone mineral density were measured using dual-energy X-ray absorptiometry. The HDL-cholesterol of senior rowers (67.4 ± 13.4 mg · dl^{-1}) was significantly ($P < 0.05$) higher than that of senior sedentary controls (59.2 ± 11.9 mg · dl^{-1}), while HDL-cholesterol was similar in senior rowers and young rowers (66.1 ± 10.8 mg · dl^{-1}). Arm, leg, and trunk lean soft tissue mass were significantly higher in senior rowers (5.6 ± 0.6 kg, 18.2 ± 1.8 kg, and 27.3 ± 3.2 kg respectively) than in senior sedentary controls (5.1 ± 0.4 kg, 16.3 ± 1.4 kg, and 24.6 ± 1.7 kg respectively; $P < 0.05$). Bone mineral density was also significantly higher in senior rowers than in senior sedentary controls (ribs, lumbar spine, and pelvic segments; $P < 0.05$). We conclude that age-related increases in the risk of lifestyle-related diseases, such as osteoporosis and sarcopenia, are attenuated in male rowers. These results suggest that regular rowing exercise may have a positive influence in the prevention of lifestyle-related diseases in older Japanese people.

Keywords: *Age, body composition, fitness, lifestyle-related diseases, oarsmen*

Introduction

Regular endurance exercise reduces the risk of developing type 2 diabetes (Helmrich, Ragland, Leung, & Paffenmbarger, 1991; Knowler et al., 2002; Lynch et al., 1996; Pan et al., 1997), decreases blood pressure (Dengel, Galecki, Hagberg, & Pratley, 1998; Hagberg, Park, & Brown, 2000; Ishikawa-Takata, Ohta, & Tanaka, 2003; Kelley, Kelley, & Tran, 2001), and improves the ability to oxidize long-chain fatty acids, particularly those from triglycerides stored within active muscle (Kiens, 1997; Martin, 1996; Turcotte, Richter, & Kiens, 1992). Therefore, endurance exercise and/or moderate-intensity physical activity are recommended to prevent coronary heart disease (American College of Sports Medicine, 2006). On the other hand, resistance training increases fat-free mass and possibly also resting metabolic rate (Poehlman & Melby, 1998), improves glycaemic control (Poehlman, Dvorak, DeNino, Brochu, & Ades, 2000), and may improve lipoprotein profile (Prabhakaran, Dowling, Branch, Swain, & Leutholtz, 1999) and reduce hypertension (Hurley & Roth, 2000). Currently, resistance training is recommended primarily for elderly people and individuals with cardiovascular disease as a means of improving overall musculoskeletal function (National Institutes of Health, 1996). Moreover, osteoporosis has a debilitating effect on both independence and quality of life. Exercise prescription, especially resistance-based and weight-bearing activity, increases bone mineral density, and aerobic weight-bearing activity and resistance training are recommended (American College of Sports Medicine, 2006). Rowing is not a weight-bearing sport, but can mobilize muscles throughout the whole body, including the upper and lower extremities and the trunk region.

Rowing is composed of both endurance and resistance exercise, and therefore enhances both muscle function and cardiopulmonary fitness. However, little information is available regarding whether regular rowing exercise reduces the risk of coronary heart disease independent of age. Yoshiga and colleagues (Yoshiga, Higuchi, & Oka, 2002b) reported that although the indices of risk factors for coronary heart disease were higher in older than in

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younger oarsmen, they were lower than those in both older and young sedentary men. Moreover, a recent study indicated that regular rowing exercise in middle-aged and older adults is associated with a favourable effect on the elastic properties of the central arteries (Cook et al., 2006). These results suggest that rowing is an appropriate type of exercise for the prevention of coronary heart disease.

However, it has been established that large fluctuations in pressure are superimposed on the normal blood pressure waveform during rowing (Clifford, Hanel, & Secher, 1994). The blood pressure response to rowing is principally influenced by a Valsalva-like manoeuvre performed at the catch of each stroke. The observed fluctuations in arterial pressure may explain the degree of myocardial hypertrophy that occurs in rowers. Pelliccia and colleagues (Pelliccia, Maron, Spataro, Proschan, & Spirito, 1991) reported that a left ventricular wall thickness of ≥ 13 mm is very uncommon in highly trained athletes, virtually confined to athletes training in rowing, and is associated with an enlarged left ventricular cavity. Thus, it is unclear whether long-term rowing exercise has a favourable effect on the prevention of coronary heart disease.

Osteoporosis is another lifestyle-related disease, and epidemiological evidence has linked osteoporosis and cardiovascular disease (Hsu et al., 2006). It has been shown that young adult rowers have a low total body bone mineral density and low leg bone mineral density compared with age-matched participants in rugby, soccer, other team sports, and fighting sports (Morel, Combe, Francisco, & Bernard, 2001), and rowers also have significantly higher bone mineral density in the spine and total body than triathletes and sedentary controls (Smith & Rutherford, 1993). However, it is unclear whether the age-related differences in body composition include the total or regional bone mineral density and lean soft tissue mass measured by dual-energy X-ray absorptiometry in young and senior rowers.

We hypothesized that habitual rowing exercise may enhance cardiorespiratory fitness and body composition, and reduce age-related risk factors, such as serum lipoprotein concentration, blood pressure, and bone mineral density. Therefore, the aim of this cross-sectional study was to compare body composition and risk factors of lifestyle-related diseases between young and older male rowers and age-matched sedentary controls.

Materials and methods

Participants

Ninety-five young and older men aged 19–73 years participated in the study, and were divided into four groups: 23 young controls (age 25.3 ± 2.7 years), 26 young rowers (age 20.3 ± 1.0 years), 22 senior controls (age 65.2 ± 4.1 years), and 24 senior rowers (age 65.7 ± 3.0 years). The sedentary participants (young sedentary controls and senior sedentary controls) were recruited through various forms of advertisement and had not participated in a regular exercise programme for at least 2 years. The rowers (young rowers and senior rowers) were recruited from various rowing clubs and had been performing vigorous rowing training. The senior rowers had been involved continuously in regular rowing exercise for 40–50 years. The age at which the seniors began rowing was 19.4 ± 1.7 years, and they had been rowing for 46.7 ± 2.8 years. At present, they rowed 2 days a week on the water or on an ergometer, each session lasting 90–120 min including warm-up, 12–16 km of rowing, and recovery. The young rowers had rowed at least 3–5 days a week on the water or on an ergometer for more than 3 years (median training distance, 60–100 km $\cdot$ week^{-1}).

