guidelines. The effects of age, sex, height, weight, alcohol consumption, and smoking on the VPT were also investigated.

Materials and methods

Subjects

The VPT was examined in 377 healthy Japanese volunteers (241 males, aged 11–74, mean 34 ± 11 years; and 136 females, aged 11–74, mean 31 ± 13 years). Subjects participated voluntarily, with informed consent obtained before testing. The age distribution and demographics of the subjects are presented in Tables 1 and 2, respectively.

A brief questionnaire that included information on smoking habits, alcohol consumption, and hand dominance was completed by each subject. Subjects who had a history of neurological diseases or medical conditions that might predispose the person to sensory abnormalities (e.g., diabetes mellitus, malignancy, alcohol abuse, neck or back disorders, kidney failure) and those who had undergone surgery within a year were excluded. Subjects who were taking medications that may cause peripheral neuropathy were also excluded. The body mass index (BMI) was calculated as by dividing the weight in kilograms by the height in meters squared (BMI = weight/height^2).

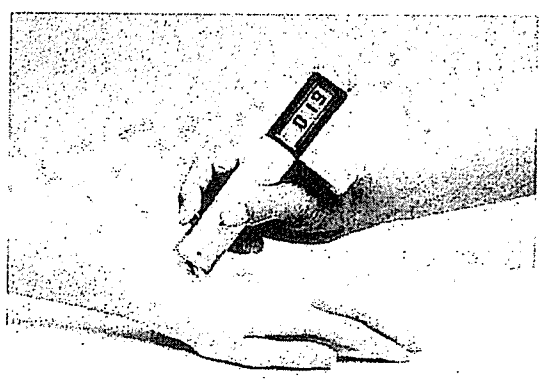

Fig. 1. Vibrometer used in present study: SMV-5 (Suzuki-Matsuoka vibrometer; Medience, Tokyo, Japan)

Stimulation and measurement procedures

Instrument

The VPT was determined by applying a stimulus from the electromagnetic vibrator, SMV-5, which is a handheld instrument producing sine-wave vibration at a frequency of 220 Hz with an accelerometer recording the actual movements of a vibrating probe (between 0 and 150×10^{-2} G) by automatically controlling stimulatory strength. The probe is 15 mm in diameter with a flat contacting surface in a firm plastic cylinder. The real vibratory acceleration could be monitored directly on a digital display. The principle of the device action has been described by Suzuki et al.[9,10] Previous studies have already confirmed the validity and reliability of the VPT measurements by this equipment.[7] The coefficients of variation for the intra- and interobserver of the VPT measurements by the SMV-5 have been reported to be 15.2% and 18.5%, respectively.[5]

Testing procedure

The measurements were obtained in a silent, closed room with ambient temperature control (20°–24°C).

Table 1. Age distribution of subjects

Subjects	No. of patients, by decades of age						
	11–19	20–29	30–39	40–49	50–59	60–74	Total
Males	5	105	73	29	16	13	241
Females	10	74	22	14	13	3	136

Table 2. Demographics of subjects

Characteristic	Males (M = 241)	Females (M = 136)
Age	33.8 ± 11.2 (11–74)	30.8 ± 12.9 (11–74)
Height (cm)	171.6 ± 5.8 (151.0–185.0)	157.8 ± 6.0 (135.0–171.5)
Weight (kg)	68.0 ± 9.4 (41.5–110.0)	52.0 ± 7.4 (30.0–80.0)
BMI (kg/m^2)	23.1 ± 2.8 (15.9–34.7)	20.9 ± 2.7 (16.4–32.2)
Hand dominance	R:183, L:12, A:8, U38	R:100, L:5, A:2, U:29
Skin temperature (°C)	32.0 ± 1.6 (28.0–35.2)	31.7 ± 1.5 (28.7–35.3)

Results are means ± SD (range)
R, right dominance; L, left dominance; A, ambidextrous; U, unknown; BMI, body mass index

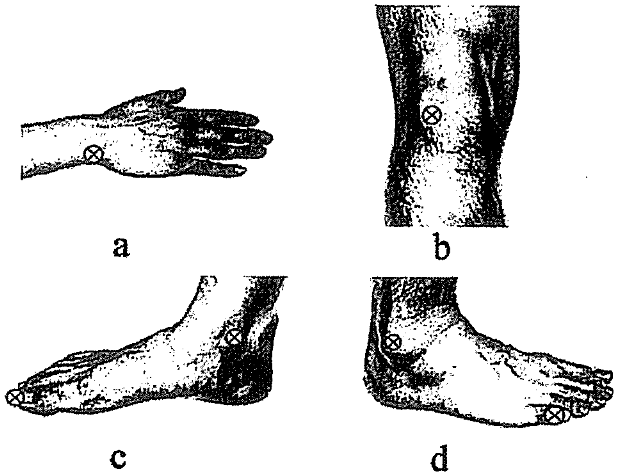

Fig. 2. Regions examined by SMV-5. a Ulnar styloid. b Patella. c Tip of great toe and medial malleolus of tibia. d Lateral malleolus of fibula and dorsal aspect of distal phalanx of fifth toe

The subject was in a supine or sitting position to provide optimal relaxation and concentration. The probe was placed at a right angle to the bare skin with gentle pressure to ensure full contact. The VPT was measured at 12 points (Fig. 2.): the ulnar styloids, the patellae, the medial malleoli and tip of the great toes, the dorsal aspect of the distal phalanx of the fifth toes, and the lateral malleoli. The stimulus was gradually increased from zero; and when the subject first perceived the stimulus, the value on the display was recorded. The measurements were repeated five times, and the median of five measurements was used to represent the VPT for each site. After completing the measurements, the peripheral temperature at the bilateral dorsal foot of each subject was measured by surface thermometer (Nihon-koden, Tokyo, Japan). Total time for the interview, trials, and actual measurements using SMV-5 was 20–25 min for each subject. The same apparatus was used throughout the whole study, and all measurements were carried out by the principal investigator.

To examine the effect of leg positions during measurements, the VPT values were compared between two age- and sex-matched groups of 76 subjects each who were tested with their knees bent or extended. To investigate the effect of the dominant side of the hand on the VPT value, the subjects were divided into groups based on their dominant hand. The differences in VPT values were assessed for all the combinations of dominant/nondominant hand and the measurement sites. To examine the effect of obesity, the VPT values at the six measurement sites were compared between 59 subjects with a BMI of 25 or more and 315 subjects with a BMI of less than 25. The subjects were also divided by the amount of alcohol consumed (i.e., those with none and intake of less than twice per week and those with intake of more than twice per week), and the VPT between the two groups were compared. The VPTs of the nonsmokers and habitual smokers were also compared. Heavy smokers who consume more than two packs per day and occasional smokers were excluded for this study.

Data analysis

In subjects who had a higher than maximum intensity of vibration ($>150 \times 10^{-2}$ G), 150×10^{-2} G was used as the VPT value. Although the VPT of the whole sample group (377 subjects) did not show a normal distribution, normality could be demonstrated by the Smirnov-Kolgomonov test when VPT values underwent logarithmic transformation ($\log_{10}$). However, because VPTs in each of the stratified groups did not show a normal distribution, nonparametric tests were used to compare VPTs among groups. Wilcoxon tests were used to determine statistically significant differences in VPTs between left and right sides of the body. The Mann-Whitney U-test was used to compare the results in different sex and age groups. The Wilcoxon signed rank test was used to assess differences among measured sites. The correlation between age and VPT measurements at each site was estimated by Spearman's rank correlation coefficients. $P < 0.05$ was considered significant. All statistical analyses were performed on a Macintosh computer (Apple, Cupertino, CA, USA) using Statview (version 5.0; SAS Institute, Cary, NC, USA).

Results

Males were significantly taller than females (171 ± 6 vs. 157 ± 6 cm, $P < 0.001$). The mean skin temperature of the dorsum of the foot in whole subjects was 31.9°C ± 1.6°C (range 28.0°–35.4°C). There were no significant differences in VPTs at any site between the two groups with measurements in different leg positions. Both the average and standard deviation of the VPTs showed a tendency to increase with age. There was a highly significant ($P < 0.001$) correlation between the age of the subjects and the VPT (Fig. 3), and the age-related increase in VPT was significant at all sites: The correlation between VPTs and age was strongest at the fifth toe ($r = 0.519$) followed by the great toe ($r = 0.443$), the lateral malleolus ($r = 0.391$), the medial malleolus ($r = 0.368$), the ulnar styloid ($r = 0.303$), and the patella ($r = 0.285$).

Table 3 shows means (±SD) of the vibratory perception thresholds at the six measurement sites for the left and right sides. Among all tested sites, the medial

Table 3. Vibration perception thresholds for tested sites

	Right	Left	*P*
Head of the ulna	1.8 ± 1.0	1.6 ± 0.7	**0.044**
Lateral malleolus	5.0 ± 5.3	5.0 ± 5.4	0.916
Fifth toe	5.1 ± 6.0	4.8 ± 5.1	0.916
Great toe	4.8 ± 5.7	5.1 ± 6.4	**0.047**
Medial malleolus	4.8 ± 5.1	4.1 ± 4.4	**0.004**
Foot	5.0 ± 5.0	4.9 ± 4.9	0.52
Patella	22.5 ± 40.1	25.0 ± 44.4	0.578

[$\times 10^{-2}$G]

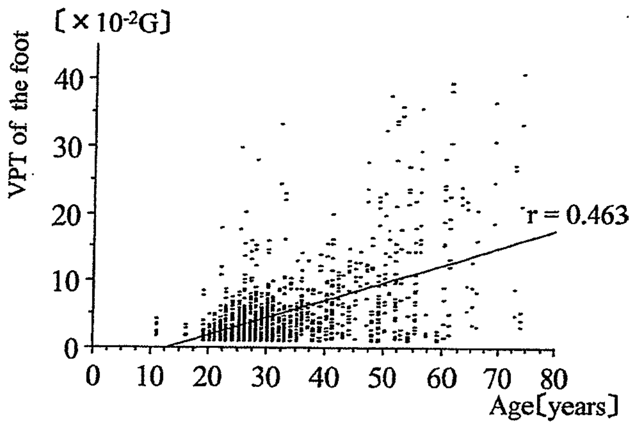

Fig. 3. Scatter-plots of vibration perception thresholds (*VPT*) of the foot in 377 normal individuals. Mean values of tested sides for two sides were plotted

malleolus, the great toe, and the ulnar styloid showed significant differences in VPT between the left and right sides. The VPT values were not significantly different between the dominant and nondominant sides.

Because it was not feasible to compare VPT values directly between males and females owing to uneven age distribution, the same number ($n = 96$) of subjects adjusted for age were chosen from both groups and compared. As a result, the average VPT was higher in men than in women at the lateral malleolus, the great toe, the patella, and the ulnar styloid but not significantly different at the fifth toe or the medial malleolus.

The VPT values for the lower extremities were higher than those for the upper extremities in all decades. There was no significant difference in VPTs among the four sites of the foot. The VPT values measured at the foot were significantly lower than that at the patella. Wide variations of VPT were observed for the patella, and in 50 subjects (16%) the VPT at the patella exceeded the upper limit of measurement (150 $\times 10^{-2}$G).

There was no significant difference in VPTs with regard to different BMI groups at any measurement site. Similarly, no significant difference in VPT was observed at any site between 134 smokers and 229 nonsmokers. There were also no significant associations between the VPTs and alcohol consumption.

