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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.

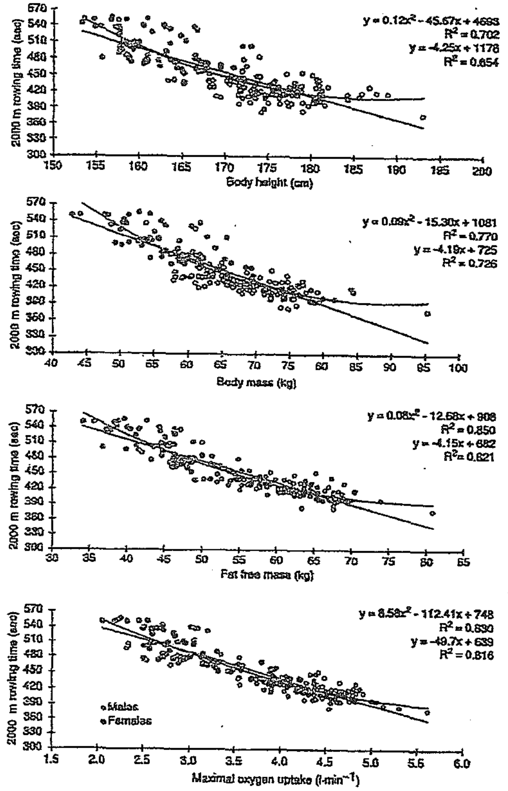

FIGURE 16-1. *Relationship between rowing performance and body height, body mass, and VO2max.*

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

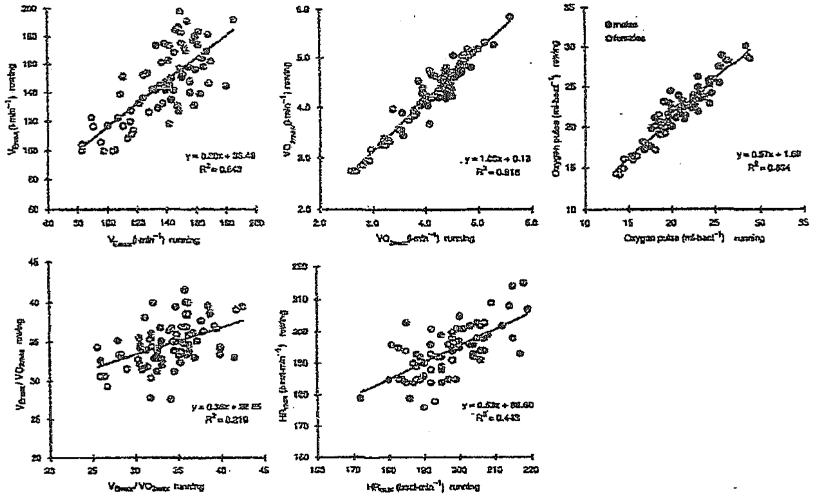

FIGURE 16-2. *Relationship for maximal minute ventilatory volume (VEmax), maximal oxygen uptake(VO2max), ventilatory equivalent for oxygen(VEmax/VO2max), maximal heart rate(HRmax), and oxygen pulse(VO2max/HRmax) between rowing and running.*

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).

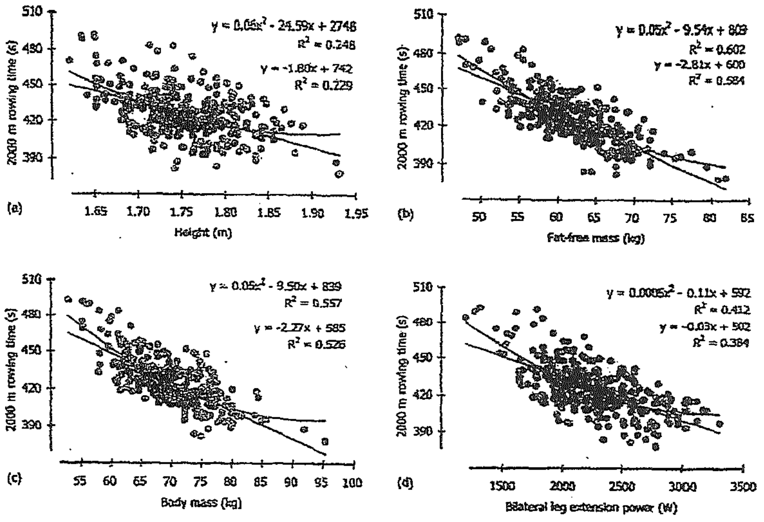

FIGURE 16-3. *Relationship between 2000m rowing ergometer performance time and (a)height, (b)fat-free mass, (c)body mass, and (d)bilateral leg extension power.*

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)%).