Body mass was measured on a beam-balance scale (Yamato 7920; Yamato Scale, Akashi, Japan) to the nearest 0.1 kg and height was measured to the nearest 0.1 cm. The body mass index was also calculated (kg $\cdot$ m^{-2}).

None of the participants were taking medications, such as beta-blockers or hormone replacement therapy, or smoked cigarettes, which are known to affect the study variables. The aim, procedures, and risks of the study were explained to each participant before their inclusion, and all participants provided their written informed consent before taking part in the study, which was approved by the Ethics Committee of Waseda University and was performed in accordance with the guidelines of the Declaration of Helsinki.

Whole-body dual-energy X-ray absorptiometry

Lean soft tissue mass, fat mass, bone mineral content, and bone mineral density were determined for the whole body using dual-energy X-ray absorptiometry (DXA) (Hologic QDR-4500A scanner; Hologic, Waltham, MA, USA). Participants were positioned for whole-body scans according to the protocol recommended by the manufacturer. Participants lay supine on the DXA table with the limbs close to their body. Fat-free body mass was the sum of lean soft tissue mass and bone mineral content. To minimize inter-observer variation, all scans and analyses were carried out by the same investigator, and the day-to-day coefficients of variation of their observations were $<0.8\%$ for bone mineral density in the whole body, calculated in six men. Bone mineral density was measured in the whole body. The whole-body bone mineral content and lean soft tissue mass were divided into several regions: the arms, legs, trunk, and head.

The body compositions were analysed 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 tips 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 tips of the toes. The sub-total body was defined as the region extending from the shoulders to the distal tips of the toes. This process was performed to exclude the bones in the head and teeth. We selected a reference point that could be clearly visualized on the DXA system terminal.

Blood sampling

All blood samples were drawn with the participant in a seated position. Fasting (> 12 h) blood samples for plasma or serum were collected by venepuncture in tubes with or without ethylenediamine tetra-acetic acid, refrigerated immediately, and centrifuged at 1500 rev $\cdot$ min^{-1} for 30 min at 4°C within 2 h. Serum and plasma samples from each participant were stored at −20°C. Serum concentrations of total cholesterol and triglyceride were determined using commercial kits (Mitsubishi Chemical Medience, Tokyo, Japan). Serum high-density lipoprotein (HDL)-cholesterol was measured by an enzymatic method (Mitsubishi Chemical Medience, Tokyo, Japan). Serum low-density lipoprotein (LDL)-cholesterol was calculated as follows: Total cholesterol (mg $\cdot$ dl^{-1}) − HDL-cholesterol (mg $\cdot$ dl^{-1}) − Triglyceride (mg $\cdot$ dl^{-1}) × 0.2 (Friedewald, Levy, & Fredrickson, 1972). Plasma glucose was measured using the glucose dehydrogenase method (Kuan, Kuan, & Guilbault, 1977).

Arterial blood pressure at rest

Chronic arterial blood pressure at rest was measured with a semi-automated device (Form PWV/ABI; Colin Medical Technology, Komaki, Japan) over the brachial and dorsalis pedis arteries. Recordings were made in triplicate with the participants in the supine position. Brachial-ankle pulse wave velocity was measured by the volume plethysmographic method, and brachial-ankle velocity was then calculated and used as a measure of atherosclerosis in leg arteries. The brachial-ankle pulse wave velocity provides qualitatively similar information to that derived from central arterial stiffness (Sugawara et al., 2005).

Measurement of fitness

Peak oxygen uptake ($\dot{V}O_{2peak}$) was measured by an incremental exercise test using a cycle ergometer (Monark, Varberg, Sweden) in sedentary participants or rowing ergometer (Model C; Concept II, Morrisville, VT, USA) in rowers, because of concerns for the safety of sedentary participants and specificity of training in rowers. The incremental cycle exercise began at a work rate of 90 W (60 rev $\cdot$ min^{-1}), and power output was increased by 30 W each minute until the participant could not maintain the fixed pedalling frequency. During ergometer rowing, the initial intensity was 100 W and it was increased by 50 W every 2 min. The rowing intensity was increased through additional resistance. The participants were encouraged during the test to exercise at as high intensity as possible. Exercise was terminated when the participant could not maintain the required intensity. Heart rate (Life Scope 6; Nihon Kohden, Tokyo, Japan) and a rating of perceived exertion [RPE; modified Borg Scale (Borg, 1982)] were monitored minute by minute during exercise. Oxygen uptake ($\dot{V}O_2$) was monitored during the last 30 s of each increase in work rate after the RPE reached 18 using the Douglas bag method. The participants breathed through a low-resistance two-way valve, and the expired air was collected in Douglas bags. Expired O_2 and CO_2 gas concentrations were measured by mass spectrometry (WSMR-1400; Westron, Chiba, Japan), and gas volume was determined using a dry gas meter (Shinagawa Dev. NDS-2A-T, Tokyo, Japan). The highest value of $\dot{V}O_2$ during the exercise test was designated $\dot{V}O_{2peak}$. Handgrip strength of the right upper limb was measured using a hand-held dynamometer. In the standing position, arms straight by the sides, the participant gripped the dynamometer as hard as possible for 3 s without pressing the instrument against the body or bending at the elbow. Values (kg) were recorded as the averages of two attempts.

Statistical analysis

All measurements and calculated values are expressed as means ± standard deviations. The data were analysed by two-way analysis of variance (ANOVA: age × physical activity status). In the case of significant interactions, the effects of age were analysed in rowers and controls separately, and the effects of rowing were analysed in young and older participants separately. A *post hoc* test using the Newman-Keuls method was used to identify significant differences among mean values. Statistical significance was set at $P < 0.05$. All statistical analyses were performed using Stat View v5.0 for Windows (SAS Institute, Cary, NC, USA).

Results

The physical characteristics of the participants are presented in Table I. Percent body fat in the young group was significantly lower than that in the senior group ($P = 0.001$). Percent body fat in rowers was also significantly lower than in controls ($P < 0.0001$). Peak $\dot{V}O_2$ in the young group was significantly higher than in the senior group ($P < 0.0001$). In addition, $\dot{V}O_{2peak}$ was significantly higher in rowers than in controls ($P < 0.0001$). The interaction between age and rowing (age × rowing) was not significant for $\dot{V}O_{2peak}$. Thus, aerobic fitness associated with rowing training was independent of age. Handgrip strength in the young group was significantly higher than that in the senior group ($P < 0.01$). The interaction between age and rowing (age × rowing) was significant ($P < 0.001$) for handgrip strength. A separate analysis revealed greater strength in senior rowers than senior sedentary controls, whereas no differences were observed between young sedentary controls and young rowers. In addition, young sedentary controls were stronger than senior sedentary controls, but no differences were observed between young rowers and senior rowers.