However, the difference in the VPT values between the two sides of the body was small ($<3 \times 10^{-2}$G) and negligible enough to determine the reference intervals. There was also no significant difference in the VPTs among the four sites of the foot. These eight values, therefore, were averaged for each subject. The mean and standard deviation were calculated for each sex and decade. As suggested by document C-28P (NCCLS), it is probably advisable to consider 95% range of the value of reference population as the reference intervals; which could be obtained by calculating the mean value ± 1.96× standard deviations of VPTs in our subjects. The upper limit alone was specified, as the lower limit has no clinical meaning. The reference intervals of the VPT for the foot of normal Japanese were defined by decades for each sex in Table 4. The reference interval for the VPT of the lower extremity is less than 13×10^{-2}G for the total subjects.

Discussion

Although we cannot completely exclude abnormal values that may be obtained in normal subjects by chance, we set exclusion criteria (including metabolic disease, habitual drug use, and prior surgery) known to affect VPTs in the previous literature (a priori exclusion) when selecting the reference population. In addition, data obtained from these subjects (reference values) were subjected to rigorous statistical exclusion (a posteriori exclusion). As a result, the reference VPT values obtained in the present study from the population that included 377 subjects were confirmed to show a normal distribution by logarithmic transformation.

Several instruments have been developed to overcome lack of sensitivity and reproducibility in VPT

Table 4. Reference interval of VPT in the foot, by age group

Group	No.	Mean	SD	Minimum	Maximum	Reference interval
11–19 years						
Male	5	3.3	1.6	2.0	6.0	6.4
Female	10	2.0	1.2	1.0	5.0	4.4
20–29 years						
Male	105	3.3	2.1	1.0	12.0	7.4
Female	74	2.4	2.1	1.0	15.0	6.4
30–39 years						
Male	73	4.2	2.8	1.0	16.5	9.8
Female	22	3.9	2.4	1.0	10.0	8.7
40–49 years						
Male	29	6.8	4.8	2.0	21.0	16.1
Female	14	7.2	6.1	1.0	20.5	19.1
50–59 years						
Male	16	10.8	7.3	1.0	26.0	25.2
Female	13	4.9	5.2	1.0	20.0	15.1
60–74 years						
Male	13	13.3	10.1	3.0	32.0	33.1
Female	3	10.8	3.2	8.5	13.0	17.0
Totes						
Male	241	4.9	4.7	1.0	32.0	14.1
Female	136	3.5	3.6	1.0	20.5	10.5
All	377	4.4	4.4	1.0	32.0	12.9

[×10^{-2}G]

VPT, vibration perception threshold

measurements.[10–13] The reliability of VPT measurements seems to be dependent on the type of vibrometer used and on the observers who perform the procedure. Because of its high precision,[5] the SMV-5 vibrometer is sensitive enough to detect sensory impairment that cannot be detected by conventional neurological examinations.[9] In many studies, the VPT has been tested in normal subjects.[1,14–18] Hilz et al. reported the reference values for VPT in 530 healthy subjects using the Vibrameter. They presented the VPT in terms of amplitude, and only one site was studied in the lower extremity.[1] The Vibrameter requires a control unit in addition to the stimulating probe. The advantages of the SMV-5 vibrometer are that it is noninvasive, time-efficient, and easy to apply at various test sites and angles as it is small and portable. We applied it to five sites in the lower extremity on both sides and compared the VPT values of different anatomical sites.

The VPTs of normal subjects increased significantly with age in both the upper and lower extremities, as in earlier reports. Pearson was the first (1928) to study a large series with respect to the influence of aging on VPTs.[17] He found a slight decrease in vibratory sensitivity in different age groups, which became striking after age 50.[17] The present study yielded similar results. Usually, the vibration sense diminishes in the legs and feet with advancing age.[14,15,17,18] On the other hand, Laidlaw and Hamilton found no significant increase in VPTs in the hands and fingers with aging,[19] whereas a significant increase was obtained for the ulnar styloid in our study. The precise nature of the mechanism responsible for the age-related decrease in vibration sensitivity remains unknown. Among various hypotheses, one possibility is a diminution in the blood supply to the peripheral nerves,[20] as arteriosclerosis become prominent with aging.[21] It is generally accepted that VPTs determined at high frequencies (80–400 Hz) are the result of neural activity in Pacinian corpuscles and that the changes in the structures of the Pacinian corpuscle occur between birth and 93 years of age.[22] In addition to the changes in the structures, the population of Pacinian corpuscles decreases with age.[22] These changes, therefore, could be associated with the loss of vibratory sensitivity at high frequencies.[23] Moreover, there is progressive fiber loss and demyelinization in the peripheral nerve and the spinal nerve roots with aging.[24] Progressive changes such as loss of nerve cells also occur in the central nervous system, which may also contribute to the decreased vibration sense.[25] The spinal cord and spinal nerve roots may suffer significant compression in the elderly because of degenerative changes in the cervical and lumbar spine, even in the absence of symptoms and clinical findings. Indeed, we found a wide variation in the VPT values of elderly persons.

We found women to be more sensitive than age-matched men at several of the tested sites. The difference between the sexes has been studied previously.[2,15,18,26] It has been suggested that the vascular disorders of the heart and the lower limbs occur more frequently and earlier in men than in women.[18] Therefore, separate reference intervals of VPT should be determined for each sex and decade.

Several authors have reported that sensitivity differs on the left and right sides of the body, with the limb on the left side reported to be more sensitive.[26] In the present study, the left side was more sensitive than the right side on the great toe, medial malleolus, and ulnar styloid. However, the difference in VPT values between the two sides of the body was small ($<3 \times 10^{-2}$G) and negligible enough for determining the reference intervals.

The VPT of the ulnar styloid was lower than those in the lower extremities, which is in accordance with previous reports. As early as 1897, Treitel showed that the VPT is most sensitive in the upper limbs, and that it is finest in the distal parts of the limbs and poorer on the trunk. One explanation may be the difference in the size of the projection field in the central nervous system. The hands have wide projection areas in the cerebral cortex. The difference in the areas of perception may be due to the difference in receptor density.[14]

The knees are not very sensitive to vibratory stimuli.[26,27] It was concluded that measuring the VPT at the patella with this instrument (SMV-5) is not feasible. No significant differences were found among the four foot regions (medial malleolus, lateral malleolus, great toe, fifth toe). Therefore, we provide average VPT values of the four sites as the reference interval of the foot.

The influence of BMI, smoking, and alcohol consumption on the VPT were not apparent in the present study. Previous studies have also revealed that neither habitual drinking nor smoking affected the VPT.

This study provides reference intervals of the VPT around the foot regions. The upper limit alone was specified, as the lower limit has no clinical meaning.

In the actual clinical applications there are several points to take into account. Measurements can be performed with the knees either bent (sitting position) or extended (supine position). Green[28] reported a U-shaped relation between skin temperature and the VPT in nondiabetic subjects, with 34°C being the nadir. He concluded that cooling might affect VPT by decreasing the sensitivity of Pacinian corpuscles; the reason for the decreased sensitivity due to warming is unclear. According to several other reports[15,29] the VPT may be stable between 28°C and 36°C skin temperature. It would be preferable to measure the VPT at four sites of the foot bilaterally for comparison.

The VPT assessment can be used in diagnostic procedures, research, and follow-up studies to investigate the course of the disease and the therapeutic effect. VPT measurements can be recommended as a complement to conventional neurological and neurophysiological evaluations. The present study is the first to define the reference interval of the VPT using a large population and taking into account the possible variables that may affect the measurement.

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

References

1. Hilz MJ, Axelrod FB, Hermann K, Haertl U, Duetsch M, Neundörfer B. Normative values of vibratory perception in 530 children, juveniles and adults aged 3–79 years. J Neurol Sci 1998;159:219–25.
2. Mirsky IA, Futterman P, Brohkahn RH. The quantitative measurement of the vibration perception in subjects with and without diabetes mellitus. J Lab Clin Med 1953;41:221–35.
3. Mountcastle VB, LaMotte RH, Carli G. Detection thresholds for stimuli in humans and monkeys: comparison with threshold events in mechanoreceptive afferent nerve fibers innervating the monkey hand. J Neurophysiol 1972;35:122–36.
4. Mountcastle VB, Talbot WH, Darian-Smith I, Kornhuber HH. Neural basis of the sense of flutter vibration. Science 1967;155: 597–600.
5. Shindo H, Tawata M, Inoue M, Yokomori N, Hosaka Y, Ohtaka M, et al. The effect of prostaglandin E1α CD on vibratory threshold determined with the SMV-5 vibrometer in patients with diabetic neuropathy. Diabetes Res Clin Pract 1994;24:173–80.
6. Yoshioka K, Kameda T, Ohsawa A, Yokoo S. Vibratory perception threshold in diabetic patients measured by Suzuki-Matsuoka Vibrometer (SMV-5). J Kyoto Pref Univ Med 1992;101:645–9.
7. Ohnishi A, Haba S, Yamamoto T, Murai Y, Ikeda M. Comparative studies on the evaluation of vibratory perception threshold using three different instruments, vibratron II, TM-31A and SMV-5: reliability, correlation with age and interrelationship. J UOEH 1994;16:61–70 (in Japanese).
8. Sasse ES, Aziz KJ, Harris EK, Krishnamurthy S, Lee HT, Ruland A, et al. How to define, determine reference intervals in the clinical laboratory; approved guideline. NCCLS Document C28-A, 1995;15:1–59.
9. Suzuki Y, Matsuoka K. A process of inventing new vibratory sensation meter (SMV-5). Ther Res 1991;12:4189–96 (in Japanese).
10. Tomioka M, Kodama K, Otani T, Uchikata Y, Hirata Y, Matsuoka K, et al. Suzuki-Matsuoka vibrometer (SMV-4) is easily swayed by short term blood sugar control. Ann Jpn Soc Res Diab Complications 1990;3:65–71 (in Japanese).
11. Armstrong FM, Bradbury JE, Ellis SH, Owens DR, Rosen I, Sonksen P, et al. A study of peripheral diabetic neuropathy: the application of age-related reference values. Diabet Med 1991;8:S94–9.
12. Harazin B, Kuprowski J, Stolorz G. Repeatability of vibrotactile perception thresholds obtained with two different measuring systems. Int J Occup Med Environ Health 2003;16:311–9.
13. Peters EW, Bienfait HME, DeVisser M, DeHaan J. The reliability of assessment of vibration sense. Acta Neurol Scand 2003; 107:293–8.
14. Goldberg JM, Lindblom U. Standardised method of determining vibratory perception thresholds for diagnosis and screening in neurological investigation. J Neurol Neurosurg Psychiatry 1979; 42:793–803.

15. Halonen P. Quantitative vibration perception thresholds in healthy subjects of working age. Eur J Appl Physiol 1986;54:647–55.
16. Meier PM, Berde CB, DiCanzio J, Zurakowski D, Sethna NF. Quantitative assessment of cutaneous thermal and vibration sensation and thermal pain detection thresholds in healthy children and adolescents. Muscle Nerve 2001;24:1339–45.
17. Pearson GHJ. Effect of age on vibratory sensibility. Arch Neurol Psychiatry 1928;20:482–96.
18. Steiness IB. Vibratory perception in normal subjects: a biothesiometric study. Acta Med Scand 1957;158:315–25.
19. Laidlaw RW, Hamilton MA. Thresholds of vibratory sensibility as determined by the pallesthesiometer: a study of sixty normal subjects. Bull Neurol Inst 1937;6:493–503.
20. Fetterman JL, Spitler DK. Vascular disorders of peripheral nerves. JAMA 1940;114:2275–9.
21. Ahrens RS. A study of the vibratory sensation. Arch Neurol Psychiatry 1925;14:793–805.
22. Cauna N. The effect of aging on the receptor organs of the human dermis. In: Montagna W, editor. Advances in biology of skin. Vol 6: Aging. Oxford: Pergamon; 1965.
23. Verrillo RT. Age related changes in the sensitivity to vibration. J Gerontol 1980;35:185–93.
24. Ochoa J, Mair WGP. The normal sural nerve in man. I. Ultrastructure and numbers of fibres and cells. Acta Neuropathol (Berl) 1969;13:197–216.
25. Brody H. Organization of the cerebral cortex. III. A study of aging in the human cerebral cortex. J Comp Neurol 1955;102:511–56.
26. Goff GD. Differential discrimination of frequency of cutaneous mechanical vibration. J Exp Psychol 1967;74:294–9.
27. Gregg EC. Absolute measurement of the vibratory threshold. Arch Neurol Psychiatry 1951;66:403–11.
28. Green BG. The effect of skin temperature on vibrotactile sensitivity. Percept Psychophys 1977;21:243–8.
29. Aaserud O, Juntunen J, Matikainen E. Vibration sensibility thresholds: methodological considerations. Acta Neurol Scand 1990;82:277–83.