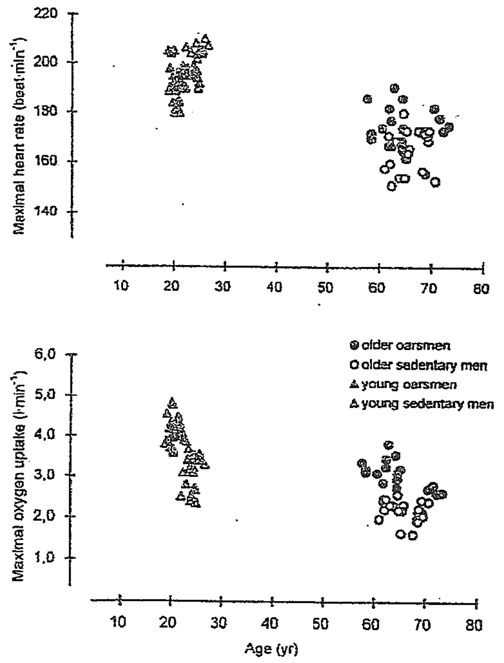

FIGURE 16-4. *Maximal heart rate and maximal oxygen uptake related to age.*

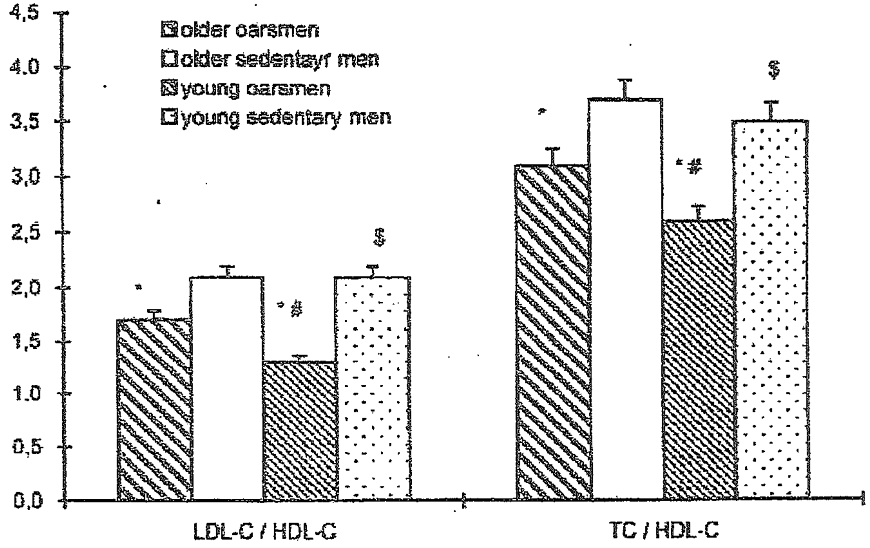

FIGURE 16-5. *Atherosclerosis indices (the ratio of LDL-C to HDL-C, and TC to HDL-C).*

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 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