Table II presents the blood sample results and arterial blood pressure at rest. All rowers had higher HDL-cholesterol and HDL-cholesterol/LDL-cholesterol ratio than controls; there was a significant effect of rowing that was independent of age ($P < 0.05$). All rowers had higher diastolic blood pressure than controls; there was a significant effect of rowing that was independent of age ($P < 0.01$). In addition, although brachial-ankle velocity in rowers was similar to that in controls, all rowers had lower brachial-ankle pulse wave velocity than controls, independent of age ($P < 0.05$) (Figure 1).

All rowers had higher total, leg, and trunk lean soft tissue mass than controls; there was a significant effect of rowing that was independent of age ($P < 0.01$) (Table III). Arm lean soft tissue mass in the senior group was significantly lower than that in the young group ($P < 0.0001$). However, the interaction between age and rowing (age × rowing) was significant ($P < 0.01$) for arm lean soft tissue mass. Thus, the age-related difference in arm lean soft tissue mass was attenuated in rowing-trained

Table I. Physical characteristics of the participants (mean ± *s*).

	Controls		Rowers		P (two-way ANOVA)			
	Young ($n=23$)	Senior ($n=22$)	Young ($n=26$)	Senior ($n=24$)	Rowing	Age	Interaction	Tukey test
Age (years)	25.3 ± 2.7	65.2 ± 4.1	20.3 ± 1.0	65.7 ± 3.0				
Body mass (kg)	70.8 ± 11.2	67.9 ± 8.1	69.3 ± 5.7	67.9 ± 8.2	0.658	0.221	0.676	
BMI (kg · m^{-2})	23.5 ± 3.7	24.3 ± 2.6	22.3 ± 1.4	23.0 ± 2.9	0.030	0.205	0.859	
% Body fat	14.8 ± 4.9	22.4 ± 4.7	11.7 ± 2.2	18.8 ± 5.0	0.001	<0.0001	0.805	
$\dot{V}O_{2peak}$ (ml · kg^{-1} · min^{-1})	44.7 ± 10.0	29.1 ± 3.1	57.6 ± 6.1	35.0 ± 6.5	<0.0001	<0.0001	0.084	
Handgrip strength (kg)	51.7 ± 11.3	39.9 ± 6.0	47.3 ± 8.3	48.8 ± 6.9	0.209	0.004	0.0003	*#

*$P < 0.05$ young controls vs. senior controls. #$P < 0.05$ senior controls vs. senior rowers.

Table II. Blood sample results and arterial blood pressure at rest (mean ± *s*).

	Controls		Rowers		P (two-way ANOVA)			
	Young ($n=23$)	Senior ($n=22$)	Young ($n=26$)	Senior ($n=24$)	Rowing	Age	Interaction	Tukey test
Glucose (mg · dl^{-1})	91.1 ± 10.3	103.1 ± 17.6	90.3 ± 5.4	103.2 ± 18.8	0.908	<0.0001	0.888	
Trigylceride (mg · dl^{-1})	78.0 ± 38.6	117.8 ± 69.7	55.9 ± 12.9	117.5 ± 65.0	0.288	<0.0001	0.300	
Total cholesterol (mg · dl^{-1})	181 ± 37	191 ± 50	165 ± 22	207 ± 18	0.979	0.0003	0.022	‡
HDL cholesterol (mg · dl^{-1})	60.0 ± 12.8	59.2 ± 11.9	66.1 ± 10.8	67.4 ± 13.4	0.006	0.904	0.682	
LDL cholesterol (mg · dl^{-1})	105.4 ± 33.5	117.7 ± 32.6	88.0 ± 16.5	116.0 ± 16.4	0.074	0.0002	0.138	
HDL/LDL ratio	0.62 ± 0.22	0.56 ± 0.24	0.77 ± 0.16	0.60 ± 0.18	0.019	0.005	0.205	
Systolic blood pressure (mmHg)	116.5 ± 9.1	142.7 ± 21.9	115.3 ± 8.9	134.5 ± 14.4	0.119	<0.0001	0.247	
Diastolic blood pressure (mmHg)	66.4 ± 5.9	86.6 ± 13.9	59.0 ± 5.8	82.7 ± 9.4	0.004	<0.0001	0.377	
Resting heart rate (beats · min^{-1})	56.5 ± 7.1	60.4 ± 12.1	54.1 ± 5.5	58.9 ± 9.4	0.287	0.018	0.816	
Brachial-ankle PWV (cm · s^{-1})	1183 ± 123	1711 ± 362	1143 ± 153	1544 ± 237	0.037	<0.0001	0.201	
Ankle-brachial index (units)	1.12 ± 0.09	1.16 ± 0.11	1.14 ± 0.05	1.19 ± 0.08	0.330	0.013	0.754	

‡$P < 0.05$ young rowers vs. senior rowers.

men. All rowers had higher bone mineral density of the ribs and lumbar spine segments than the control group ($P < 0.01$). Arm bone mineral density in the senior group was significantly lower than that in the younger group ($P < 0.0001$). However, the interaction between age and rowing (age × rowing) was significant ($P < 0.01$) for arm bone mineral density (Figure 2). Thus, the age-related differences in arm bone mineral density were attenuated in rowing-trained men.

Discussion

The aim of this cross-sectional study was to compare body composition and risk factors of lifestyle-related diseases between young and older male rowers and sedentary age-matched controls. The major findings of this cross-sectional study were as follows: (1) all rowers had higher a HDL-cholesterol and HDL-cholesterol/LDL-cholesterol ratio than controls independent of age; (2) although brachial-ankle velocity in rowers was similar to that in controls, all rowers had lower brachial-ankle pulse wave velocity than controls independent of age; and (3) age-related losses in arm lean soft tissue mass and bone mineral density were attenuated in rowing-trained men. These results suggest that regular rowing exercise may have a positive effect in the prevention of lifestyle-related diseases in middle-aged and elderly rowers.

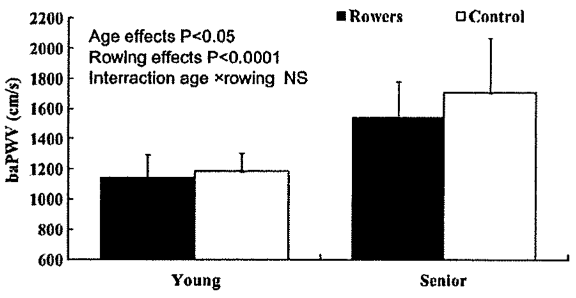

Figure 1. Brachial-ankle pulse wave velocity (baPWV) in young and senior rowers. Two-way ANOVA indicated that all rowers had lower brachial-ankle pulse wave velocity than age-matched controls, independent of age ($P < 0.05$). ■, rowers; □, controls.