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16

Effects of Rowing on Health Promotion in Older People

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Key Words: rowing, aerobic capacity, fat-free mass, serum lipoprotein profile, older people

INTRODUCTION

Many people are currently involved in cardiorespiratory fitness and resistance training programs and efforts to promote participation in all forms of physical activity are being developed and implemented. Based upon the existing evidence concerning exercise prescription for healthy adults, the American College of Sports Medicine (ACSM) has made the recommendations for the quantity and quality of training for developing and maintaining cardiorespiratory fitness, body composition, muscular strength and endurance, and flexibility in the healthy adult (1998). In the Position Stand of ACSM any activity that uses large muscle groups, which can be maintained continuously, and is rhythmical and aerobic in nature, such as walking-hiking, running-jogging, cycling-bicycling, cross-country skiing, aerobic dance, rope skipping, rowing, stair climbing, swimming, skating, and various endurance game activities have been recommended for developing and maintaining cardiorespiratory fitness.

ROWING PERFORMANCE AND RELATED PARAMETERS

Rowing involves both the lower and upper body, e.g. almost all the muscles in the body, and consists of rhythmical muscle contractions and demands a high aerobic capacity (Secher 1983). A direct relationship exists between the average maximal oxygen uptake (VO2max) of the crew and their placing in an international regatta (Secher et al.,1982; Secher,1983, 2000). The VO2max relates to body size (Secher, 1983; Secher et al., 1983; Jensen et al., 2001), and the VO2max for female rowers is lower than that of male rowers (Secher, 2000; Jensen et al.,2001) because of smaller body size in female rowers that in their male counterparts (Ingjer, 1991; Jensen et al., 2001). Accordingly, it was assumed that the rowing performance of females lags behind that of males because of their smaller VO2max.

In this study (Yoshiga and Higuchi, 2003), seventy-one female rowers (age range 18–24 years; mean(SD) 19(2) years, body height 153–173 cm; 163(5) cm, body mass 43–69 kg; 57(6) kg, 2000-m ergometry rowing time 437–556 sec.; 498(32) sec. and 120 male rowers (age range 18–24 years; 21(2) years, body height 164–193 cm; 176(5) cm, body mass 58–95 kg; 70(7) kg, 2000-m ergometry rowing time 378–484 sec.; 424(19) sec.) volunteered to evaluate rowing performance of male and female rowers with regard to their body size. Both the male and female subjects rowed at least 5 days a week on water or on an ergometer. None of the subjects had any known cardiovascular disease or took any medication.

The percent body fat was derived according to Brozek formula (1963). The fat-free mass (FFM) was the difference between the body and the fat mass. The subjects completed an all-out 2000-m row on an ergometer (Concept II model C, VT, USA) designed to simulate an actual rowing race on water (Secher, 1983). On a separate day, the subjects performed a progressive running test on a treadmill (Hermansen and Saltin, 1969). Exercise was terminated when the subjects could not complete a given running speed. The expired gas was collected in Douglas bags during the last 1 min of each stage. The volume of the gas was measured with a dry gas meter and O2 and CO2 were determined. The heart rate (HR) was determined electrocardiographically.

Linear and curvilinear regression analyses were used to evaluate the relationship between rowing performance and body size, fat-free mass, and VO2max.

The average body height and mass were smaller for the female than for the male rowers and rowing performance was correlated to both body height and body mass (**Figure 1**). The average fat-free mass was also smaller for the female than for the male rowers (45.1(4.4) (34.0–55.2) vs. 61.7(5.5) (50.2–80.8) kg, P<0.01) and rowing performance was significantly correlated to the fat-free mass (Fig.1). Equally, the average VO2max was lower for the female than for the male rowers (2.9 (0.4) (2.1–3.9) vs. 4.3 (0.4) (3.4–5.6) L/min, P,0.01) and rowing performance was significantly correlated to VO2max (**Figure 1**).

Regarding the relationship between rowing performance and body mass, a curvilinear regression provided a better fit to the variances of rowing performance compared to a linear regression. Similarly, curvilinear regressions fitted rowing performance to body height, fat-free mass, and VO2max better than linear relationships.

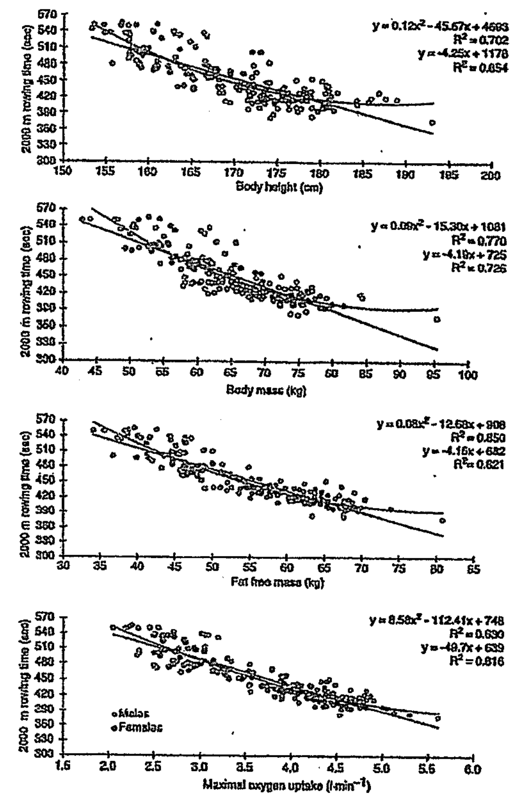

FIGURE 16-1. *Relationship between rowing performance and body height, body mass, and VO2max.*

The main finding of this study is that rowing performance increased with body size. More specifically, a large fat-free mass and a large VO2max resulted in a high level of rowing performance, supporting the fact that rowing is an aerobic type of exercise that demands activation of almost all muscles in the body (Secher, 1983, 2000; Yoshiga et al.,2003). However, rowing performance time on ergometer was slower in the female than in the males with a similar body height (by ~10%) and body mass (by ~9%), but the sex difference was smaller when the fat-free mass (by ~4%) and VO2max (by ~4%) were taken into consideration. A lower haemoglobin concentration may also account for a lower aerobic capacity of women than of men after considering differences in body and fat-free mass (Keller and Katch,1991; Wilmore and Costill, 1999). It is also to be considered that rowing consists of rhythmical extensions of both legs (Secher, 1983) and that rowing performance is associated with the size of the leg muscle (Yoshiga et al., 2002b). Thus, although body size and aerobic capacity are major determinants of rowing performance, the performance of the female rowers remains inferior to that of the male rowers when the major determinants are taken into consideration.

OXYGEN UPTAKE AND VENTILATION DURING ROWING

Periodic contraction of muscles and movement during rowing elevates pleural pressure. An increased pleural pressure reduces venous return, end-diastolic volume, and the stroke volume of the heart. Also the increased intra-abdominal pressure impairs ventilation at stroke catch or stroke finish. These physiological changes are considered to impair the expiratory volume (VE) and oxygen uptake (VO2) at maximal rowing effort. On the other hand, rowing involves both upper- and lower-body exercise, while running mainly involves the legs (Secher et al., 1983; Clifford et al., 1994). VO2 increases as the muscle mass involved increases (Secher et al., 1974; Secher et al., 1977). We hypothesized that ventilation and oxygen consumption during rowing are larger than during running.

In this study (Yoshiga and Higuchi, 2003), we recruited the subjects including 55 males (age mean(SD), 21(3) years; body height 176(5) cm; body mass 72(6) kg; body fat 11(3)%) and 18 females (20(2) years; 164(5) cm; 61(4) kg; 22(4)%). All subjects completed two bouts of progressive incremental exercise: running on a treadmill and rowing on an ergometer (Comcept II model C). All subjects are regularly running on a treadmill and rowing on an ergometer and were familiar with both types of exercise. Exercise was terminated when the subjects were no longer able to maintain the required intensity.

VEmax was larger during ergometer rowing than during treadmill running (males: 157(16) vs. 147(13) L/min; females: 114(9) vs. 105(11) L/min,$P<0.05$). VO2max was also larger during rowing compared to during running (males: 4.5(0.5) vs. 4.3(0.4) L/min; females: 3.3(0.4) vs. 3.2(0.4) L/min,$P<0.05$). VEmax, VO2max, oxygen pulse, VEmax/VO2max and HRmax during rowing were significantly correlated to those parameters during running (**Figure 2**). HRmax was lower during ergometer rowing than during treadmill running (males: 194(8) vs. 198(11) beats/min; females: 192(6) vs. 196(8) beats/min,$P<0.05$).

We showed that bending the body during rowing does not impair ventilation in both sexes. The results of this study showed that the cardiorespiratory response to "seated" ergometer rowing is enhanced compared to "upwright" treadmill running. Also ergometer rowing attenuates a HRmax compared to treadmill running. The findings of this study indicate that the involvement of more muscles, the entrainment, and the position during rowing facilitates ventilation and venous return for both males and females.

BILATERAL LEG EXTENSION POWER AND FAT-FREE MASS IN ROWERS

During rowing, the activated muscle mass is larger than during leg exercise such as running, since rowing engages both the upper and the

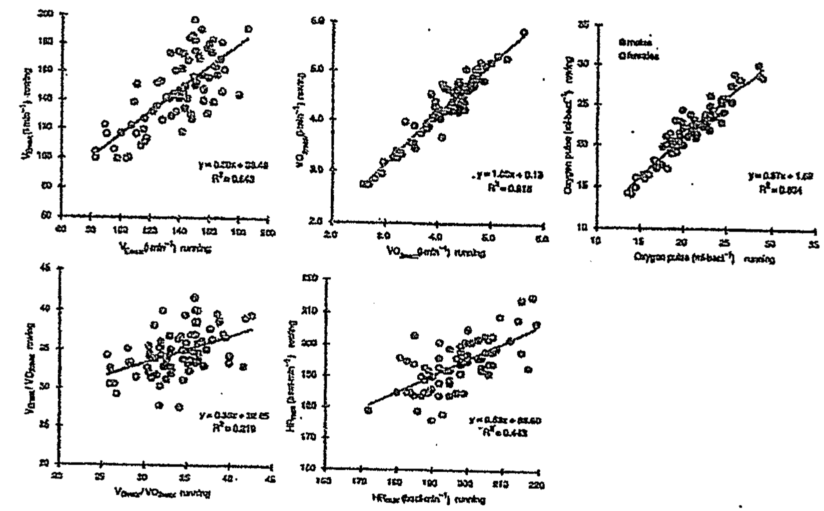

FIGURE 16-2. *Relationship for maximal minute ventilatory volume (VEmax), maximal oxygen uptake(VO2max), ventilatory equivalent for oxygen(VEmax/VO2max), maximal heart rate(HRmax), and oxygen pulse(VO2max/HRmax) between rowing and running.*

lower musculature (Secher, 1983, 2000). For both sedentary males and active males who engage in physical activities other than rowing, bilateral leg strength is lower than the sum of the left and right leg strength (Secher, 1975,1983). In particular, rhythmic extensions of the leg muscles produce the propulsive power required during rowing (Secher, 1983, 2000). In light of the rowing motion, we hypothesized that the ability to produce a high bilateral leg extension power is important for rowing.

