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Hiroshi Kawano, Motoyuki Iemitsu, Yuko Gando, Toshimichi Ishijima, Meiko Asaka, Tomoko Aoyama, Takafumi Ando, Ken Tokizawa, Motohiko Miyachi, Shizuo Sakamoto & Mitsuru Higuchi

Faculty of Sport Sciences, Waseda University, Saitama, Japan
College of Sport and Health Science, Ritsumeikan University, Shiga, Japan
Sport Science Research Centre, Waseda University, Saitama, Japan
Graduate School of Sport Sciences, Waseda University, Saitama, Japan
National Institute of Health and Nutrition, Shinjuku, Tokyo, Japan

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Habitual rowing exercise is associated with high physical fitness without affecting arterial stiffness in older men

HIROSHI KAWANO1, MOTOYUKI IEMITSU2, YUKO GANDO1, TOSHIMICHI ISHIJIMA3, MEIKO ASAKA4, TOMOKO AOYAMA1, TAKAFUMI ANDO4, KEN TOKIZAWA1, MOTOHIKO MIYACHI5, SHIZUO SAKAMOTO1, & MITSURU HIGUCHI1

1Faculty of Sport Sciences, Waseda University, Saitama, Japan, 2College of Sport and Health Science, Ritsumeikan University, Shiga, Japan, 3Sport Science Research Centre, Waseda University, Saitama, Japan, 4Graduate School of Sport Sciences, Waseda University, Saitama, Japan, and 5National Institute of Health and Nutrition, Shinjuku, Tokyo, Japan

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Abstract

The present study elucidated the effects of habitual rowing exercise on arterial stiffness and plasma levels of the vasoconstrictor endothelin-1 and the vasodilator nitric oxide (NO) in older men. Eleven rowers (68.0 ± 1.6 years) and 11 sedentary control older men (64.9 ± 1.1 years) were studied. Peak oxygen uptake (36.0 ± 1.7 vs. 27.7 ± 1.9 ml·kg$^{-1}$·min$^{-1}$), leg press power (1346 ± 99 vs. 1077 ± 68 W), and HDL-cholesterol (75 ± 5 vs. 58 ± 3 mg·ml$^{-1}$) were higher and triglyceride (78 ± 9 vs. 120 ± 14 mg·ml$^{-1}$) was lower in rowers than in control participants (all $P < 0.05$). Arterial stiffness indices (carotid β-stiffness and cardio-ankle vascular index) and plasma endothelin-1 and NOx (nitrite + nitrate) levels did not differ between the two groups. These results suggest that habitual rowing exercise in older men is associated with high muscle power and aerobic capacity, and favourable blood lipid profile without affecting arterial stiffness or plasma levels of endothelin-1 and NO.

Keywords: Rowing, arterial stiffness, combined training, endothelin-1, nitric oxide

Introduction

Arterial stiffening (Avolio et al., 1985; Tanaka, DeSouza, & Seals, 1998; Vaitkevicius et al., 1993) and muscular weakening (Janssen, Heymsfield, & Ross, 2002; Metter, Talbot, Schrager, & Conwit, 2002) develop with advancing age. Increased arterial stiffness is associated with mortality in patients with end-stage renal failure (Blacher et al., 1999) and essential hypertension (Laurent et al., 2001). Arterial stiffness is reduced with endurance training (Tanaka et al., 2000; Vaitkevicius et al., 1993), and increases with resistance training (Bertovic et al., 1999; Miyachi et al., 2003; Miyachi et al., 2004). Moreover, simultaneously performed aerobic training prevents the arterial stiffening caused by resistance training (Kawano, Tanaka, & Miyachi, 2006). Therefore, combined aerobic and resistance training may be used as protocol for maintaining vascular health.

Vascular endothelial cells play an important role in the regulation of vascular tone by producing vasoactive substances, such as endothelin and nitric oxide (NO). Endothelin-1, a peptide produced by vascular endothelial cells, is a potent vasoconstrictor (Miyachi & Masaki, 1999), and contributes to arterial stiffness (Luscher & Barton, 2000; Miyachi & Masaki, 1999). NO produced by vascular endothelial cells has a potent vasodilator effect, and consequently prevents and inhibits hypertension and arteriosclerosis (Moncada, Palmer, & Higgs, 1991), while the bioavailability of NO decreases with advancing age (Dohi, Kojima, Sato, & Luscher, 1995; Dohi, Thiel, Buhler, & Luscher, 1990; Taddei et al., 1997). Plasma endothelin-1 levels are reduced by aerobic training in older people (Maeda et al., 2003; Stauffer, Westby, & DeSouza, 2008; White et al., 1997), but plasma nitrite/nitrate (NOx: measured as the stable end product of NO) was elevated by aerobic exercise training in elderly women (Maeda et al., 2004).
Rowing training is unique because it includes components of both aerobic endurance and muscular strength training. In a boat race, rowers are required to have high muscular power to accelerate the boat at the beginning and large aerobic capacity to maintain the speed. In addition, when they spurt to accelerate the boat at more than a constant speed in the final phase of the race, they row at maximum muscular strength. Indeed, rowing training is identified as a combination of resistance and aerobic training (Yoshiga, Higuchi, & Oka, 2002a, 2002b). The age-related increase in brachial-ankle pulse wave velocity, as an index of systemic arterial stiffness, is attenuated in rowing-trained older men (Sanada et al., 2009). However, it remains unclear whether endogenous endothelin-1 and NO are affected by rowing training in older humans.