Regular rowing, ageing, and risk factors for coronary heart disease

The prevalence of obesity is increasing at an alarming rate worldwide. The American College of Sports Medicine recommends that the exercise component of obesity-management programmes should be based on exercises that use large muscle groups, are rhythmic and aerobic, can be done over prolonged periods of time, and are associated with a relatively low risk of injury. Rowing exercise meets all these criteria.

The indices of risk factors for coronary heart disease (LDL-cholesterol/HDL-cholesterol and/or total cholesterol/HDL-cholesterol) were lower in older oarsmen than in both older and younger sedentary men (Yoshiga et al., 2002b). Therefore, it was suggested that rowing is an appropriate type of exercise for the promotion of health. However, it is unclear whether there are age-related differences in the risk factors for coronary heart disease, including arterial blood pressure. In the present study, all rowers had higher HDL-cholesterol and HDL-cholesterol/LDL-cholesterol ratio than controls, and there was a significant effect of rowing that was independent of age (Table II).

In addition, rowers had higher diastolic blood pressure than controls, independent of age

Table III. Total and regional lean soft tissue mass and bone mineral density (mean ± *s*).

	Controls		Rowers		*P* (two-way ANOVA)			
	Young ($n = 23$)	Senior ($n = 22$)	Young ($n = 26$)	Senior ($n = 24$)	Rowing	Age	Interaction	Tukey test
Lean soft tissue mass (kg)								
Total	53.8 ± 5.7	46.2 ± 3.1	55.5 ± 4.6	51.2 ± 5.5	0.002	<0.0001	0.120	
Arm	6.9 ± 1.2	5.1 ± 0.4	6.3 ± 0.5	5.6 ± 0.6	0.861	<0.0001	0.003	* ‡
Leg	20.0 ± 2.7	16.3 ± 1.4	21.1 ± 1.8	18.2 ± 1.8	0.001	<0.0001	0.358	
Trunk	27.1 ± 3.1	24.6 ± 1.7	28.1 ± 5.4	27.3 ± 3.2	0.003	0.008	0.165	
Bone mineral density ($g \cdot cm^{-2}$)								
Total	1.22 ± 0.09	1.10 ± 0.10	1.20 ± 0.08	1.16 ± 0.09	0.362	<0.0001	0.056	
Arm	0.88 ± 0.08	0.77 ± 0.06	0.83 ± 0.05	0.80 ± 0.06	0.468	<0.0001	0.002	* †
Rib	0.73 ± 0.08	0.66 ± 0.08	0.76 ± 0.07	0.73 ± 0.08	0.001	0.003	0.165	
Thoracic spine	0.93 ± 0.09	0.91 ± 0.14	0.94 ± 0.10	0.95 ± 0.13	0.436	0.977	0.469	
Lumbar spine	1.07 ± 0.13	1.02 ± 0.16	1.13 ± 0.12	1.12 ± 0.17	0.007	0.154	0.344	
Pelvis	1.30 ± 0.16	1.12 ± 0.14	1.31 ± 0.14	1.24 ± 0.16	0.093	0.001	0.125	
Leg	1.32 ± 0.13	1.17 ± 0.09	1.30 ± 0.10	1.23 ± 0.08	0.668	<0.0001	0.097	

*$P < 0.05$ young controls vs. senior controls. ‡$P < 0.05$ young rowers vs. senior rowers. †$P < 0.05$ young controls vs. young rowers.

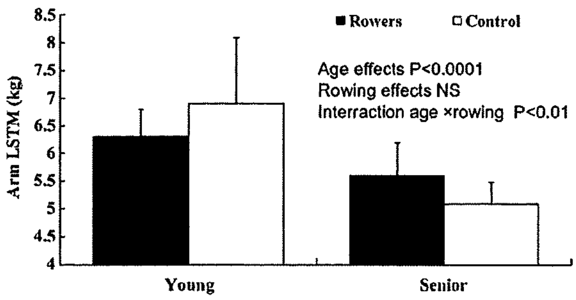

Figure 2. Arm lean soft tissue mass (LSTM) measured by DXA in young and senior rowers. Two-way ANOVA indicated that arm lean soft tissue mass was significantly lower in the senior group than in the younger group ($P < 0.0001$). However, the interaction between age and rowing (age × rowing) was significant ($P < 0.01$) for arm lean soft tissue mass. Thus, the age-related difference in arm lean soft tissue mass was attenuated in rowing-trained men.

($P < 0.01$). The blood pressure response to rowing is mostly influenced by a Valsalva-like manoeuvre performed at the catch of each stroke. Clifford et al. (1994) reported that mean arterial pressure increased only modestly from 110 ± 13 to 122 ± 24 mmHg ($P < 0.05$) in ten male oarsmen who performed a 6-min bout of "all-out" exercise on a rowing ergometer. Cook et al. (2006) reported that brachial blood pressure, carotid blood pressure, carotid artery intima-media thickness, and ankle-brachial pressure index were not different between rowers and sedentary controls, but central arterial compliance (simultaneous ultrasound and applanation tonometry on the common carotid artery) was higher and carotid-stiffness index was lower in rowers than in sedentary controls. Arterial stiffness is a major contributing factor to cardiovascular disease and is becoming a focal point in efforts aimed at the early detection and prevention of cardiovascular disease (Safar & London, 2000).

The brachial-ankle pulse wave velocity is the gold standard technique for measuring arterial stiffness, as described in the consensus statement on arterial stiffness (O'Rourke, Staessen, Vlachopoulos, Duprez, & Plante, 2002). Sugawara et al. (2005) reported that the brachial-ankle pulse wave velocity provides qualitatively similar information to that derived from central arterial stiffness. The greatest advantage of the brachial-ankle pulse wave velocity is that it is a simple method involving only wrapping the four extremities with blood pressure cuffs. In this study, although brachial-ankle velocity in rowers was similar to that in controls, all rowers had lower brachial-ankle pulse wave velocity than controls independent of age ($P < 0.05$) (Figure 1). Although a longitudinal study may provide the final answer, this cross-sectional study suggests that regular rowing exercise may have a positive effect in the prevention of serum lipid abnormalities and arterial stiffening.