Altogether, 332 young oarsmen (age mean(SD) 21(2) years, height 176(5) cm, body mass 70(6) kg) volunteered to participate in this study (Yoshiga and Higuchi, 2003). Maximal bilateral leg extension power was determined using a dynamometer. (Anaeropress 3500, Combi Co., Tokyo, Japan). This movement involves knee and hip extensions in a coordinated manner. On a separate day, the participants completed an all-out 2000 m row on an ergometer. All participants were familiar with the rowing ergometer from their daily training.

The range of 2000 m rowing performance times on the ergometer was 378–498 sec. Rowing performance time was significantly related height, body mass, fat-free mass and bilateral leg extension power, respectively (Figure 3). Multiple regression revealed that fat-free mass was the strongest independent predictor of rowing performance. Bilateral leg extension power accounted for an additional 5% of the variance in rowing performance. Thus, 2000 m rowing time (sec) was predicted as 598 minus 2.24 times the fat-free mass(kg) minus 0.02 times the bilateral leg extension power(W). For the relationship between rowing performance and bilateral leg extension power, a curvilinear regression provided a better fit to the variance in rowing performance than a linear regression.

Our results suggest that rowing requires the involvement of almost all muscles in the body, including those in the legs, arms, back and trunk (Secher, 1983, 2000). The rhythmic extensions of both legs are a unique attribute of rowing (Secher, 1975,1983). The main finding of this study is that both fat-free mass and bilateral leg extension power were important physiological parameters of 2000 m ergometer rowing performance in young oarsmen.

For weight-bearing physical activities such as long-distance running, a large body mass hinders exercise performance. However, the results of the present study indicate that a large body mass contributes to favorable rowing performance, possible because the body is supported during rowing (Secher, 1983).

SERUM LIPOPROTEIN CHOLESTEROLS IN OLDER ROWERS

Dyslipoproteinaemia is a primary risk factor for coronary heart disease (CHD), i.e. elevated concentrations of total cholesterol (TC), triglyceride (TG), and low-density lipoprotein cholesterol (LDL-C), and a reduced high-density lipoprotein cholesterol (HDL-C). In cross-sectional studies, the death of older people with hypercholesterolaemia may affect the artherosclerosis indexes (Thompson et al., 1995).

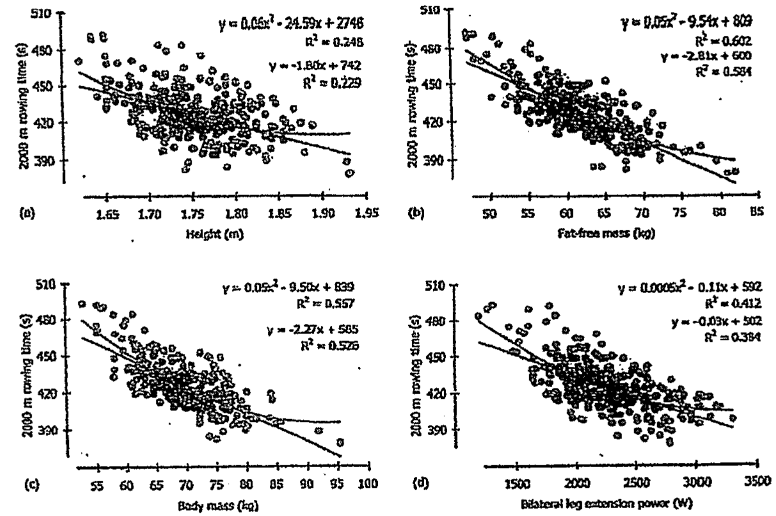

FIGURE 16-3. *Relationship between 2000m rowing ergometer performance time and (a)height, (b)fat-free mass, (c)body mass, and (d)bilateral leg extension power.*

Rowing involves both the lower and upper body, e.g. almost all the muscles in the body, and consists of rhythmic muscle contractions and demands a high aerobic capacity (Secher, 1983). However, little information has been available to evaluate the effects of regularly performed rowing exercise in older adult on serum lipid and lipoprotein profiles, cardiorespiratory function and body composition. Therefore, this study was undertaken to evaluate the serum concentrations of lipid and lipoprotein cholesterols, body composition, and maximal aerobic capacity of older men trained for rowing (Yoshiga et al., 2002).

A group of 17 older trained men (age mean(SD) 64(4) years, height 172(6) cm, body mass 172(6) cm, body fat 18(4)%) were matched to both older sedentary (65(3) years, 172(7) cm, 70(7) kg,23(4)%) and to young trained men (22(2) years, 174(5) cm, 70(4) kg, 12(4)%) on the basis of body size. Also the older oarsmen were matched to young sedentary men (22(3) years, 172(6) cm, 69(7) kg, 17(4)%) for body size and composition. The young sedentary men underwent treadmill running while the other three groups of subjects rowed on an ergometer for measuring of VO2max. Following a 12 h overnight fast, blood sample was collected from an antecubital vein in the early morning and the plasma was separated by centrifugation to be used for the lipid analysis. The TC was analyzed using an enzymatic method, HDL-C using a selective inhibition method, and TG using an enzymatic method. The LDL-C was calculated according to Friedewald et al. and the ratios of LDL-C to HDL-C and that of TC to HDL-C were calculated.

The VO2max of the older oarsmen was lower than that of the young oarsmen (3.0(0.4) vs. 4.1(0.3) L/min, $P<0.05$), but it was similar to that in the young sedentary men (3.1(0.5) L/min), and it was higher than that of the older sedentary men (2.2(0.3) L/min, $P<0.05$) (**Figure 4**). Older oarsmen had a lower rowing performance than the young oarsmen (2,000m ergometer rowing time 489(16) vs. 451(12) sec, $P<0.05$). Although in the older oarsmen the indices of risk factors for coronary artery disease were higher than those in young oarsmen (LDL-C/HDL-C 1.7(0.2) vs. 1.3(0.4), and TC/HDL-C 3.1(0.2) vs. 2.6(0.4)),$P<0.05$), they were lower than those in both the older (2.1(0.3), 3.6(0.3), $P<0.05$), and the young sedentary men (2.1(0.4), 3.5(0.4), $P<0.05$) (**Figure 5**).

The first main finding of this study is that in the older men trained in rowing risk factors for CHD were lower than those obtained in both older and young sedentary men. Second, the older oarsmen had a higher aerobic capacity than the older sedentary men. These findings indicate that rowing, which is an aerobic type of exercise and involves a large muscle mass (Secher, 1983), is associated with a low risk factor index for CHD. The results therefore support the possibility that rowing is associated with a prolonged life expectancy.

EFFECT OF ROWING ON PREVENTION OF MUSCLE WASTING IN OLDER MEN

With advancing age, leg muscle size declines with subsequent decrements in leg muscle functional ability. For older people, the ability of the leg extensor muscles to develop power is important for tasks of daily life such as climbing stairs, walking, and recovering balance, and the decline in the leg extensor muscle increases the risk of falls and limb disability (Rubenstein et al.,2000; Lamoureux et al. 2001). As rowing involves rhythmical muscle extensions of both legs (Secher, 1983; Gustafsson et al., 1996), it may have a positive influence not only on risk factors for CHD but also for limb disability and falling. This study was undertaken to evaluate effects of rowing on the morphology and strength of the leg extensor muscle in old people (Yoshiga et al., 2002).

Fifteen elderly trained men (age mean(SD) 65(3) years, height 171(4) cm, body mass 68(6) kg, body fat 19(4)%) were matched for their body size to older sedentary men (66(4) years, 170(4) cm, 67(7) kg, 21(5)%).

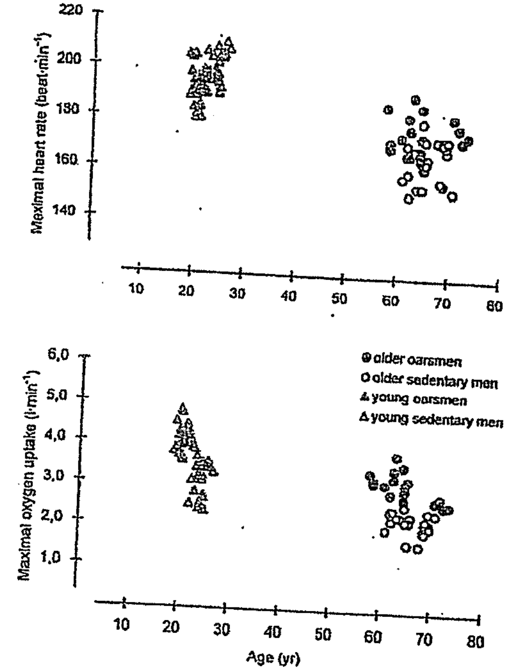

FIGURE 16-4. *Maximal heart rate and maximal oxygen uptake related to age.*

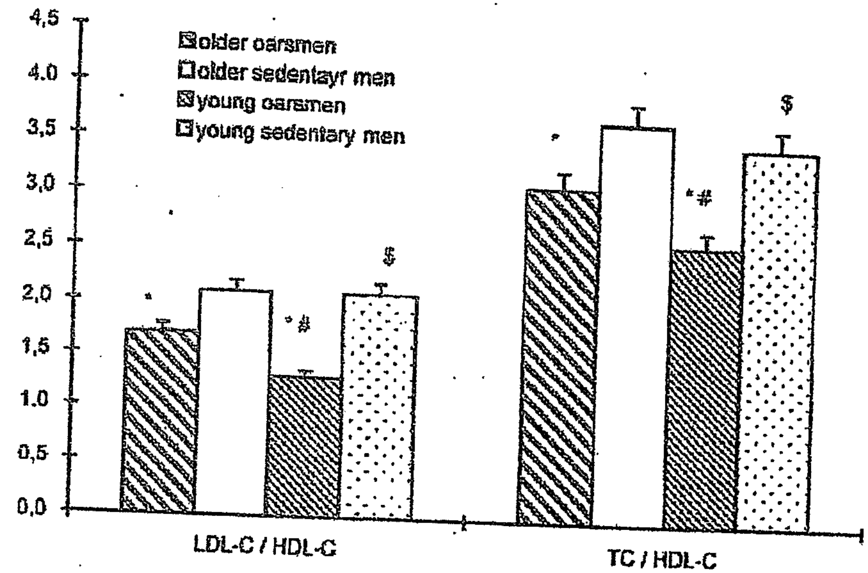

FIGURE 16-5. *Atherosclerosis indices (the ratio of LDL-C to HDL-C, and TC to HDL-C).*

the trained men had for many years and they rowed at least 2 days a week on water or on an erogmeter. Percentage body fat was derived according to Brozek formula using body density (BOD POD system). The cross-sectional area of the main leg extensor, the quadriceps femoris, was measured by proton-magnetic resonance imaging (AIRIS II Comfort System 0.3–T, Hitachi Medico Co., Tokyo, Japan) and analyzed with NIH Image software. Subjects were supine within the MR imager. With a T1–weighted spin-echo sequence, the middle of the thigh was evaluated between the greater trochanter and the lateral condyle (**Figure 6**). Maximal bilateral leg extension power was determined using a dynamometer (Anaeropress 3500). On a separate day, all trained elderly men completed an all-out 2,000 m row on an ergometer.

