Journal of Sports Sciences, August 2009; 27(10): 1027–1034

Routledge
Taylor & Francis Group

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

KIYOSHI SANADA[1], MOTOHIKO MIYACHI[3], IZUMI TABATA[3], KATSUHIKO SUZUKI[2], KENTA YAMAMOTO[1], HIROSHI KAWANO[2], CHIYOKO USUI[2], & MITSURU HIGUCHI[2]

[1]*Institute for Biomedical Engineering and* [2]*Faculty of Sport Sciences, Waseda University, Tokyo, and* [3]*National Institute of Health and Nutrition, Tokyo, Japan*

(Accepted 31 May 2009)

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 $\cdot$ dl^{-1}) was significantly ($P < 0.05$) higher than that of senior sedentary controls (59.2 ± 11.9 mg $\cdot$ dl^{-1}), while HDL-cholesterol was similar in senior rowers and young rowers (66.1 ± 10.8 mg $\cdot$ 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

Correspondence: K. Sanada, Institute for Biomedical Engineering, Waseda University, Tokyo 166-0013, Japan. E-mail: ksanada@fc.ritsumei.ac.jp

ISSN 0264-0414 print/ISSN 1466-447X online
DOI: 10.1080/02640410903081852

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 $\geq$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}) $\times$ 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 $\pm$ standard deviations. The data were analysed by two-way analysis of variance (ANOVA: age $\times$ 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.

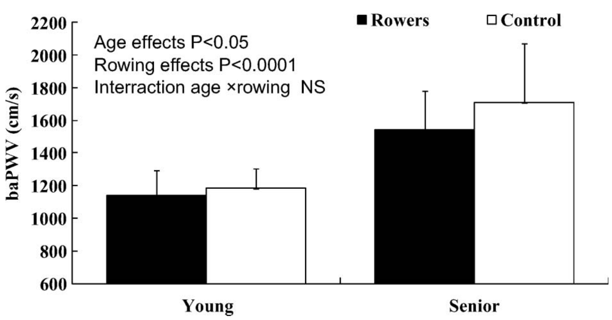

Figure 1. Brachial-ankle pulse wave velocity (baPWV) in young and senior rowers. Two-way ANOVA indicated that all rowers had lower brachial-ankle pulse wave velocity than age-matched controls, independent of age ($P < 0.05$). ■, rowers; □, controls.

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.

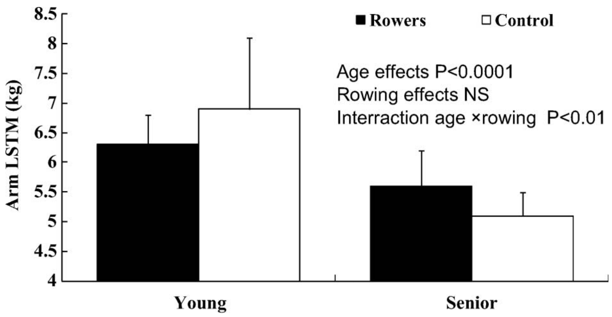

Figure 2. Arm lean soft tissue mass (LSTM) measured by DXA in young and senior rowers. Two-way ANOVA indicated that arm lean soft tissue mass was significantly lower in the senior group than in the younger group ($P < 0.0001$). However, the interaction between age and rowing (age × rowing) was significant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

Acknowledgements

This study was supported in part by a Grant-in-Aid for Scientific Research from the Ministry of Education, Culture, Sports, Science, and Technology (#13680077) and a grant from the Foundation for Comprehensive Research on Aging and Health from the Ministry of Health, Labour and Welfare. We thank the oarsmen of the Mitsubishi Senior Boat Club for participating in the study.

References

American College of Sports Medicine. (2006). *Guidelines for exercise testing and prescription* (7th edn.). Philadelphia, PA: Lippincott Williams & Wilkins.

Borg, G. A. (1982). Psychophysical bases of perceived exertion. *Medicine and Science in Sports and Exercise*, *14*, 377–381.