Regular rowing, ageing, and bone mineral density

Peak bone mass is an important determinant of the risk of osteoporosis, and the age of attainment of peak bone mass is site specific (Lorentzon, Mellstrom, & Ohlsson, 2005). It has been reported that rowers and swimmers have low total body bone mineral density (1.22 and 1.17 vs. 1.27–1.35 $g \cdot cm^{-2}$) and low leg bone mineral density (1.37 and 1.31 vs. 1.41–1.5 $g \cdot cm^{-2}$) compared with a group of 704 amateur sportsmen involved in rugby, soccer, other team sports, and fighting sports (Morel et al., 2001). However, experienced rowers showed a 2.5% increase at the spine that was significantly greater than that in novice rowers (Lariviere, Robinson, & Snow, 2003). The number of strokes (repetitions) was similar between rowing groups during training, but the higher power output in experienced rowers produced higher forces at the spine over the 6-month period of the study, which resulted in gains in spine bone mineral density. These results suggest that higher power output plays an important role in site-specific bone mineral formation, and support the theory that force magnitude is a key variable in osteogenesis. In this study, the age-related difference in arm bone mineral density was attenuated in rowing-trained men, but the total bone mineral density and leg bone mineral density in senior rowers were not significantly different from those in the senior sedentary group (Table III). This result may be associated with the type of exercise during training. Rowing exercise makes better use of the upper body and trunk compared with the other forms of weight-bearing exercise, such as walking, running, and cycling. In fact, the ribs, lumbar spine, and pelvis bone mineral densities in senior rowers were significantly greater than those in the senior sedentary group.

Regular rowing, ageing, fitness, and body composition

Rowers perform a combination of endurance and strength training during their usual training regimen, as demonstrated by their high maximal aerobic capacity and muscle strength (Cook et al., 2006; Secher, 1993; Yoshiga, Higuchi, & Oka, 2002a). Both male and female rowers have higher $\dot{V}O_{2max}$ values and also exhibit excellent isokinetic leg strength and power in comparison with other elite athletes. Oarswomen also produce higher relative leg strength values than oarsmen when lean body mass is taken into consideration (Hagerman, 1984). Hagerman et al. (1996) reported the fitness values (peak power, metabolic responses, and heart rate during rowing ergometer training) in nine 1972 silver-medallist oarsmen before the Olympic Games and 20 years later. Percent body fat increased from 12.3 to 15.6% while $\dot{V}O_{2peak}$ decreased from 65.5 to 46.8 ml · kg^{-1} · min^{-1} from 1972 to 1992. In the present cross-sectional study, percent body fat was 11.7 and 18.8% and $\dot{V}O_{2peak}$ 57.6 and 35.0 ml · kg^{-1} · min^{-1} for young rowers and senior rowers respectively (Table I). The difference in percent body fat was similar to that reported in a previous longitudinal study, but the difference in $\dot{V}O_{2peak}$ in this study was small. Moreover, although the handgrip strength of the younger group was significantly higher than that of the senior group ($P < 0.01$), the interaction between age and rowing (age × rowing) was significant for handgrip strength. Therefore, the age-related decrease in handgrip strength was attenuated in rowing-trained men.

Sarcopenia, the decline of muscle mass with age, is strongly associated with bone loss and osteoporosis and is the cause of a large percentage of late-life disability. Yoshiga et al. (2002a) reported previously that the leg extensor muscle area and bilateral leg extension power were greater in oarsmen than in sedentary controls. They suggested that rowing prevents age-related muscle wasting and weakness. However, no information is available regarding the effects of rowing on age-related decreases in the total and/or regional muscle mass measured by DXA. In the present study, total, leg, and trunk lean soft tissue mass in senior rowers were significantly greater than in senior controls (Table III). In particular, the age-related difference in arm lean soft tissue mass was attenuated in rowing-trained men (Figure 2). These results suggest that regular rowing exercise may attenuate osteoporosis and/or whole-body sarcopenia.

Conclusions

Based on the results of the present study, we conclude that age-related increases in the risk factors of coronary heart disease, and decreases in bone mineral density and muscle mass, are attenuated in rowing-trained men. Our results suggest that regular rowing exercise may have a positive effect in the prevention of lifestyle-related diseases in older rowers.

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中高年者における心肺体力とメタボリックシンドローム危険因子との関係
—“健康づくりのための運動基準2006”を用いた検討—

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METABOLIC SYNDROME RISK FACTORS IN RELATION TO AEROBIC FITNESS IN JAPANESE MIDDLE-AGED AND ELDERLY PEOPLE —ANALYSIS BASED ON “EXERCISE AND PHYSICAL ACTIVITY REFERENCE FOR HEALTH PROMOTION 2006 (EPAR2006)”—

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Abstract

PORPOSE: This study aimed to compare the prevalence of metabolic syndrome (MS) risk factors and its components in different levels of aerobic fitness established by "Exercise and Physical Activity Reference for Health Promotion 2006 (EPAR2006)" in Japanese middle-aged and elderly people.
METHOD: Men (n=102) and women (n=133), aged 30-69yrs, participated in this study. The prevalence of MS risk factors was evaluated as the number of MS risk factors, according to the diagnostic criterion for Japanese-specific MS. Aerobic fitness was quantified as maximal oxygen uptake ($\dot{V}O_2$max). Subjects were classified into the three groups by aerobic fitness level based on "Reference values" and "Reference range" established in EPAR2006; 1) High fitness group (H); $\dot{V}O_2$max (mL/kg/min) is higher than "Reference values", 2) Medium fitness group (M); $\dot{V}O_2$max is below "Reference values" but within "Reference range", 3) Low fitness group (L); $\dot{V}O_2$max is lower than "Reference range".
RESULTS: In men, M and L groups showed significantly higher frequency of risk factors for MS than H group (H: 1.09±0.98, M: 1.81±1.07, L: 2.27±0.70, P<0.01). In women, L group showed significantly higher frequency of risk factors for MS than H and M groups (H: 0.57±0.80, M: 0.81 ±1.01, L: 1.53±1.07, P<0.01).
CONCLUSION: These results suggest that higher MS risk appears when the $\dot{V}O_2$max is lower than "Reference values" in men, and below "Reference range" in women, and that particularly, men with low aerobic fitness have higher MS risk.