The leg extensor muscle area of the elderly oarsmen was larger than that of the age-matched sedentary men (77.8(5.4) vs. 68.4(5.1) cm2). Also, the bilateral leg extension power of the oarsmen was larger than that of the sedentary men (1,624(217) vs. 1,296(232) W). Thus, the leg

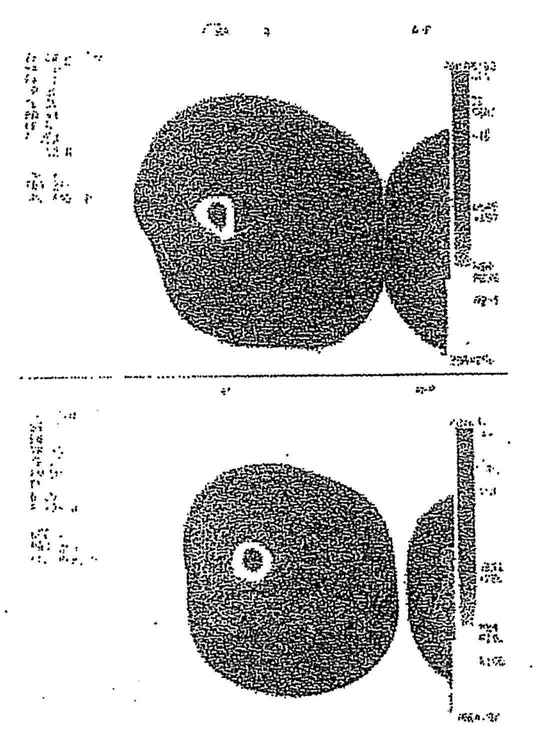

FIGURE 16-6. *Representative magnetic resonance images of an elderly trained rower (upper) and an elderly sedentary man (bottom).*

extension power per leg extensor muscle area was not significantly different between the oarsmen and the sedentary men (20.9(2.0) vs. 19.9(2.1) W/cm2). Leg extension power was correlated to the leg extensor muscle area (59–89 cm2, P<0.001) (Fig. 7). For the oarsmen, 2,000 m rowing ergometer time (495(14) sec; range 479–520 sec.) was related to the leg extensor muscle area (68–89 cm2, P<0.01) (**Figure 7**).

The main finding of this study was that in older oarsmen both morphological and functional risk factors for falling or limb disability were lower than in sedentary older men. With aging, the decline in leg muscle size and power are related to decline in the quantity and/or intensity of daily physical activity (Izquierdo et al., 1999, 2001). The older oarsmen possessed a larger leg extensor muscle area by 14% and power by 25% than the sedentary men.

The loss of leg muscle power increases the dependence on others to accomplish routine activities of daily life and furthermore contributes to a loss of self-value and satisfaction. The maintenance of the morphology

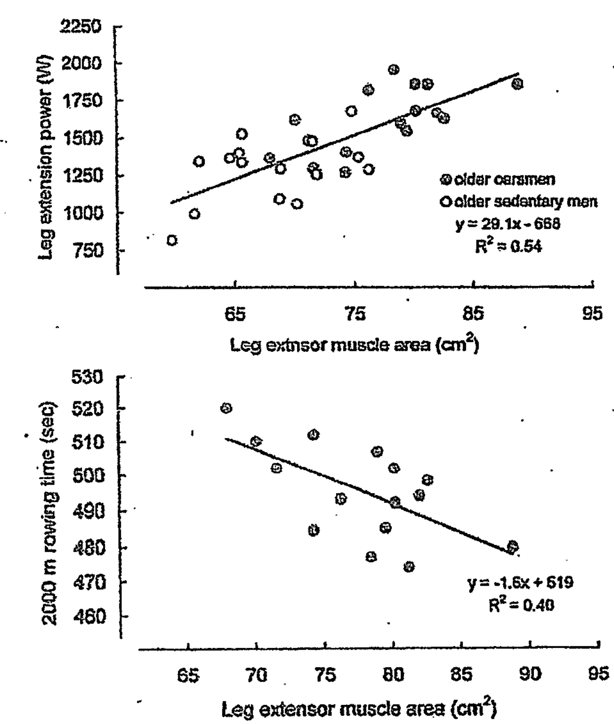

FIGURE 16-7. *Relationship between leg extension power, 2000m ergometer rowing time and leg extension muscle area in elderly men.*

and function of the leg extensor muscle is significant for a healthy and independent life in older people. The results suggest that rowing prevents age-related muscle wasting and weakness.

HEART RATE RESPONSE TO ROWING IN OLDER MEN

In prescription of exercise, heart rate (HR) is accounted for assuming that there is a given relation between %HRmax and %VO2max and between %HR reserve and %VO2 reserve (ACSM, 1999). Direct measurement of HRmax or VO2max is often not feasible for older people because they tend to be unable to work at a maximal effort. Thus, exercise may be terminated when the subject reaches an arbitrary percentage of their age-predicted HRmax or the exercise intensity is determined based on the age-predicted HRmax (ACSM, 1999). Besides exercise involving the legs such as treadmill running, other modes of activity are used including arm cycling or combined arm and leg exercise or ergometer rowing. This study evaluated the relation between HR and VO2 during ergometry rowing and treadmill running for older people (Yoshiga et al., 2003).

Fifteen older men (age 62(3) years, body mass 70(5) kg, body fat 17(4)%) participated in this study. They signed an informed consent document after a comprehensive explanation of the proposed study, methods and procedures, its benefits, inherent risks. All subjects were familiar with both ergometer rowing and treadmill running and none had any cardiorespiratory illness or took any medication.

Subjects performed a discontinuous incremental intensity protocol, in random order, both on a rowing ergometer and on a treadmill running. The expired gas was collected in Douglas bags during the last 1 min of each stage and the volume was measured using a dry gas meter and the concentrations of O2 and CO2 were determined. The HR was determined by an ECG. Blood samples were taken in heparinized glass capillaries from the fingertips immediately after each stage and at termination of exercise. Blood lactate concentration [La-]b was analyzed by an enzymatic membrane method using a 1500 Analyzer (Yellow Springs, OH,USA).

At rest HR was lower when sitting on a rowing ergometer than when standing on a treadmill (mean(SD) 72(5) vs. 80(4) beats/min), while VO2 was similar (0.4(0.2) L/min) (Fig. 8). The HR was also lower during rowing than during running (118(4) vs. 128(4) beats/min at a [La-]b of 2mM, 151(4) vs. 160(6) beats/min at a [La-]b of 4mM, 160(5) vs. 171(4) beats/min at a [La-]b of 6mM) (**Figure 8**). Also, during rowing HRmax was lower than during running (171(7) vs. 177(7) beats/min) (**Figure 8**).

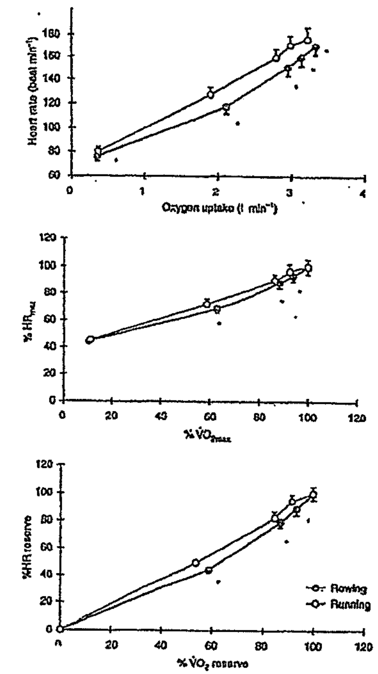

FIGURE 16-8. *Relation between heart rate and oxygen uptake, between percentage of maximal oxygen uptake(%VO2max) and percentage of maximal heart rate(%HRmax), and between percentage of heart rate reserve (%HR reserve) and percentage of oxygen uptake reserve (%VO2 reserve).*

The VO2 at rest was similar for two postures, sitting and standing (0.4(0.2) L/min) (Fig. 8). The VO2 was higher during rowing than during running (2.2(0.3) vs. 1.9(0.4) L/min at a [La-]b of 2mM, 3.0(0.4) vs. 2.7(0.4) L/min at a [La-]b of 4mM, 3.2(0.2) vs. 2.9(0.4) L/min at a [La-]b of 6mM) (Fig. 8). Also, during rowing VO2max was larger than during running (3.4(0.4) vs. 3.1(0.3) L/min) (**Figure 8**).

The main finding of this study was that the HR response to ergometer rowing was attenuated compared with treadmill running in older individuals, accompanied with a higher VO2 during ergometer rowing than during treadmill running. Secondly, %HRmax and %HR reserve during ergometer rowing was lower than during treadmill running in older people.

Subjects use both arms and legs during rowing while during running they use mainly their legs. A higher VO2 during ergometer rowing than during treadmill running supports that rowing involves a larger muscle mass than running. During dynamic exercise the active muscle works as a pump and facilitates venous return and thereby enhances the central blood volume. Enhanced venous return results in an augmented stroke volume of the heart. Also an elevated central blood volume enhances venous pressure and deactivates the cardiopulmonary baroreceptors to slow HR as sympathetic activity during exercise is reduced (Ray et al.,1993). The results indicate that the mode of exercise and /or the involved muscle mass affect the HR response to exercise for older people.

CONCLUSION

Rowing contributes to aerobic fitness and has a low injury rate. Use of larger muscle mass during combined arm and leg exercise than during leg exercise allows a greater cardio-respiratory training effect (Hoffman et al., 1996). Rowing involves both arms and legs, whereas walking and running involve mainly legs (Secher, 1983; Yoshiga and Higuchi, 2002).

A rowing ergometer is not as expensive as a walking and running treadmill. Like running and swimming, master rowing has a large and growing number of participants in the world, with national and world veteran championships conducted annually. Older individuals row not only on an ergometer but also on water and make rowing trips traveling along familiar and unknown waters (Fritsch, 2000). Also, rowing is one of a social sports that provides the individual contact with the social environment, and recognition from and with others (Fritsch, 2000).

Thus older people may be encouraged to row. Aerobic and resistance exercises that use large muscle groups are to be recommended as prescribed modes of exercise and rowing is included in such two types of exercise.

SUMMARY

Rowing involves almost all the muscles in the body, and consists of rhythmical muscle contractions and demands a high aerobic capacity. Our study indicated that older rowing-trained men have higher VO2max and lower CHD risk factors than age-matched untrained men. The maintenance of the morphology and function of the leg muscle is significant for healthy and independent life for older people. Our study also indicated that older oarsmen possess larger leg extension muscle and bilateral leg extension power than sedentary men, suggesting that rowing prevents age-related muscle wasting and weakness. Furthermore, our study suggested that heart rate(HR) response to ergometer rowing is attenuated compared with treadmill running in older individuals, accompanied with a higher VO2 during rowing than during running, indicating that the mode of exercise and/or the involved muscle mass affect HR response for older people. Based upon these studies, rowing may be recommended for maintaining cardiorespiratory and muscular fitness in healthy older people as indicated in the ACSM Position Stand(1998).

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BIBLIOGRAPHY

American College of Sports Medicine (1998) Position Stand on The Recommended Quantity and Quality of Exercise for Developing and Maintaining Cardiorespiratory and Muscular Fitness, and Flexibility in Healthy Adults. *Med. Sci. Sports and Exerc.*, 30:975–991.

Clifford,P.S.,Hanel,B.,and Secher,N.H. (1994) Arterial blood pressure response to rowing. *Med.Sci.Sport Exerc.* 26:715–719.

Fritsch,W. (2000) Rowing in daily life. In:Rowing (ed. Fritsch,W.) 148–183, Meyer and Meyer Sport Ltd.,Oxford.

Gustafsson,F.,Ali,S.,Hanel,B.,Toft,J.C., and Secher,N.H. (1996) The heart of the senior oarsmen: an echocardiographic evaluation. *Med.Sci.Sport Exerc.* 28:1045–1048.