We hypothesised that habitual rowing training improves arterial stiffness and endogenous endothelin-1 and NO. To test our hypothesis, the present study was performed to compare arterial stiffness and plasma endothelin-1 and NOx concentrations between rowing-trained older men and age-matched controls.

Methods

The study population included 11 rowing-trained older men aged 68.0 ± 1.6 years and 11 sedentary controls aged 64.9 ± 1.1 years (Table I). The sedentary men were recruited through advertising and had not participated in a habitual exercise training program, such as endurance or resistance training. The rowers were recruited from rowing clubs and had rowed on the water or on an ergometer at least twice per week for 5 years or more, each session lasting 90–120 min including warm-up, 12–16 km of rowing, and recovery, but had not performed particular resistance or aerobic training. All participants were free of diabetes mellitus and overt chronic diseases based on their medical history. In addition, participants who had used anabolic steroids or other performance-enhancing drugs or who had significant carotid intima-media thickening (≥ 1.1 mm), plaque formation, and/or other characteristics of atherosclerosis [ankle-brachial index (ankle systolic blood pressure/brachial systolic blood pressure) ≤ 0.9] were excluded from the study. All participants provided informed consent as approved by the Human Research Ethics Committee of the Faculty of Sport Sciences of Waseda University. The study was performed in accordance with the guidelines of the Declaration of Helsinki 2006.

Measurements

Before testing, participants abstained from caffeine and fasted for at least 12 h overnight. All measurements were performed in the laboratory in the morning. Tests for the rowers were conducted 24–28 h after their last exercise training session. Participants were not smokers except for one in the control group. This participant abstained from smoking on the test day.

Carotid arterial intima-media thickness

Carotid arterial intima-media thickness was measured from images obtained using an ultrasound system (Sonosite Taitan; Sonosite Instruments, Bothell, WA) equipped with a high-resolution linear-array broad-band transducer. Ultrasound images were analysed using software (ImageJ 1.41, Bethesda, MD, USA). At least 10 intima-media thickness measurements were taken at each segment, and the mean value was used for analysis. This technique has a coefficient of variance of 3 ± 1% (Kawano et al., 2006; Kawano et al., 2008).

Carotid arterial compliance and β-stiffness

After 15 min of rest, carotid arterial compliance and β-stiffness were measured. A combination of ultrasound imaging of the pulsatile common carotid artery with simultaneous applanation of tonometrically obtained arterial pressure from the contralateral carotid artery permits noninvasive determination of arterial stiffness (Kawano et al., 2008; Tanaka et al., 2000). The carotid artery diameter was measured from images obtained using a Sonosite Taitan ultrasound system equipped with a high-resolution linear-array transducer. A longitudinal image of the cephalic portion of the common carotid artery was acquired 1–2 cm proximal to the carotid bulb. All image analyses were performed by the same

<table>
<thead>
<tr>
<th>Table I. Participant characteristics.</th>
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<tr>
<td></td>
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<tr>
<td>N</td>
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<tr>
<td>Age, years</td>
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<tr>
<td>Height, cm</td>
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<tr>
<td>Body weight, kg</td>
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<tr>
<td>Fat, %</td>
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<tr>
<td>HDL cholesterol, mg·dl⁻¹</td>
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<td>LDL cholesterol, mg·dl⁻¹</td>
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<td>Triglycerides, mg·dl⁻¹</td>
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<td>Plasma glucose, mg·dl⁻¹</td>
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<td>Resting heart rate, bpm</td>
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<tr>
<td>Maximal heart rate, bpm</td>
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<tr>
<td>VO₂peak l/min</td>
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<tr>
<td>Leg press power, W</td>
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</tbody>
</table>

Data are Means ± S; N, no. of subjects; HDL, high-density lipoprotein; LDL, low-density lipoprotein; VO₂peak, peak oxygen consumption. *Significant at P < 0.05 vs Control.
Arterial stiffness and endothelins-1 in rowers

Pulse wave velocity is the pulse wave velocity between the heart and ankle, $\Delta P$ is $P_1 - P_0$, $\rho$ is blood density, and a and b are constants. The systolic and diastolic brachial blood pressure and the pulse wave velocity were used for calculating the value of the cardio-ankle vascular index. The day-to-day coefficient of variation in the cardio-ankle vascular index was $2 \pm 1\%$.