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key word: metabolic syndrome, risk factors, aerobic fitness, middle-aged and elderly people

I．緒　　言

高い心肺体力は，生活習慣病を予防し，死亡率の低減に貢献することが示されている[1-3]．このため，健康の維持・増進において，心肺体力を高く保持することが重要である．近年では，メタボリックシンドローム（Metabolic syndrome; MS）の概念が世界的に注目されている．MSは，内臓脂肪の蓄積，

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血中脂質異常（高トリグリセリド，低HDLコレステロール），高血圧，高血糖などの動脈硬化危険因子が個人に集簇した状態であり，2型糖尿病および循環器系疾患を助長し[4]，循環器系疾患による死亡及び総死亡のリスクを高めることが示されている[5,6]．

欧米で行われた疫学研究では，最大酸素摂取量（$\dot{V}O_2max$）を指標とした心肺体力の低い人では，MSの発現頻度が高いことが報告されている[7,8]．さらに，大規模な疫学研究により，漸増負荷運動における総運動時間を指標とした心肺体力の低い集団では，内臓脂肪の蓄積を反映する腹囲が大きく，トリグリセリド，血圧および血糖の値が高く，HDLコレステロール値の低いことが報告されている[9~11]．したがって，高い心肺体力は，MSの発現に関連するこれらの危険因子に関与して，MSリスクを軽減すると考えられている．

我が国では，2006年に，"健康づくりのための運動基準2006―身体活動・運動・体力―（Exercise and Physical Activity Reference for Health Promotion 2006（EPAR2006））"が厚生労働省により策定され[12]，生活習慣病予防のために必要な心肺体力として，"健康づくりのための最大酸素摂取量"の「基準値」および「範囲」が示されている（Ref. 1）．欧米の研究[9~11]をもとに考えると，この体力基準を満たす日本人の集団でも，内臓脂肪の蓄積をはじめ，血中脂質異常，高血圧，高血糖の発現頻度が少なく，MSのリスクが低いと推測される．MS予防のために必要な心肺体力を明らかにする必要があるが，そのためには，大規模な運動疫学研究が必要である．しかし，これまで日本人を対象に心肺体力を実測してMS危険因子との関係を検討した研究はほとんどない．

Okuraら[13]は34～66歳の女性を対象に，心肺体力の異なる集団におけるMSの危険率を報告している．しかし，MS危険因子のどれがMS発現に関与しているかは検討されていない．また，日本人男性における心肺体力とMS及びその危険因子との関連についての検討は不十分である．日本人において，心肺体力がMSリスクとどの程度関連し，また，心肺体力がどのMS危険因子と特に関与しているかを明らかにすることは，MSや生活習慣病予防のための運動の普及・定着において重要である．また，"EPAR2006"で作成手法として用いられたシステマティックレビューにおいて，日本人を対象とした研究がわずか3本[14~16]であったことからも，日本人の心肺体力とMS予防に関するエビデンスが必要である．

我々はこれまで，日本人中高年男女の$\dot{V}O_2max$とMSに関するデータを蓄積してきた．本研究では，"EPAR2006"で基準とされた心肺体力レベルを保持している集団では，MSのリスクが低いことを検証するとともに，MS発現に関連する腹囲，血中脂質，血圧，血糖と心肺体力（$\dot{V}O_2max$）との関係についても検討を加えた．

Ⅱ．方　法

A．被験者

本研究は，2006年9月～2008年9月の期間に，早稲田大学スポーツ科学学術院運動生化学研究室における体力測定及び血液検査に参加した中高年男女を対象被験者とした．被験者は，主に地域のシルバー人材センター，大学内の教職員及びその関係者，また当研究室に縁故のある運動クラブに所属していた

Ref 1. "Reference values" and "Range" of maximal oxygen uptake (mL/kg/min) for health promotion by gender and age.

		20-29years	30-39years	40-49years	50-59years	60-69years
Males	Reference values	40	38	37	34	33
	Range	33-47	31-45	30-45	26-45	25-41
Females	Reference values	33	32	31	29	28
	Range	27-38	27-36	26-33	26-32	26-30

Ministry of Health, Labour and Welfare of Japan,
"Exercise and Physical Activity Reference for Health Promotion 2006 (EPAR2006)".

者に募集の案内を配布して集められた．被験者のうち，原則として重度の疾病を有していない（健康，または軽症で体力測定への参加が可能）30～69歳の男性102名および女性133名の計235名を分析の対象とした．本研究は，独立行政法人国立健康・栄養研究所「人間を対象とする生物医学的研究に関する倫理委員会」または早稲田大学スポーツ科学学術院「人間を対象とした研究倫理委員会」の承認を受け，ヘルシンキ宣言の精神に則って行われた．被験者には，事前に測定の目的と内容を説明し，書面により同意を得た後に，後述する諸検査及び心肺体力（$\dot{V}O_2max$）の測定を行った．

B．身体計測及び血液検査

身長，体重，腹囲及び血圧を早朝空腹状態で測定した．腹囲は立位で臍位置にて測定した．身長と体重より，BMI（Body mass index）を算出した．血圧は，椅座位で5分程度安静にした後，自動血圧計（HEM-759P，オムロン）によって測定した．被験者の上腕部にカフを巻きつけ，収縮期血圧（Systolic blood pressure; SBP）及び拡張期血圧（Diastolic blood pressure; DBP）を座位で2回ずつ測定し，それぞれの平均値を血圧の値とした．その後，早朝空腹状態のまま肘静脈から血液を採取し，トリグリセリド（Triglycerides; TG），HDLコレステロール（HDL cholesterol; HDL-C）および血糖（Blood glucose; BG）の濃度を分析した．血液分析は(株)SRLに委託して行った．

C．MSリスクの評価

MSリスクは，MSの発現に関連する危険因子の保有数を評価した．1)～4)までの日本内科学会によるMS判定基準[17]の各項目に該当する場合を「1」と数え，4項目の合計をMSリスク保有数とした; 1)腹囲（Waist circumference）≧85 cm（男性），≧90 cm（女性），2)血中脂質異常：TG≧150 mg/dL，かつ/またはHDL-C＜40 mg/dL，3)高血圧：SBP≧130 mmHg，かつ/または DBP≧85 mmHg，4)高血糖：BG≧110 mg/dL．なお，血中脂質異常，高血圧，糖尿病に対する薬剤治療をうけている場合は，それぞれの項目に含めた[17]．

D．$\dot{V}O_2max$の測定

$\dot{V}O_2max$を測定し，心肺体力の指標とした．$\dot{V}O_2max$は，自転車エルゴメータを用いた漸増負荷法により測定した．ペダル回転数を60回転に設定し，目標心拍数を110～120拍として5分間のウォーミングアップを行わせ，その後疲労困憊に至るまで1分毎に15Wずつ負荷を増加した．運動中は，各運動負荷ステージの心拍数と主観的運動強度（Rating of perceived exertion; RPE）を求めた．運動中の呼気ガスは，2006年に行われた60名の測定においては，ダグラスバッグ，ガスメーター（DC-50，品川製作所）および質量分析計（PC-9821，アルコシステム）を用いて採取・分析した．2007年以降に行われた測定においては，呼吸代謝測定装置（VO2000，Medical Graphics Corporation）を用いて分析した．VO2000の測定精度については，ダグラスバッグ法と高い妥当性が確認されている[18]．なお，2008年8～9月に行われた65名の測定においては，測定機器のメンテナンスのため，呼吸代謝測定システム（エアロモニタ AE300，ミナト医科学）を用いて分析した．$\dot{V}O_2max$の評価基準は，1)酸素摂取量のレベリングオフがみられること，2)年齢から推定される最大心拍数(220－年齢±5拍/分)に到達していること，3)呼吸交換比が1.0以上であること，4) RPEが19もしくは20であること，この4指標のうち2つ以上を満たすこととした．得られた$\dot{V}O_2max$の値は体重あたり(mL/kg/分)で評価した．