Hoffman,M.D.,Kassay,K.M.,Zeni,A.I.,Clifford,P.S. (1996) Does the amount of exercising muscle alter the aerobic demand of dynamic exercise. *Eur.J.Appl.Physiol.* 74: 541–547

Izquierdo,M.,Ibanez,J.,Gorostiage,E,Garrues,M.,Zuniga,A.,Anton,A.,Larrion,J.L, and Hakkinen,K. (1999) maximal strength and power characteristics in isometric and dynamic actions of upper and lower extremities in middle-aged and older men. *Acta Phys. Scand.* 167: 57–68.

Izquierdo,M.,Hakkinen,K.,Ibanez,J.,Garrues,M.,Anton,A.,Zuniga,A.,Larrion,J.L., and Gorostiaga,E.M. (2001) Effects of strength training on muscle power and serum hormones in middle-aged and older men. *J.Appl.Physiol.* 90:1497–1507.

Ingjer,F.(1991) Maximal oxygen uptake as a predictor of performance ability in women and men elite cross-country skier. *Scand.J.Med.Sci.Sports* 1: 25–30.

Jensen,K.,Johansen,L.,and Secher,N.H (2001) Influence of body mass on maximal oxygen uptake: effect of sample size. *Eur.J.Appl.Physiol.* 84: 201–205.

Keller,B.,and Katch,F.I. (1991) It is not valid to adjust gender differences in aerobic capacity and strength for body mass or lean body mass. *Med.Sci.Sport Exerc.* 23: S167.

Lamoureux,E.L.,Sparrow,W.A.,Murphy,A.,Newton,R.U. (2001) Differences in the neuromuscular capacity and lean muscle tissue in old and older community-dwelling adults. *J.Gerontol.* 56A: M381–M385.

Ray,C.A.,Rea,R.F.,Clary,M.P., and Mark,AL. (1993) Muscle sympathetic nerve responses to dynamic one-legged exercise: effect of body posture. *Am.J.Physiol.* 264: H1–H7.

Rubenstein,L.Z.,Josephson,K.R.,Trueblood,P.R.,Loy,S.,Harker,J.O.,Pietruszka,F.M., and Robbins,A.S. (2000) Effects of a group exercise program on strength mobility, and falls among fall-prone elderly men. *J.Gerontol.* 55A: M317–M321.

Secher,N.H.,Ruberg-Larsen,N.,Binkhorst,R.A.,and Bonde-Petersen,F. (1974) Maximal oxygen uptake during arm and cranking and combined arm plus leg exercise. *J.Appl.Physiol.* 36: 515–518.

Secher,N.H. (1975) Isometric rowing strength of experienced and inexperienced oarsmen. *Med.Sci. Sports* 7: 280–283.

Secher,N.H.,Clausen,J.P.,Klausen,K.,Noer,I.,and Trap-Jensen,J. (1977) Central and regional circulatory effects of adding arm exercise to leg exercise. *Acta Physiol.Scand.* 100: 288–297.

Secher,N.H.,Vaage,O.,and Jackson,R.C. (1982) Rowing performance and maximal aerobic power of aorsmen. *Scand.J.Sports Sci.* 4: 9–11.

Secher,N.H. (1983) The physiology rowing. J.Sports Sci. 1:23–53.

Secher,N.H.,Vaage,O.,Jensen,K.,and Jackson,R.C.(1983) Maximal aerobic power in oarsmen. *Eur.J.Appl.Physiol* 51: 155–162.

Secher,N.H. (2000) Rowing. In:Shephard,R.J.,Astrand,P.-O. Endurance in Sport. Eds.Oxford:Blackwell Science Pty Co., 836–843.

Thompson,K.K.,Larsen,S.,and Schroll,M. (1995) Cardiovascular risk factorsand age: across-sectional survey of Danish men and women from the Glostrup population studies. *Am.J.Geriatr.Cardiol.* 3: 31–41.
Wilmore,J.H.,and Costill,D.L. (1999) Sex differences and the female athletes. In: Wilmore,J.H.,and Costill,D.L. Physiology of Sport and Exercise. Eds. Champaign,IL:Human Kinetics 570–606.
YoshigaC.C., and Higuchi,M. (2002) Heart rate is lower during ergometer rowing than during treadmill running. *Eur. J.Appl.Physiol.* 87: 97–100
Yoshiga,C.C., Higuchi,M., and Oka,J. (2002) Serum lipoprotein cholesterols in older oarsmen. *Eur. J. Appl. Physiol.* 87: 228–232.
Yoshiga,C.C., Yashiro,K.,Higuchi,M, and Oka,J. (2002) Rowing prevents muscle wasting in older men. *Eur. J. Appl. Physiol.* 88: 1–4.
Yoshiga, C.C. and Higuchi,M. (2003) Rowing performance of female and male rowers. *Scand.J.Med.Sci.Sports* 13: 313–321.
Yoshiga,C.C.,and Higuchi,M. (2003) Oxygen uptake and ventilation during rowing and running in females and males. *Scand.J.Med.Sci.Sports* 13: 359–363.
Yoshiga,C.C., and Higuchi,M. (2003) Bilateral leg extension power and fat-free mass in young oarsmen. *J. Sports Sci.* 21: 905–909.
Yoshiga,C.C., Higuchi,M., and Oka,J. (2003) Lower heart rate response to ergometry rowing than to treadmill running in older men. *Clin. Physiol. Func. Im.* 23: 58–61.

Q & A

DIETZ: Since disease of the knee and hip joint is a problem in the elderly, is there any evidence that rowing exercise places less stress on joints than running?
HIGUCHI: We do not have direct evidence to demonstrate that rowing exercise places less stress on joints than running in the elderly. However, the rhythmic extensions of both legs, 20–40 repeated bouts per minute, are a unique attribute of rowing, and during rowing body mass is supported by the sliding seat in a boat or on an ergometer. Therefore, it is reasonable to consider that rowing exercise is favorable and recommendable for older people who have any knee problems because peak force during rowing is not very high when compared to those in other sports such as explosive or weight-bearing sports.
TANAKA: Do you have any suggestions how older people can enjoy rowing exercise at home?
HIGUCHI: I think that a rowing ergometer, Concept II, is too large to use for Japanese older people in the small room at home, but older people can enjoy to do ergometer rowing with watching TV or listening music if they have compact-size one.
YAMASHITA: 1. There is the some method measured VO2 max. I want to listen your opinion, the rowing exercise most superior method?
2. I would like to ask some question. When the people start the rowing exercise for improving and/or keeping health and various biological function, How many time per week, How long, How intensity?
HIGUCHI: 1. I think that using rowing ergometer to test VO2max is much safety method because subjects can perform on seated position, and they exert power by themselves at any given work loads during incremental test. In addition, higher VO2max can be obtained by ergometer rowing than other methods such as treadmill and bicycle ergometer because subjects can use almost all muscles such as legs, trunk, and arms, during evaluate aerobic capacity for older people. 2. It is easy to consider that the people who have no exercise habit for long time in their life should start exercises for shorter duration at lower intensity 2–3 times a week with an exercise supervisor after medical check-up, and the people can gradually increase duration, intensity and frequency in any exercises. In rowing exercise in a boat on water or on ergometer in the training room, the middle-aged and older healthy people who are familiar with rowing can perform rowing at moderate- to high-intensity, 1–2 hours a bout, 2–3 times a week.

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Lack of age-related decreases in basal whole leg blood flow in resistance-trained men

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Miyachi, Motohiko, Hirofumi Tanaka, Hiroshi Kawano, Mayumi Okajima, and Izumi Tabata. Lack of age-related decreases in basal whole leg blood flow in resistance-trained men. *J Appl Physiol* 99: 1384–1390, 2005. First published June 16, 2005; doi:10.1152/japplphysiol.00061.2005.—Reductions in basal leg blood flow have been implicated in the pathogenesis of metabolic syndrome and functional impairment in humans. We tested the hypothesis that reductions in basal whole leg blood flow with age are either absent or attenuated in those who perform regular strength training. A total of 104 normotensive men aged 20–34 yr (young) and 35–65 yr (middle aged), who were either sedentary or resistance trained, were studied. Mean and diastolic blood pressures were higher ($P < 0.05$–0.001) in the middle-aged compared with the young men, but there were no significant differences between the sedentary and resistance-trained groups. In the sedentary group, basal whole leg blood flow (duplex Doppler ultrasound) and vascular conductance were lower (~30 and ~38%, respectively; $P < 0.01$) in the middle-aged compared with the young men. There were no such age-related differences in the resistance-trained group. In the young men, basal whole leg blood flow and vascular conductance were not different between the two activity groups, but, in the middle-aged men, they were higher (~35 and ~36%, respectively; $P < 0.01$) in the resistance-trained men than in the sedentary men. When blood flow and vascular conductance were expressed relative to the leg muscle mass, the results were essentially the same. We concluded that the age-related reduction in basal whole leg blood flow is absent in resistance-trained men. These results suggest that resistance training may favorably influence leg perfusion in aging humans, independent of its impact on leg muscle mass.

aging; artery; exercise; hemodynamics; ultrasonics

BASAL WHOLE LEG BLOOD FLOW decreases progressively with advancing age in healthy men and women (9, 10, 23), which is related to corresponding reductions in leg fat-free mass and estimated leg oxygen demand (10). Reduced peripheral blood flow has been suggested to be mechanistically involved in the metabolic syndrome, a cluster of disease states that include hyperinsulinemia, dyslipidemia, and hypertension (18). Additionally, older adults appear to be limited in their ability to vasodilate in response to functionally demanding tasks and/or states, including dynamic exercise, energy intake, and heat stress (16, 19, 31). Accordingly, the prevention and treatment of the age-related reductions in basal leg blood flow are of great clinical importance.

Regular physical activity is regarded as an important component of prevention and treatment of cardiovascular disease (24) and functional disability (11). It is reasonable to hypothesize that habitual aerobic exercise exerts beneficial influence on basal peripheral blood flow. However, habitual aerobic exercise does not appear to modulate the age-related reductions in basal leg blood flow in healthy men (10). The lack of influence of regular aerobic exercise is presumably due to the fact that the key determinants of leg blood flow, i.e., leg fat-free mass, decreased similarly with advancing age in both sedentary and endurance-trained healthy men (28). Resistance training is an important part of preventive and rehabilitative program for the age-related loss in muscle mass and function (i.e., sarcopenia). Given this, it is plausible to hypothesize that habitual resistance training attenuates the age-related reduction in basal whole leg blood flow through its impact on leg skeletal muscle mass. Accordingly, the primary aim of the present cross-sectional study was to determine the relation between resistance training, leg muscle mass, and basal leg blood flow. We hypothesized that resistance training is associated with elevated leg perfusion in aging humans through its impact on leg skeletal muscle mass.

METHODS

Subjects

A total of 104 healthy men aged 20–34 yr ("young") and 35–65 yr ("middle aged") participated in the present study (Table 1). The sedentary subjects were recruited through various forms of advertisements and had not participated in a regular exercise program for at least the previous 2 yr. The resistance-trained men were recruited from various fitness clubs and had been performing vigorous resistance training for >2 yr. All resistance-trained men have been performing moderate- to high-intensity "full-body" resistance exercise involving large muscle groups. To better isolate the effect of resistance exercise training, those who had been concurrently performing regular aerobic exercise (i.e., "cross-training") were excluded. All subjects were normotensive (<140/90 mmHg), nonobese, and free of overt chronic diseases as assessed by medical history, physical examination, and complete blood chemistry and hematological evaluation. Men aged >40 yr were further evaluated by ECG at rest and, along with blood pressure, during incremental treadmill exercise performed to exhaustion. Candidates who smoked in the past 4 yr, were taking medications, had ever used anabolic steroids or other performance-enhancing drugs, or had significant femoral intima-media thickening (IMT; <1.1 mm), plaque formation, and/or other characteristics of atherosclerosis [ankle-brachial index (ABI) < 0.90] were excluded. All subjects gave their written, informed consent to participate. All procedures were reviewed and approved by the Human Research Committee of the National Institute of Health and Nutrition.