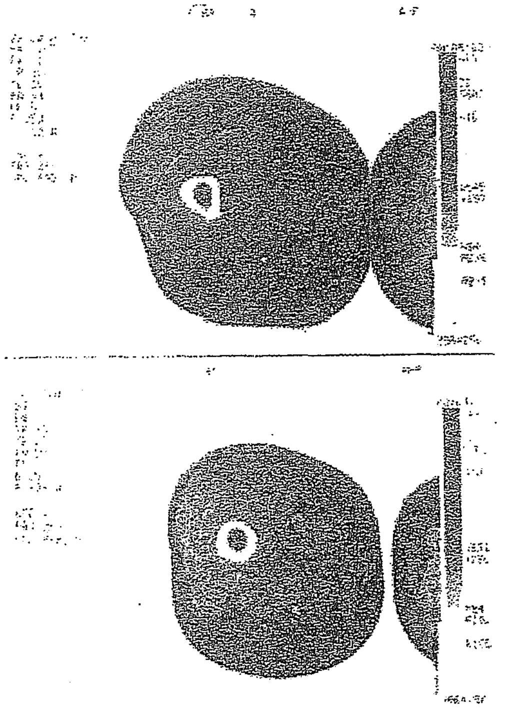

FIGURE 16-6. *Representative magnetic resonance images of an elderly trained rower (upper) and an elderly sedentary man (bottom).*

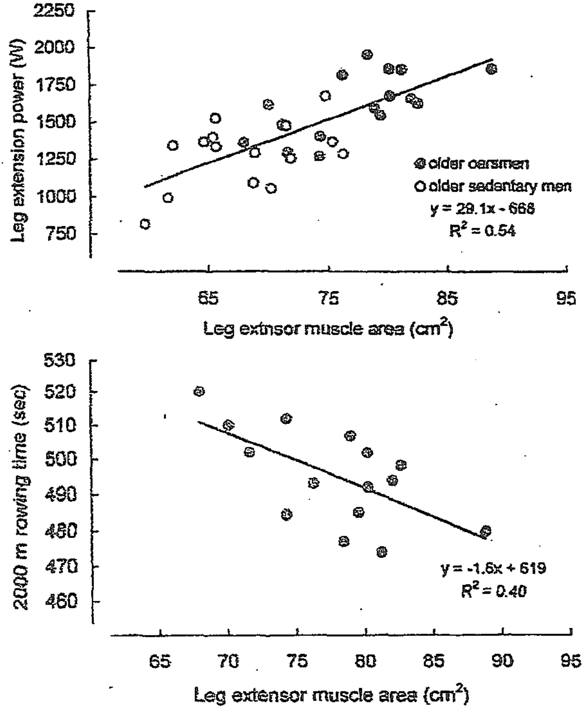

FIGURE 16-7. *Relationship between leg extension power, 2000m ergometer rowing time and leg extension muscle area in elderly men.*

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).

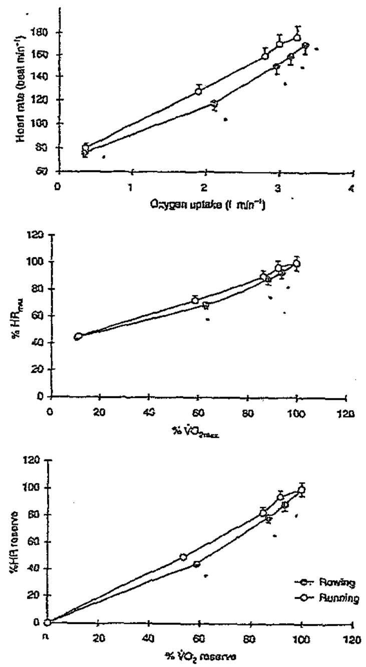

FIGURE 16-8. *Relation between heart rate and oxygen uptake, between percentage of maximal oxygen uptake(%VO2max) and percentage of maximal heart rate(%HRmax), and between percentage of heart rate reserve (%HR reserve) and percentage of oxygen uptake reserve (%VO2 reserve).*

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 female 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*
$\text{Vo}_{2\max}$, l/min	3.0±0.1	2.9±0.1	3.7±0.1†	3.3±0.1*†
$\text{Vo}_{2\max}$/body weight, $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$	42.3±1.6	36.9±1.4*	44.9±1.4	40.7±1.6*†
$\text{Vo}_{2\max}$/LBM, $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$	51.4±1.7	50.2±1.6	53.6±1.4	49.5±1.5

Values are means ± SE; *n*, no. of subjects. $\text{Vo}_{2\max}$, 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).