E．体力水準による被験者の分類

$\dot{V}O_2max$の測定結果をもとに，被験者を“健康づくりのための最大酸素摂取量”の「基準値」および「範囲」（Ref. 1）によって3つの心肺体力レベルに分類した；$\dot{V}O_2max$が 1)「基準値」以上を満たす心肺体力が高い群（High; H），2)「範囲」内かつ「基準値」未満の心肺体力がやや低い群（Medium; M），3)「範囲」を下回る心肺体力が低い群（Low; L）．

F．統計処理

各測定項目の値は平均値±標準偏差で示した．心肺体力レベルが異なる3群間の平均値の比較には，一元配置分散分析を用いて検定し，有意差が認められた項目には，Tukeyの事後検定を実施した．3群間でBMIと年齢に有意差が認められた場合，MSリ

スク保有数の比較において，BMIおよび年齢を共変量として共分散分析を行った．なお，体重は，BMIの構成要素として含まれるため共変量としなかった．また，MSリスクの異なる2群において，年齢と$\dot{V}O_2max$との関係をピアソンの相関係数によって検討するとともに，単回帰により回帰直線を求めた．両群とも年齢と$\dot{V}O_2max$との間に有意な相関関係が認められた場合，両群間の回帰係数の差を，傾き及びy切片の差のt値を検定することによって確認した．いずれの場合も統計的有意水準は5％未満とした．

Table 1. The characteristics of subjects.

	Men	Women
N	102	133
Age (yrs)	52 ± 13	55 ± 11
Height (cm)	171.1 ± 7.3	156.0 ± 5.5
Weight (kg)	72.5 ± 10.5	55.3 ± 8.5
BMI (kg/m²)	24.7 ± 3.1	22.8 ± 3.4
VO_2max (L/min)	2.41 ± 0.53	1.52 ± 0.33
(mL/kg/min)	33.4 ± 6.6	27.7 ± 5.5
WC (cm)	87.2 ± 7.7	84.8 ± 10.0
TG (mg/dL)	140 ± 129	90 ± 55
HDL-C (mg/dL)	59 ± 14	68 ± 14
SBP (mmHg)	130 ± 19	127 ± 21
DBP (mmHg)	85 ± 10	76 ± 11
BG (mg/dL)	101 ± 23	95 ± 14
Number of MS risk factors	1.63 ± 1.07	1.03 ± 1.06
Percentage of meeting the criterion for MS (%)		
WC	56	33
High TG and/or low HDL-C	28	17
High SBP and/or high DBP	63	44
High blood glucose	16	10
Percentage of taking medicine (%)		
Blood lipid abnormality	3	9
Hypertension	12	8
Diabetes	5	2
Distribution of the number of MS risk factors (%)		
0	15	41
1	34	26
2	28	23
3	19	8
4	4	2

Data are shown as mean ± SD or %. BMI indicates body mass index; $\dot{V}O_2max$, maximal oxygen uptake; WC, waist circumference; TG, triglycerides; HDL-C, HDL cholesterol; SBP, systolic blood pressure; DBP, diastolic blood pressure; BG, blood glucose.

Table 2. Physical characteristics in different levels of aerobic fitness.

Fitness level		N	Age (yrs)	Height (cm)	Weight (kg)	BMI (kg/m²)	$\dot{V}O_2max$ (mL/kg/min)
Men	High	35	49 ± 13	172.4 ± 5.8	69.7 ± 9.7	23.4 ± 2.5	40.3 ± 6.7
	Medium	52	53 ± 12	170.8 ± 8.0	72.7 ± 8.9	24.9 ± 2.3*	31.2 ± 7.1
	Low	15	55 ± 14	168.9 ± 8.0	78.5 ± 15.0*	27.4 ± 4.5*†	24.9 ± 6.6
	P-value		P=0.215	P=0.295	P=0.023	P<0.001	—
Women	High	42	54 ± 9	156.0 ± 5.7	53.3 ± 6.9	21.9 ± 2.6	33.8 ± 5.1
	Medium	36	50 ± 13	156.7 ± 5.3	54.4 ± 6.9	22.2 ± 2.9	28.3 ± 4.7
	Low	55	60 ± 9*†	155.5 ± 5.5	57.5 ± 10.0*	23.8 ± 3.9*	22.6 ± 4.8
	P-value		P<0.001	P=0.579	P=0.038	P=0.011	—

BMI indicates body mass index; $\dot{V}O_2max$, maximal oxygen uptake.
*: Significant difference from group H (High).
†: Significant difference from group M (Medium).

Ⅲ. 結　　果

男女ごとに被験者の特性をTable 1に示した．MSのリスク保有の状況についてみると，リスク保有数は，男性では1.63±1.07，女性では1.03±1.06と，男性は女性より約1.6倍高い値を示し，リスク保有数別に被験者を分類したところ，男性ではMS危険因子を1つ保有する者の割合が最も多く（34%），女性ではMS危険因子を保有しない者の割合が最も多かった（41%）．MS危険因子の発現頻度についてみると，男女とも共通して高血圧，腹囲，血中脂質異常，高血糖の順に，発現頻度が高かった．なお，本研究には，血中脂質異常，高血圧，糖尿病に対する薬剤治療をうけている被験者が，男性では3%（3名），12%（12名），5%（5名），女性では9%（12名），8%（10名），2%（2名）含まれていた．

被験者を心肺体力レベルによって3群に分類したところ，Table 2に示すように，男性では3群間で年齢や身長に有意な差は認められなかったものの，L群の体重がH群より有意に重く，L群及びM群のBMIはH群と比べて有意に高い値を示した．女性では，3群間で身長に有意な差は認められなかったものの，L群において，年齢が他の2群に比べて有意に高く，体重及びBMIがH群に比べて有意に高い値を示した．