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Table 1. *Selected subject characteristics*

Variables	Sedentary		Resistance Trained	
	Young	Middle aged	Young	Middle aged
n	30	25	27	22
Age, yr	26±1	50±2*	27±1	48±2*
Height, cm	174±1	172±1	177±1	175±2
Waist-to-hip ratio	0.93±0.03	0.95±0.02	0.90±0.02	0.91±0.02†
Total cholesterol, mmol/l	4.64±0.22	5.01±0.19	4.35±0.20	4.83±0.19*
HDL cholesterol, mmol/l	1.47±0.07	1.48±0.11	1.57±0.14	1.38±0.09
Plasma glucose, mmol/l	5.01±0.12	5.31±0.09*	4.90±0.11	5.29±0.12*
Resting heart rate, beats/min	57±1	59±2	58±2	58±2
Maximal heart rate, beats/min	193±2	177±3*	192±2	179±3*
$\dot{V}O_{2max}$, l/min	3.0±0.1	2.9±0.1	3.7±0.1†	3.3±0.1*†
$\dot{V}O_{2max}$/body weight, ml·kg^{-1}·min^{-1}	42.3±1.6	36.9±1.4*	44.9±1.4	40.7±1.6*†
$\dot{V}O_{2max}$/LBM, ml·kg^{-1}·min^{-1}	51.4±1.7	50.2±1.6	53.6±1.4	49.5±1.5

Values are means ± SE; *n*, no. of subjects. $\dot{V}O_{2max}$, maximal oxygen consumption; LBM, lean body mass. *$P < 0.05$ vs. young. †$P < 0.05$ vs. sedentary of same age group.

Measurements

Before they were tested, subjects abstained from caffeine and fasted for at least 4 h (a 12-h overnight fast was used for determination of metabolic risk factors). Subjects were studied 20–24 h after their last exercise training session to avoid the immediate (acute) effects of exercise, but they were still considered to be in their normal (i.e., habitually exercising) physiological state.

Femoral blood flow. A duplex ultrasound machine (model 180Plus, Sonosite) equipped with a high-resolution (5–10 MHz) linear-array transducer was used to measure vessel diameter and blood velocity on the right common femoral artery, as previously described (9, 10). Femoral arterial diameter was determined by a perpendicular measurement from the media-adventitia interface of the near wall to the lumen-intima interface of the far wall of the vessel. Mean blood velocity measurements were performed with the insonation angle <60° and were corrected for the insonation angle. The sample volume gate was adjusted to cover the width of the vessel and thus blood velocity distribution. To minimize turbulence from the bifurcation, these measurements were performed below the inguinal ligament, ~2 cm above its bifurcation. Blood flow was calculated from the following formula: (mean blood velocity) × (circular area) × (6×10^4). The constant 6×10^4 is the conversion factor from meters per second to liters per minute. The data reported were time averages of 10 measurements for all variables and were analyzed by the same investigator, who was blinded to the identity of the subject. In our laboratory, the day-to-day reproducibility of the measurements for common femoral diameter, mean blood velocity, and absolute blood flow were 3 ± 1, 7 ± 2, and 6 ± 2%, respectively. Leg vascular conductance and resistance were calculated as femoral blood flow/ankle mean blood pressure and ankle mean blood pressure/femoral blood flow, respectively.

IMT. Femoral artery IMT was measured from the images derived from an ultrasound machine equipped with a high-resolution linear-array transducer, as previously described (22). Ultrasound images were analyzed by use of computerized image analysis software (NIH Image, version 1.63). All image analyses were performed by the same investigator, who was blinded to the group assignment of subjects. At least 10 measurements of IMT were taken at each segment, and the mean values were used for analysis. Femoral IMT was used as a measure of subclinical atherosclerosis in the lower limbs. Plaque was considered to be present if a localized irregular thickening was at least 1.5 mm thick. In our laboratory, the technique has excellent day-to-day reproducibility [coefficient of variation (CV) 3 ± 2%] for the measurement of femoral IMT.

Arterial blood pressure at rest. Chronic levels of arterial blood pressure at rest were measured with a semiautomated device (Form PWV/ABI, Colin Medical Technology) over the brachial and dorsalis pedis artery. Recordings were made in triplicate with subjects in the supine position. ABI was then calculated and was used as a measure of atherosclerosis in leg arteries.

Body composition. Body composition was determined by using dual-energy X-ray absorptiometry (DEXA; model DPX-IQ, Lunar Radiation) with subjects in the supine position. Leg tissue mass was determined using body landmark sites for the legs (i.e., from the femoral neck to the phalange tips). Leg skeletal muscle mass reported represents right leg lean soft tissue mass. The measurement of leg muscle and fat mass using DEXA has been well validated against other standards (12, 13). Waist circumference was measured at the narrowest part of the torso and was used as a surrogate measure of total abdominal fat.

Left ventricular function. Echocardiography was used to measure left ventricular (LV) function, according to established guidelines (7, 27). Stroke volume (SV) was measured from LV end-diastolic and end-systolic volumes calculated from LV internal dimensions (20). Cardiac output was derived as SV times heart rate. Total peripheral resistance was calculated by the following formula: brachial mean blood pressure/cardiac output.

Incremental exercise. To demonstrate that the subjects had been sedentary, we measured maximal oxygen consumption during an incremental cycle ergometer exercise (21). Oxygen consumption (CV = 4 ± 1%), heart rate, and ratings of perceived exertion were measured throughout the protocol (21).

Metabolic risk factors for coronary heart disease. To screen for the presence of coronary heart disease, fasting plasma concentrations of cholesterol and glucose were determined with enzymatic techniques (29).

Statistical Analyses

Statistical analyses were performed using the Statistica software (Statsoft). Data were analyzed by two-way ANOVA (age × physical activity status). In the case of a significant *F* value, a post hoc test using the Newman-Keuls method identified significant differences among mean values. Relations of interest were identified by univariate correlational and regressional analysis. All data are reported as means ± SE. Statistical significance was set a priori at $P < 0.05$ for all comparisons.

RESULTS

Selected subject characteristics are presented in Table 1. There was a >20-yr age difference between young and middle-aged subjects. There were no significant differences in height among all four groups. Although all metabolic risk factors were well within clinically normal levels in all groups, total cholesterol and plasma glucose concentrations were higher ($P < 0.05$) in middle-aged compared with young groups. Average years of training were 4.2 ± 1.3 and 18.3 ± 2.4 yr ($P < 0.001$) in young and middle-aged resistance-trained men, respectively. There were no significant differences in training frequency (4.8 ± 0.4 and 4.6 ± 0.4 times/week) and duration (63 ± 12 and 52 ± 5 min/session) between young and middle-aged resistance-trained men.

As shown in Table 2, systolic blood pressure was similar among all groups. Mean and diastolic blood pressures were higher ($P < 0.05$) in the middle-aged compared with the young men; there were no significant differences between the sedentary and resistance-trained groups. Femoral arterial lumen diameter in the resistance-trained young and middle-aged men was larger ($P < 0.001$) than that in their sedentary peers. There were no significant differences in SV and cardiac output index among all four groups.

In the young men, basal whole leg blood flow, vascular conductance, and vascular resistance were not different between the two activity groups ($P = 0.08–0.09$). In the sedentary group, basal whole leg blood flow and vascular conductance were lower and vascular resistance was higher (all $P < 0.01$) in the middle-aged compared with the young men (Fig. 1). Moreover, basal whole leg blood flow and blood flow relative to the leg muscle mass were negatively related with age ($r = -0.39$ and -0.30, $P < 0.001$; Fig. 2, *left*). However, in the resistance-trained group, there were no age-related differences in basal whole leg blood flow and vascular conductance. Additionally, there were no relations between age and femoral blood flow in resistance-trained men [$r = -0.15$ and 0.05, not significant (NS); Fig. 2, *right*]. Furthermore, basal whole leg blood flow and vascular conductance were higher and vascular resistance was lower ($P < 0.01$) in the resistance-trained middle-aged men compared with the sedentary middle-aged men. When basal blood flow, vascular conductance, and vascular resistance were expressed relative to the leg muscle mass, these results were essentially unchanged (Fig. 3).

Whole body mass and lean body mass were higher ($P < 0.01$) in resistance-trained men compared with their age-matched sedentary peers (Table 3). In the middle-aged men, body fat and waist-to-hip ratio of the resistance-trained group were smaller ($P < 0.01$) than those of the sedentary group. There were no significant differences in absolute right leg muscle mass between young and middle-aged men. As expected, leg muscle mass in the resistance-trained men was

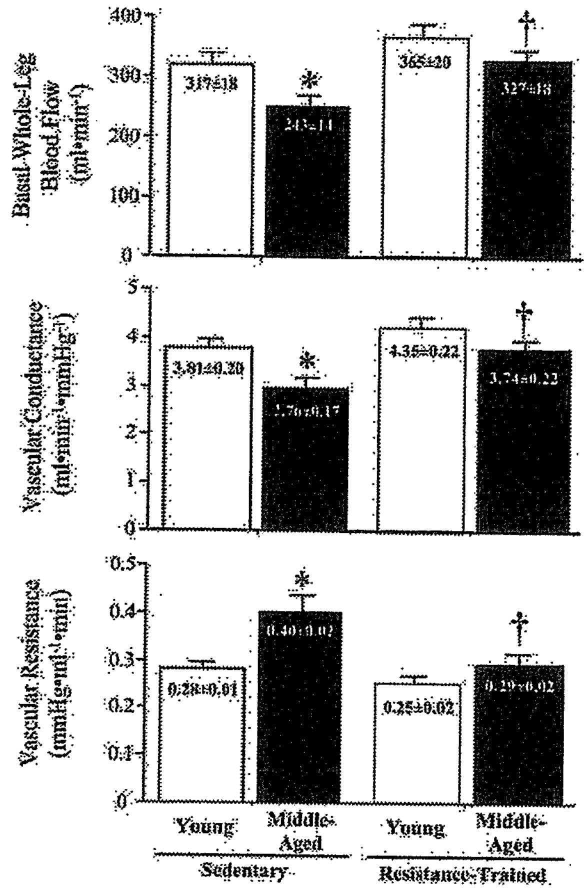

Fig. 1. Basal whole leg blood flow (*top*), vascular conductance (*middle*), and vascular resistance (*bottom*) of sedentary and resistance-trained men. Values are means ± SE. *$P < 0.05$ vs. young. †$P < 0.05$ vs. sedentary of same age group.

Table 2. *Cardiovascular measures*

Variables	Sedentary		Resistance Trained	
	Young	Middle aged	Young	Middle aged
Brachial systolic BP, mmHg	115±2	119±3	117±2	120±3
Brachial mean BP, mmHg	83±1	90±2*	84±1	90±2*
Brachial diastolic BP, mmHg	65±1	74±2*	66±1	73±2*
Ankle-brachial index, units	1.12±0.01	1.18±0.02*	1.11±0.02	1.16±0.02*
Femoral artery diameter, mm	9.0±0.2	8.9±0.2	9.3±0.2†	9.7±0.2*†
Femoral artery IMT, mm	0.46±0.01	0.53±0.02*	0.48±0.02	0.59±0.04*†
Femoral artery MBV, cm/s	8.3±0.5	6.7±0.4*	8.7±0.3	7.3±0.3*
Stroke volume, ml	89±6	99±4	94±4	86±5
Stroke volume index, ml/kg	1.2±0.1	1.2±0.1	1.2±0.1	1.1±0.1
Cardiac output, l/min	5.2±0.2	5.0±0.3	5.9±0.2†	5.4±0.3
Cardiac output index, $ml \cdot min^{-1} \cdot kg^{-1}$	74±3	67±3	72±3	68±4
TPR, $mmHg \cdot ml^{-1} \cdot kg$	16.1±0.5	19.0±1.1*	15.0±0.8	17.6±1.0*

Values are means ± SE. BP, blood pressure; IMT, intima-media thickness; MBV, mean blood velocity; TPR, total peripheral resistance. *$P < 0.05$ vs. young. †$P < 0.05$ vs. sedentary of same age group.