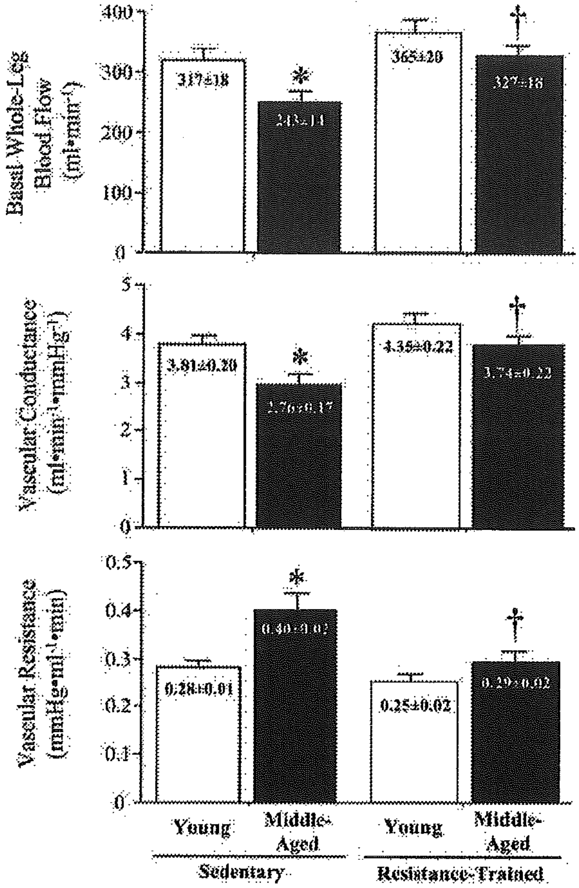

Fig. 1. Basal whole leg blood flow (*top*), vascular conductance (*middle*), and vascular resistance (*bottom*) of sedentary and resistance-trained men. Values are means ± SE. $*P < 0.05$ vs. young. $†P < 0.05$ vs. sedentary of same age group.

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

Table 2. *Cardiovascular measures*

Variables	Sedentary Young	Sedentary Middle aged	Resistance Trained Young	Resistance Trained 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.