Blood biochemistry

Following a 12-h overnight fast, blood was collected from an antecubital vein in the early morning. Each blood sample was placed in a chilled tube containing aprotinin (300 kallikrein inhibitor $\text{U} \cdot \text{ml}^{-1}$) and EDTA (2 mg $\cdot$ ml$^{-1}$) and was centrifuged at 2000 rpm for 15 min at 4°C. The plasma was stored at $-80$°C until assay. Plasma concentrations of endothelins-1 were determined using a sandwich-enzyme immunoassay (EIA) kit (Immuno-Biological Laboratories, Fujioka, Japan) (coefficient of variation, 11%) (Iemitsu et al., 2006). Plasma concentration of NOx was determined using a commercial NO ($\text{NO}_2$/NO$_3$) assay kit (R&D Systems, Minneapolis, MN) according to the manufacturer’s instructions (coefficient of variation, 4%). Serum concentrations of cholesterol, triglycerides and plasma concentrations of glucose were determined using enzymatic techniques.

Brachial arterial blood pressure at rest

Arterial blood pressure at rest was measured with a semi-automated device (VaSera VS-1500) over the brachial and dorsalis pedis arteries using the oscillometric method (Shirai et al., 2006). Recordings were made in triplicate with participants supine. The day-to-day coefficient of variation in the cardio-ankle vascular index. The day-to-day coefficient of variation in the cardio-ankle vascular index was $2 \pm 1\%$.

Peak oxygen uptake

We measured peak oxygen consumption ($\dot{V}O_{2\text{peak}}$) during incremental cycle ergometer exercise (Miyachi et al., 2001), as the cardiorespiratory fitness index. Oxygen consumption (coefficient of variation, 4 ± 1%), heart rate, and ratings of perceived exertion were monitored throughout the protocol (Miyachi et al., 2001).

Muscle strength

Muscle strength was assessed by leg extension power (Kawano et al., 2008). Briefly, leg extension power (coefficient of variation, 2 ± 1%) was determined using a dynamometer (Anaero Press 3500; Combi Wellness, Tokyo, Japan) in the sitting position. The
participants were secured in a chair using a seatbelt. In the starting position, the feet were placed on a sliding plate with the knee angle adjusted to 90°. Five trials were performed at 15-s intervals, and the average of the two highest recorded power outputs (W) was taken as the definitive measurement.

Body composition

Body composition was determined using the bioelectric impedance method (coefficient of variation, 4 ± 2%) (Bolanowski & Nilsson, 2001).

Statistics

Statistical analyses were performed using StatView (SAS, Cary, NC) with presented means ± s. Mean differences between rowers and control men were examined using Student’s unpaired t test. Statistical significance was set at P < 0.05.

Results

Height and HDL-cholesterol were higher, and triglyceride was lower in rowers compared with controls (Table I; all P < 0.05). Rowers had greater $\dot{V}O_{2peak}$ and leg press power than controls. There were no significant differences in other parameters between the two groups.

Blood pressures of the brachial and carotid arteries were not significantly different between the two groups (Table II). There were no differences in carotid systolic or diastolic diameters or in intima-media thickness between the two groups. Also there were no significant differences in cardio-ankle vascular index, carotid arterial compliance, or $\beta$-stiffness between the two groups. Plasma endotheline-1 concentration and plasma NOx concentration did not differ between rowers and controls, although plasma endotheline-1 tended to be lower in the rowers (Table II).

Discussion

The results indicate that rowing-trained older men demonstrate greater cardiorespiratory fitness, muscular strength, and superior blood lipid profiles, but not differences in indices of arterial stiffness or plasma endotheline-1 and NOx concentrations.

Resistance training is associated with an increase in arterial stiffness (Bertovic et al., 1999; Miyachi et al., 2003; Miyachi et al., 2004). Although rowing training includes a component of resistance training, this study demonstrated that arterial stiffness indices were not different between older men who were rowers and sedentary controls. Considering the favourable effect of aerobic training on arterial stiffness, the findings suggest that the aerobic component of rowing training negates the higher arterial stiffness associated with the resistance training component. In addition, we observed that habitual rowing training was associated with lower triglyceride and higher HDL-cholesterol levels, and also with greater leg press power and $\dot{V}O_{2peak}$. Furthermore, this type of training is not associated with unfavourable effects on arterial stiffness. Considering these results, we suggest that rowing training should be proposed as an effective exercise model for prevention of sarcopenia or lifestyle-related diseases, such as cardiovascular diseases.