男女別に各群のMSリスク保有数を比較した結果，Fig. 1Aに示すように，男性ではM群およびL群において保有数がH群より高い値を示し，H群に対してM群では1.7倍，L群では2.1倍であった．一方，Fig. 1Bに示すように，女性ではL群においてMSリスク保有数がH群およびM群より高い値を示し，L群ではH群に対して2.7倍，M群に対して1.9倍を示した．男性では3群間でBMIに有意な差がみられたが，共分散分析によってBMIの影響を除いた後でも，MSリスク保有数に3群間で有意な差が認められた（P<0.05）．女性では3群間で年齢とBMIに有意な差が認められたが，共分散分析によってBMIと年齢の影響を除いた後でも，MSリスク保有数に3群間で有意な差が認められた（P<0.05）．

心肺体力がどのMS危険因子と関与しているのかを検討するために，3群間のMS危険因子の値を比較した．その結果，Table 3に示すように，男性では心肺体力が低いと，腹囲が有意に大きく，HDL-Cが有意に低く，DBPが有意に高かった．一方，女性では心肺体力が低いと，腹囲が有意に大きく，TG，SBP，DBPおよびBGが有意に高く，HDL-Cが有意に低い値を示した．

さらに，MSリスクが異なる集団において，心肺体力に差があるか否かを検討した．被験者をMSリ

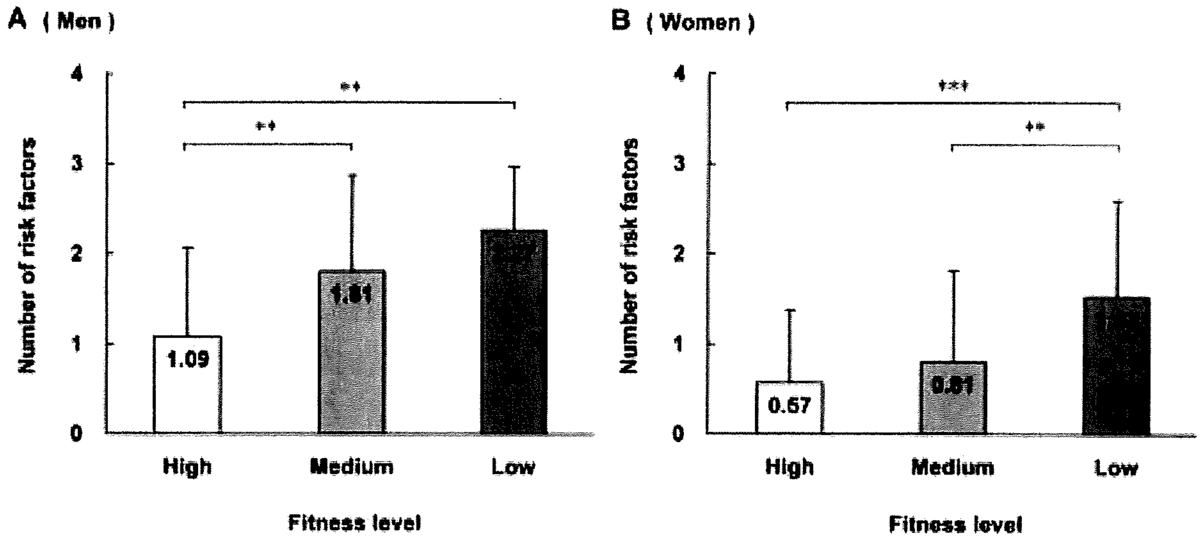

Fig. 1. Number of risk factors for metabolic syndrome in different levels of aerobic fitness in men (A) and women (B).
** $P<0.01$, *** $P<0.001$

Table 3. MS risk factors in different levels of aerobic fitness.

	Fitness level	N	WC (cm)	TG (mg/dL)	HDL-C (mg/dL)	SBP (mmHg)	DBP (mmHg)	BG (mg/dL)
Men	High	35	83.1 ± 6.6 (31)	104 ± 95 (14)	64 ± 14 (0)	129 ± 19 (37)	82 ± 10 (31)	99 ± 17 (17)
	Medium	52	88.0 ± 5.8* (65)	147 ± 132 (25)	56 ± 13* (8)	131 ± 19 (56)	86 ± 10 (56)	104 ± 28 (17)
	Low	15	94.3 ± 10.1*† (80)	195 ± 165 (47)	55 ± 13 (13)	133 ± 17 (60)	89 ± 12* (87)	96 ± 11 (7)
	P-value		P<0.001	P=0.059	P=0.012	P=0.751	P=0.043	P=0.388
Women	High	42	82.3 ± 9.5 (21)	79 ± 37 (10)	71 ± 14 (0)	119 ± 19 (19)	72 ± 10 (12)	93 ± 15 (5)
	Medium	36	81.1 ± 10.1 (25)	79 ± 42 (11)	70 ± 14 (0)	123 ± 20 (31)	76 ± 11 (25)	90 ± 8 (6)
	Low	55	89.1 ± 8.8*† (47)	105 ± 69* (24)	64 ± 13* (4)	136 ± 21*† (62)	79 ± 11* (44)	101 ± 14*† (16)
	P-value		P<0.001	P=0.025	P=0.020	P<0.001	P=0.005	P=0.001

WC indicates waist circumference; TG, triglycerides; HDL-C, HDL cholesterol; SBP, systolic blood pressure; DBP, diastolic blood pressure; BG, blood glucose.
(　　) = Percentage of meeting the criterion for MS in each category.
Data include values in subject taking medicine for blood lipid abnormality, hypertension, and/or diabetes.
*: Significant difference from group H (High).
†: Significant difference from group M (Medium).

スク保有数が 0 または 1 の群（低リスク群）と，保有数が 2 以上の群（高リスク群）に分類し，両群の年齢に対する $\dot{V}O_2max$ の差を比較した（Fig. 2A および Fig. 2B）．男性では，年齢と $\dot{V}O_2max$ との間には，低リスク群（$r=-0.38$，$P<0.05$），高リスク群（$r=-0.36$，$P<0.01$）とも負の相関関係が認められた．$\dot{V}O_2max$ を目的変数（y），年齢を説明変数（x）とした場合の回帰直線は，低リスク群 $y=-0.20x+45.6$，高リスク群 $y=-0.17x+40.4$ であり，両群の回帰直線の傾きに有意な差は認められなかったものの，低リスク群は高リスク群に比べて y 切片が有意に高い値を示した（$P<0.001$）．一方，女性では，低リスク群においては，年齢と $\dot{V}O_2max$ との間に，負の相関関係が認められた（$r=-0.32$，$P<0.01$）が，高リスク群では，年齢と $\dot{V}O_2max$ との間に有意な相関関係はみられなかった．