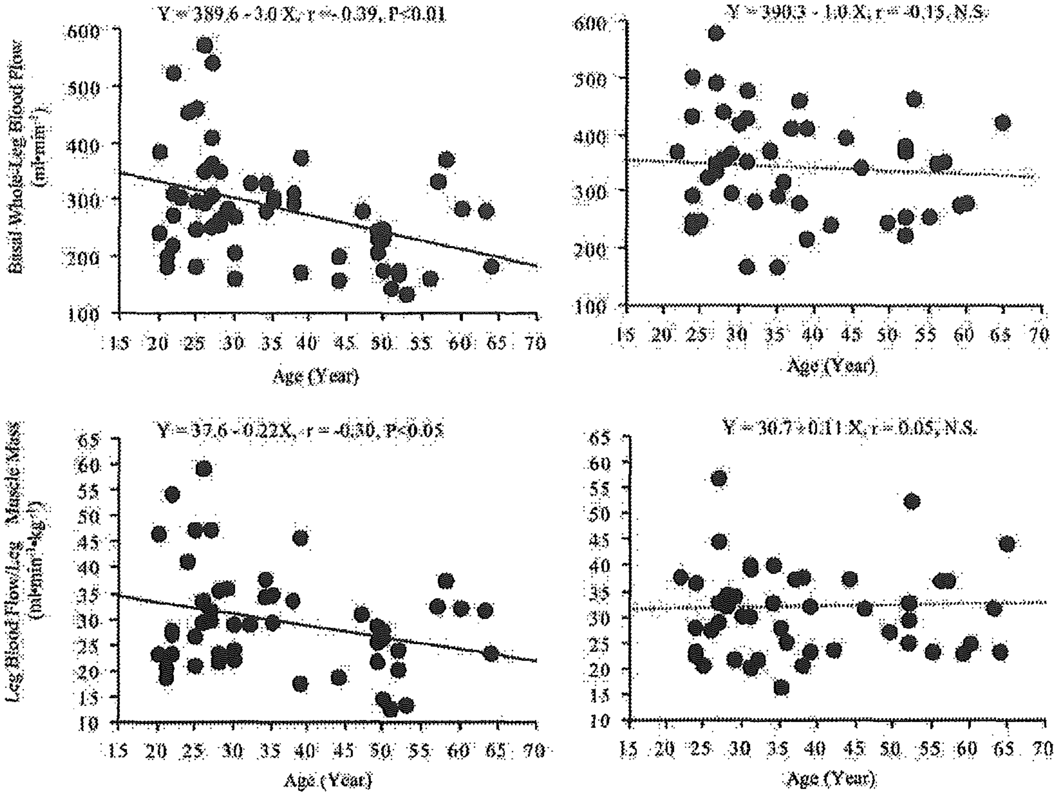

Fig. 2. Relations between age and basal blood flow in sedentary men (*left*) and resistance-trained men (*right*).

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-

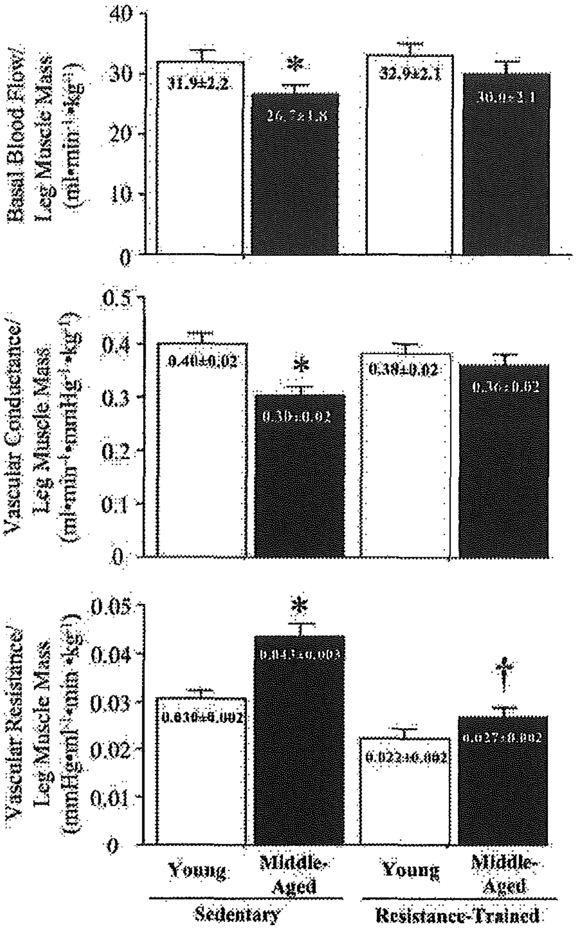

Fig. 3. Basal blood flow (*top*), vascular conductance (*middle*), and vascular resistance (*bottom*) relative to leg muscle mass of sedentary and resistance-trained men. Values are means ± SE $*P < 0.05$ vs. young. $\dagger P < 0.05$ vs. sedentary of same age group.

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

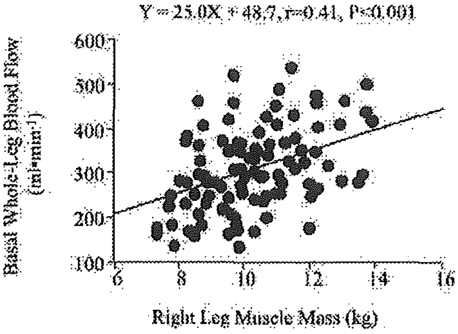

Fig. 4. Relation between basal whole leg blood flow and leg muscle mass. $r = 0.41$, $P < 0.001$

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. $\dagger P < 0.05$ vs. sedentary of same age group.

a simple reflection of changes in systemic (total) blood flow (17). However, there were no obvious group differences in the cardiac output and total peripheral resistance, and no significant relation was found between cardiac output and basal whole leg blood flow. Age-related reductions in basal whole leg blood flow are associated with tonically elevated muscular sympathetic nerve activity that would result in vasoconstriction (9). However, sympathetic nerve activity is reported to be higher, rather than lower, in resistance-trained older adults than in sedentary controls (26). Together, these findings do not support the hypothesis that changes in systemic blood flow and sympathetic nerve activity contributed to the preserved leg blood flow in resistance-trained men in the present study. Clearly, further studies are warranted to determine physiological mechanisms underlying effects of resistance exercise on arterial hemodynamics.