The results indicated that there were no significant differences in plasma levels of endotheline-1 and NOx between rowing-trained older men and similar sedentary controls. Aerobic training induces a decrease in endotheline-1 level and an increase in NOx level with improvement of arterial stiffness (Maeda et al., 2004; Miyaki et al., 2009). On the other hand, arterial stiffening with resistance training is associated with greater plasma levels of endotheline-1 (Otsuki et al., 2007). Regulation of arterial stiffness via arterial tonus is adjusted by the balance between the vasoconstrictor endotheline-1 (Miyachi & Masaki, 1999) and the vasodilator NO (Moncada et al., 1991). Furthermore, vascular Table II. Vascular indices, plasma endothelin-1 and NOx concentrations.

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>Rowers</th>
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<tbody>
<tr>
<td>Brachial systolic BP, mmHg</td>
<td>140 ± 18</td>
<td>142 ± 19</td>
</tr>
<tr>
<td>Brachial mean BP, mmHg</td>
<td>111 ± 15</td>
<td>113 ± 17</td>
</tr>
<tr>
<td>Brachial diastolic BP, mmHg</td>
<td>89 ± 8</td>
<td>91 ± 12</td>
</tr>
<tr>
<td>Brachial PP, mmHg</td>
<td>48 ± 11</td>
<td>52 ± 11</td>
</tr>
<tr>
<td>Carotid systolic BP, mmHg</td>
<td>138 ± 24</td>
<td>147 ± 31</td>
</tr>
<tr>
<td>Carotid PP, mmHg</td>
<td>47 ± 16</td>
<td>55 ± 25</td>
</tr>
<tr>
<td>Carotid diastolic diameter, mm</td>
<td>6.7 ± 0.8</td>
<td>7.2 ± 1.0</td>
</tr>
<tr>
<td>Carotid systolic diameter, mm</td>
<td>7.0 ± 0.8</td>
<td>7.6 ± 1.1</td>
</tr>
<tr>
<td>ΔCarotid diameter, mm</td>
<td>0.3 ± 0.1</td>
<td>0.3 ± 0.2</td>
</tr>
<tr>
<td>Carotid IMT, mm</td>
<td>0.7 ± 0.1</td>
<td>0.8 ± 0.1</td>
</tr>
<tr>
<td>Cardio-ankle vascular index, Arbitrary unit</td>
<td>8.4 ± 1.0</td>
<td>8.4 ± 1.0</td>
</tr>
<tr>
<td>Carotid arterial compliance, mm²/mmHg</td>
<td>0.06 ± 0.02</td>
<td>0.08 ± 0.03</td>
</tr>
<tr>
<td>Carotid arterial compliance, mm²/kPa</td>
<td>0.008 ± 0.003</td>
<td>0.010 ± 0.004</td>
</tr>
<tr>
<td>Carotid $\beta$-stiffness index, Arbitrary unit</td>
<td>11.2 ± 2.8</td>
<td>10.0 ± 1.5</td>
</tr>
<tr>
<td>Plasma endothelin-1, pg/ml</td>
<td>3.0 ± 0.7</td>
<td>3.3 ± 0.8</td>
</tr>
<tr>
<td>Plasma nitrite/nitrate (NOx), $\mu$M</td>
<td>45 ± 30</td>
<td>40 ± 24</td>
</tr>
</tbody>
</table>

Data are Means ± S; BP, blood pressure; PP, pulse pressure; IMT, intima-media thickness.
adaptations to changes in physical activity (such as training) may be regulated through the interaction between vasodilation and vasoconstriction (Thijssen, Rongen, Smits, & Hopman, 2008). Since aerobic and resistance training components in rowing training may negate changes in NO or endothelin-1, we speculate that these factors balance each other, which might have contributed to the lack of a difference in arterial stiffness between rowing-trained men and controls.

Dyslipoproteinemia is risk factor for coronary artery disease, i.e., elevated concentrations of triglyceride, total cholesterol, and LDL-cholesterol, and a reduced level of HDL-cholesterol, which is improved with performing aerobic (Higuchi et al., 1984) and resistance training (Fahlman, Boardley, Lambert, & Flynn, 2002). Accordingly, these observations suggest that habitual rowing training in older men is associated with lower risk factor indices for coronary artery disease.

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Acknowledgments

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