Clifford, P. S., Hanel, B., & Secher, N. H. (1994). Arterial blood pressure response to rowing. *Medicine and Science in Sports and Exercise*, *26*, 715–719.

Cook, J. N., DeVan, A. E., Schleifer, J. L., Anton, M. M., Cortez-Cooper, M. Y., & Tanaka, H. (2006). Arterial compliance of rowers: Implications for combined aerobic and strength training on arterial elasticity. *American Journal of Physiology: Heart and Circulatory Physiology*, *290*, H1596–H1600.

Dengel, D. R., Galecki, A. T., Hagberg, J. M., & Pratley, R. E. (1998). The independent and combined effects of weight loss and aerobic exercise on blood pressure and oral glucose tolerance in older men. *American Journal of Hypertension*, *11*, 1405–1412.

Friedewald, W. T., Levy, R. I., & Fredrickson, D. S. (1972). Estimation of the concentration of low-density lipoprotein cholesterol in plasma, without use of the preparative ultracentrifuge. *Clinical Chemistry*, *18*, 499–502.

Hagberg, J. M., Park, J. J., & Brown, M. D. (2000). The role of exercise training in the treatment of hypertension: An update. *Sports Medicine*, *30*, 193–206.

Hagerman, F. C. (1984). Applied physiology of rowing. *Sports Medicine*, *1*, 303–326.

Hagerman, F. C., Fielding, R. A., Fiatarone, M. A., Gault, J. A., Kirkendall, D. T., Ragg, K. E. et al. (1996). A 20-yr longitudinal study of Olympic oarsmen. *Medicine and Science in Sports and Exercise*, *28*, 1150–1156.

Helmrich, S. P., Ragland, D. R., Leung, R. W., & Paffenbarger, R. S., Jr. (1991). Physical activity and reduced occurrence of non-insulin-dependent diabetes mellitus. *New England Journal of Medicine*, *325*, 147–152.

Hsu, Y. H., Venners, S. A., Terwedow, H. A., Feng, Y., Niu, T., Li, Z. et al. (2006). Relation of body composition, fat mass, and serum lipids to osteoporotic fractures and bone mineral density in Chinese men and women. *American Journal of Clinical Nutrition*, *83*, 146–154.

Hurley, B. F., & Roth, S. M. (2000). Strength training in the elderly: Effects on risk factors for age-related diseases. *Sports Medicine*, *30*, 249–268.

Ishikawa-Takata, K., Ohta, T., & Tanaka, H. (2003). How much exercise is required to reduce blood pressure in essential hypertensives: A dose–response study. *American Journal of Hypertension*, *16*, 629–633.

Kelley, G. A., Kelley, K. A., & Tran, Z. V. (2001). Aerobic exercise and resting blood pressure: A meta-analytic review of randomized, controlled trials. *Preventive Cardiology*, *4*, 73–80.

Kiens, B. (1997). Effect of endurance training on fatty acid metabolism: Local adaptations. *Medicine and Science in Sports and Exercise*, *29*, 640–645.

Knowler, W. C., Barrett-Connor, E., Fowler, S. E., Hamman, R. F., Lachin, J. M., Walker, E. A. et al. (2002). Reduction in the incidence of type 2 diabetes with lifestyle intervention or metformin. *New England Journal of Medicine*, *346*, 393–403.

Kuan, J. W., Kuan, S. S., & Guilbault, G. G. (1977). Determination of plasma glucose with use of a stirrer containing immobilized glucose dehydrogenase. *Clinical Chemistry*, *23*, 1058–1061.

Lariviere, J. A., Robinson, T. L., & Snow, C. M. (2003). Spine bone mineral density increases in experienced but not novice collegiate female rowers. *Medicine and Science in Sports and Exercise*, *35*, 1740–1744.

Lorentzon, M., Mellstrom, D., & Ohlsson, C. (2005). Age of attainment of peak bone mass is site specific in Swedish men – The GOOD study. *Journal of Bone and Mineral Research*, *20*, 1223–1227.