The present findings have potentially important clinical and physiological implications. It is widely accepted that resistance training in middle-aged and older adults increases power, reduces the difficulty of performing daily tasks, and promotes participation in spontaneous physical activity (6, 15). The present findings extend the beneficial influence of resistance training to vascular function in the aging human, contributing to the preservation of basal whole leg blood flow with age. The reduction in leg blood flow may limit peripheral glucose uptake and contribute to glucose intolerance and hyperinsulinemia in middle-aged and older adults (18). Additionally, it may also impair the clearance of atherogenic lipids and contribute to chronic dyslipidemia (5). Daily resistance training may contribute to the lower incidence of cardiovascular disease through its influence on basal leg blood flow.

Our laboratory has previously reported that the repeated increases in blood flow due to exercise training are associated with expansive arterial remodeling in the femoral artery (21). Our present results extend these previous reports in endurance-trained men to resistance training. In the present study, resistance-trained men had larger femoral arterial diameter compared with sedentary counterparts. Taken together, these results suggest that both aerobic and resistance exercise appear to cause arterial enlargement at the level of major conduit arteries. Although the cause-and-effect relation cannot be determined with our research design, it is plausible to hypothesize that the diameter of femoral artery enlarges over years to more easily accommodate the daily dose of high blood flow during repeated exercise sessions.

As illustrated in the present study as well as in other studies, age is an important factor for determining leg blood flow and hemodynamics. However, it should be noted that age explains only 10–20% of variance associated with leg blood flow. Thus many more aspects need to be critically analyzed in the future studies.

In summary, the age-associated reduction in basal whole leg blood flow did not occur in resistance-trained men, suggesting that daily weight training may prevent decreases in basal whole leg blood flow with advancing age. Importantly, preserved blood flow in resistance-trained men was independent of muscle mass. These results suggest that habitual resistance exercise may favorably influence leg perfusion and hemodynamics in the aging human.