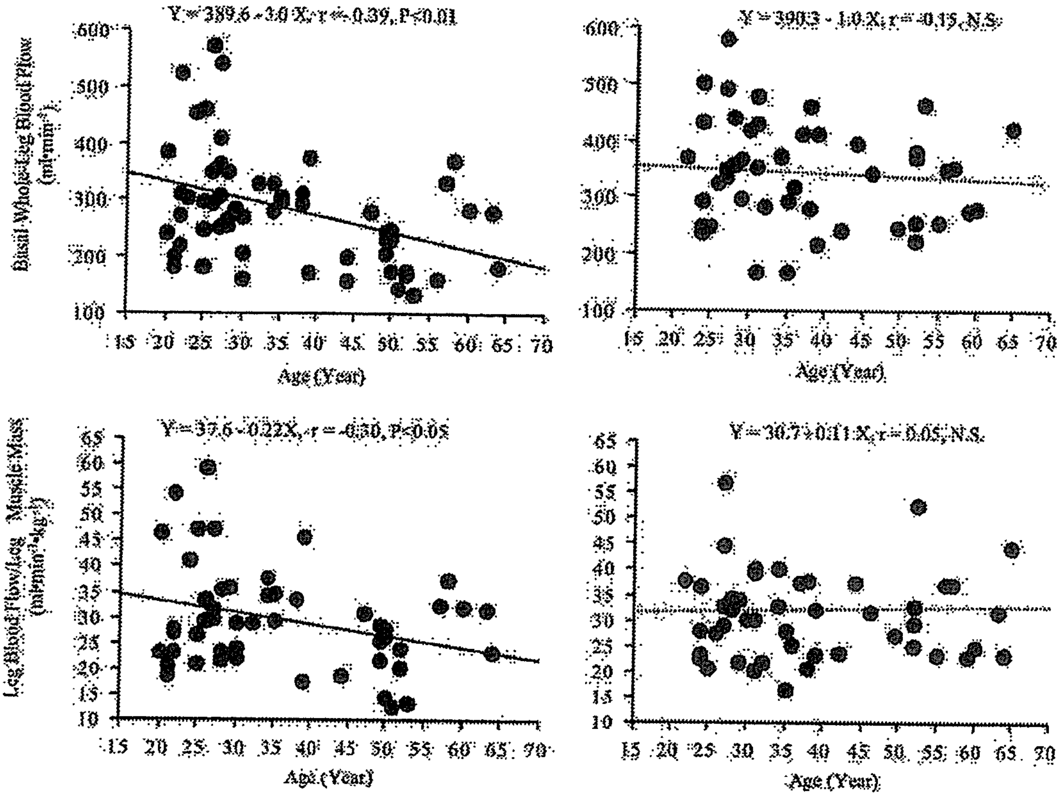

Fig. 2. Relations between age and basal blood flow in sedentary men (*left*) and resistance-trained men (*right*).

significantly higher than that in their sedentary peers ($P < 0.001$).

In the pooled population, absolute leg muscle mass was significantly associated with whole leg basal blood flow (Fig. 4; $r = 0.41$, $P < 0.001$). Whole leg basal blood flow was not significantly related to cardiac output at rest ($r = 0.19$, NS).

DISCUSSION

The salient findings of the present study were as follows. First, basal whole leg blood flow in the resistance-trained middle-aged men was ~35% higher than in their sedentary healthy controls. Second, because the blood flow was not significantly different between sedentary and resistance-trained young men, the age-related decrease in the basal whole leg blood flow was greater in the sedentary men compared with the resistance-trained men. Third, when basal blood flow was expressed relative to the leg tissue mass and leg muscle mass, the results were essentially the same. These findings suggest that the age-related reduction in basal whole leg blood flow is absent in resistance-trained men independent of leg muscle mass.

Resistance training has become an integral component of exercise training programs for health and disease prevention (1, 2, 25, 30, 32). Because of the clinical and functional importance associated with basal leg blood flow, we initiated our effort to address the impact of resistance training on leg blood flow. As an initial approach to address this question, we used a cross-sectional study design. Because of the well-recognized limitations associated with this design (8), we attempted to isolate the influence of resistance training and aging as much as possible. To do so, resistance-trained men were carefully matched for age, height, brachial blood pressure, and metabolic risk factors compared with their sedentary counterparts. Additionally, in an attempt to isolate the effect of chronic resistance training per se, we excluded those who had been concurrently performing endurance training or those taking anabolic steroids or other performance-enhancing drugs. Our present results indicate that chronic resistance training is associated with higher whole leg basal blood flow in healthy middle-aged men. Nevertheless, the results of the present cross-sectional study need to be confirmed prospectively with the exercise intervention study in the future.

Because there was no age-related differences in leg muscle mass, it may be argued that a lack of age-related reductions in basal whole leg blood flow in resistance-trained men may be due to the examination of less trained and less elite young vs. middle-aged resistance-trained men and that, if the young subjects were highly resistance trained, it is possible that an age-related difference in basal leg blood flow would be observed in the resistance-trained group. However, in the present study, the young and middle-aged resistance-trained men were carefully matched for current training volume (training frequency and duration/session). Additionally, we believe that the resistance-trained men were homogeneous with regard to relative competitiveness, as their bench press one-repetition maximum strength (102 ± 9 and 87 ± 9 kg in young and middle-aged men, respectively) was matched for age-adjusted Masters power-lifting records (4). Ideally, the present cross-

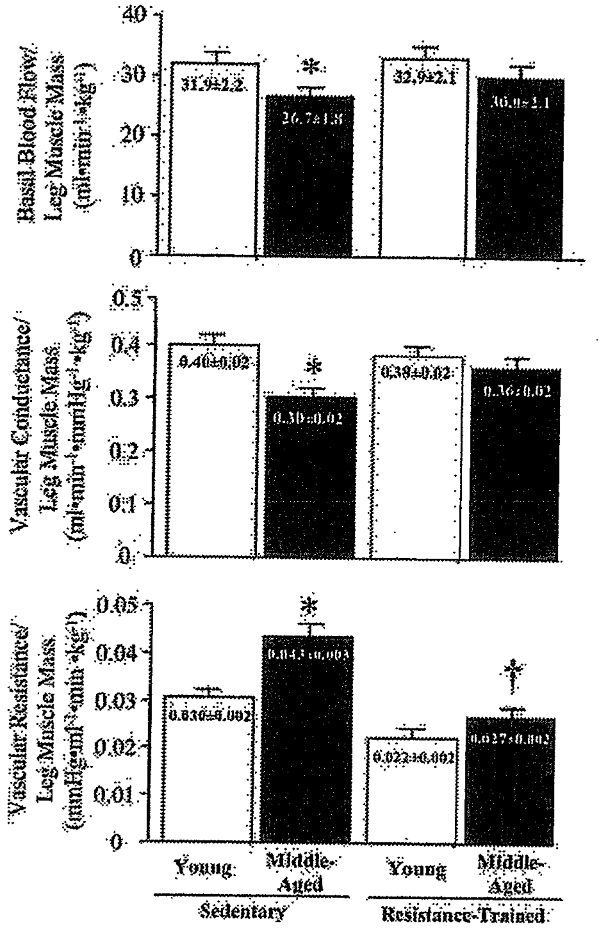

Fig. 3. Basal blood flow (*top*), vascular conductance (*middle*), and vascular resistance (*bottom*) relative to leg muscle mass of sedentary and resistance-trained men. Values are means ± SE *$P < 0.05$ vs. young. †$P < 0.05$ vs. sedentary of same age group.

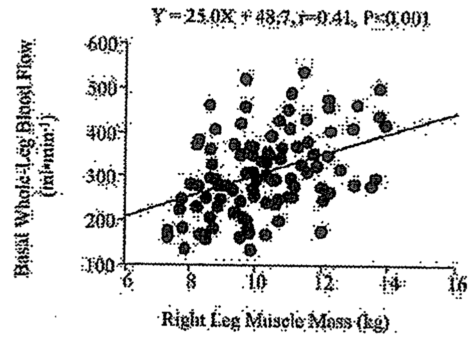

Fig. 4. Relation between basal whole leg blood flow and leg muscle mass. $r = 0.41$, $P < 0.001$

sectional findings should be confirmed with prospective studies. However, because the latter studies will be difficult to perform, our cross-sectional results will probably remain unique in that they will provide the only currently available information on effect of resistance training on age-related reduction in basal leg blood flow.

Physiological mechanisms underlying the preserved basal leg blood flow in resistance-trained men are not clear. On the basis of the well-known coupling between blood flow and metabolism, we initially hypothesized that resistance-trained men would demonstrate a greater basal leg blood flow because of the larger skeletal muscle mass and the greater metabolic demands because both leg oxygen consumption and fat-free mass are strongly associated with whole leg blood flow (10). Consistent with these concepts, in the pooled population, leg muscle mass was significantly related to whole leg basal blood flow ($r = 0.41$). These findings suggest that absence of age-related decreases in whole leg basal blood flow in resistance-trained men is, at least in part, associated in the larger leg muscle mass. In the present study, however, there were no obvious differences in leg muscle mass between young and middle-aged men, and the magnitude of age-related reductions in leg muscle mass was similar between sedentary and resistance-trained men. Interestingly, when blood flow was expressed relative to leg muscle mass, the results remained essentially the same as whole leg blood flow (Figs. 2 and 3). These results suggest that not only quantitative but also qualitative changes in skeletal muscle and/or alterations in nonskeletal muscle components induced by resistance training may be responsible for an absence of age-related reduction in basal leg blood flow in resistance-trained men. In this context, resistance training is known to be a strong stimulus to increase leg skeletal muscle turnover (syntheses and degradation) (14) and basal metabolic demands (3) in older subjects, which may have acted to preserve leg blood flow independent of leg muscle mass. Leg oxygen demand was not measured in the present study, because it requires a highly invasive procedure involving both arterial and venous catheterizations, and this is an important limitation in this study.

Additional possibility for explaining group differences in leg blood flow is that a reduction in local (leg) blood flow may be

Table 3. *Whole body and whole leg body composition*

Variables	Sedentary		Resistance Trained	
	Young	Middle aged	Young	Middle aged
Whole body mass, kg	71.8±2.0	76.0±1.9*	82.9±2.4†	80.5±1.9
Whole body fat, %	18±1	24±1*	17±1	18±1†
Lean body mass, kg	59.2±1.4	57.6±1.1	68.3±1.6†	65.7±1.5†
Right leg total tissue mass, kg	12.3±0.4	12.1±0.4	14.1±0.5†	13.0±0.6
Right leg muscle mass, kg	9.6±0.3	9.0±0.2	11.2±0.3†	10.8±0.4†
Right leg fat mass, kg	2.8±0.2	3.0±0.2	2.8±0.3	2.4±0.3
Right leg fat, %	19±1	23±1*	18±1†	16±2†

Values are means ± SE. *$P < 0.05$ vs. young. †$P < 0.05$ vs. sedentary of same age group.