Lynch, J., Helmrich, S. P., Lakka, T. A., Kaplan, G. A., Cohen, R. D., Salonen, R. et al. (1996). Moderately intense physical activities and high levels of cardiorespiratory fitness reduce the risk of non-insulin-dependent diabetes mellitus in middle-aged men. *Archives of Internal Medicine*, *156*, 1307–1314.

Martin, W. H., III. (1996). Effects of acute and chronic exercise on fat metabolism. *Exercise and Sport Sciences Reviews*, *24*, 203–231.

Morel, J., Combe, B., Francisco, J., & Bernard, J. (2001). Bone mineral density of 704 amateur sportsmen involved in different physical activities. *Osteoporosis International*, *12*, 152–157.

National Institutes of Health (1996). Physical activity and cardiovascular health. NIH Consensus Development Panel on Physical Activity and Cardiovascular Health. *Journal of the American Medical Association*, *276*, 241–246.

O'Rourke, M. F., Staessen, J. A., Vlachopoulos, C., Duprez, D., & Plante, G. E. (2002). Clinical applications of arterial stiffness: Definitions and reference values. *American Journal of Hypertension*, *15*, 426–444.

Pan, X. R., Li, G. W., Hu, Y. H., Wang, J. X., Yang, W. Y., An, Z. X. et al. (1997). Effects of diet and exercise in preventing NIDDM in people with impaired glucose tolerance: The Da Qing IGT and Diabetes Study. *Diabetes Care*, *20*, 537–544.

Pelliccia, A., Maron, B. J., Spataro, A., Proschan, M. A., & Spirito, P. (1991). The upper limit of physiologic cardiac hypertrophy in highly trained elite athletes. *New England Journal of Medicine*, *324*, 295–301.

Poehlman, E. T., Dvorak, R. V., DeNino, W. F., Brochu, M., & Ades, P. A. (2000). Effects of resistance training and endurance training on insulin sensitivity in nonobese, young women: A controlled randomized trial. *Journal of Clinical Endocrinology and Metabolism*, *85*, 2463–2468.

Poehlman, E. T., & Melby, C. (1998). Resistance training and energy balance. *International Journal of Sport Nutrition*, *8*, 143–159.

Prabhakaran, B., Dowling, E. A., Branch, J. D., Swain, D. P., & Leutholtz, B. C. (1999). Effect of 14 weeks of resistance training on lipid profile and body fat percentage in premenopausal women. *British Journal of Sports Medicine*, *33*, 190–195.

Safar, M. E., & London, G. M. (2000). Therapeutic studies and arterial stiffness in hypertension: Recommendations of the European Society of Hypertension, The Clinical Committee of Arterial Structure and Function, Working Group on Vascular Structure and Function of the European Society of Hypertension. *Journal of Hypertension*, *18*, 1527–1535.

Secher, N. H. (1993). Physiological and biomechanical aspects of rowing: Implications for training. *Sports Medicine*, *15*, 24–42.

Smith, R., & Rutherford, O. M. (1993). Spine and total body bone mineral density and serum testosterone levels in male athletes. *European Journal of Applied Physiology and Occupational Physiology*, *67*, 330–334.

Sugawara, J., Hayashi, K., Yokoi, T., Cortez-Cooper, M. Y., DeVan, A. E., Anton, M. A. et al. (2005). Brachial-ankle pulse wave velocity: An index of central arterial stiffness? *Journal of Human Hypertension*, *19*, 401–406.

Turcotte, L. P., Richter, E. A., & Kiens, B. (1992). Increased plasma FFA uptake and oxidation during prolonged exercise in trained vs. untrained humans. *American Journal of Physiology: Endocrinology and Metabolism*, *262*, E791–E799.

Yoshiga, C. C., Higuchi, M., & Oka, J. (2002a). Rowing prevents muscle wasting in older men. *European Journal of Applied Physiology*, *88*, 1–4.

Yoshiga, C. C., Higuchi, M., & Oka, J. (2002b). Serum lipoprotein cholesterols in older oarsmen. *European Journal of Applied Physiology*, *87*, 228–232.