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REFERENCES

1. **American Association of Cardiovascular and Pulmonary Rehabilitation.** *Guidelines for Cardiac Rehabilitation and Secondary Prevention Programs* (3rd ed.). Champaign, IL: Human Kinetics, 1999.
2. **American College of Sports Medicine.** American College of Sports Medicine Position Stand. Exercise and physical activity for older adults. *Med Sci Sports Exerc* 30: 992–1008, 1998.
3. **Ades PA, Savage PD, Brochu M, Tischler MD, Lee NM, and Poehlman ET.** Resistance training increases total daily energy expenditure in disabled older women with coronary heart disease. *J Appl Physiol* 98: 1280–1285, 2005.
4. **Anton MM, Spirduso WW, and Tanaka H.** Age-related declines in anaerobic muscular performance: weightlifting and powerlifting. *Med Sci Sports Exerc* 36: 143–147, 2004.
5. **Baron AD, Laakso M, Brechtel G, Hoit B, Watt C, and Edelman SV.** Reduced postprandial skeletal muscle blood flow contributes to glucose intolerance in human obesity. *J Clin Endocrinol Metab* 70: 1525–1533, 1990.
6. **Borst SE.** Interventions for sarcopenia and muscle weakness in older people. *Age Ageing* 33: 548–555, 2004.
7. **Cheitlin MD, Alpert JS, Armstrong WF, Aurigemma GP, Beller GA, Bierman FZ, Davidson TW, Davis JL, Douglas PS, and Gillam LD.** ACC/AHA Guidelines for the Clinical Application of Echocardiography. A report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (Committee on Clinical Application of Echocardiography) developed in collaboration with the American Society of Echocardiography. *Circulation* 95: 1686–1744, 1997.
8. **Costa P, McCrae RR.** Design and analysis of aging studies. In: *Handbook of Physiology. Aging.* Bethesda, MD: Am. Physiol. Soc., 1995, sect. 11, chapt. 2, p. 25–36.
9. **Dinenno FA, Jones PP, Seals DR, and Tanaka H.** Limb blood flow and vascular conductance are reduced with age in healthy humans: relation to elevations in sympathetic nerve activity and declines in oxygen demand. *Circulation* 100: 164–170, 1999.
10. **Dinenno FA, Seals DR, DeSouza CA, and Tanaka H.** Age-related decreases in basal limb blood flow in humans: time course, determinants and habitual exercise effects. *J Physiol* 531: 573–579, 2001.
11. **Feigenbaum MS and Pollock ML.** Prescription of resistance training for health and disease. *Med Sci Sports Exerc* 31: 38–45, 1999.
12. **Haarbo J, Gotfredsen A, Hassager C, and Christiansen C.** Validation of body composition by dual energy X-ray absorptiometry (DEXA). *Clin Physiol* 11: 331–341, 1991.
13. **Hansen NJ, Lohman TG, Going SB, Hall MC, Pamenter RW, Bare LA, Boyden TW, and Houtkooper LB.** Prediction of body composition in premenopausal females from dual-energy X-ray absorptiometry. *J Appl Physiol* 75: 1637–1641, 1993.
14. **Hasten DL, Pak-Loduca J, Obert KA, and Yarasheski KE.** Resistance exercise acutely increases MHC and mixed muscle protein synthesis rates in 78–84 and 23–32 yr olds. *Am J Physiol Endocrinol Metab* 278: E620–E626, 2000.
15. **Hunter GR, McCarthy JP, and Bamman MM.** Effects of resistance training on older adults. *Sports Med* 34: 329–348, 2004.
16. **Kenney WL.** Thermoregulation at rest and during exercise in healthy older adults. *Exerc Sport Sci Rev* 25: 41–76, 1997.
17. **Leithe ME, Margorien RD, Hermiller JB, Unverferth DV, and Leier CV.** Relationship between central hemodynamics and regional blood flow in normal subjects and in patients with congestive heart failure. *Circulation* 69: 57–64, 1984.
18. **Lind L and Lithell H.** Decreased peripheral blood flow in the pathogenesis of the metabolic syndrome comprising hypertension, hyperlipidemia, and hyperinsulinemia. *Am Heart J* 125: 1494–1497, 1993.
19. **Meneilly GS, Elliot T, Bryer-Ash M, and Floras JS.** Insulin-mediated increase in blood flow is impaired in the elderly. *J Clin Endocrinol Metab* 80: 1899–1903, 1995.
20. **Miyachi M, Kawano H, Sugawara J, Takahashi K, Hayashi K, Yamazaki K, Tabata I, and Tanaka H.** Unfavorable effects of resistance

training on central arterial compliance: a randomized intervention study. *Circulation* 110: 2858–2863, 2004.

21. **Miyachi M, Tanaka H, Yamamoto K, Yoshioka A, Takahashi K, and Onodera S.** Effects of one-legged endurance training on femoral arterial and venous size in healthy humans. *J Appl Physiol* 90: 2439–2444, 2001.
22. **Moreau KL, Donato AJ, Seals DR, Dinenno FA, Blackett SD, Hoetzer GL, Desouza CA, and Tanaka H.** Arterial intima-media thickness: site-specific associations with HRT and habitual exercise. *Am J Physiol Heart Circ Physiol* 283: H1409–H1417, 2002.
23. **Moreau KL, Donato AJ, Tanaka H, Jones PP, Gates PE, and Seals DR.** Basal leg blood flow in healthy women is related to age and hormone replacement therapy status. *J Physiol* 547: 309–316, 2003.
24. **Pate RR, Pratt M, Blair SN, Haskell WL, Macera CA, Bouchard C, Buchner D, Ettinger W, Heath GW, King AC, et al.** Physical activity and public health. A recommendation from the Centers for Disease Control and Prevention and the American College of Sports Medicine. *JAMA* 273: 402–407, 1995.
25. **Pollock ML, Franklin BA, Balady GJ, Chaitman BL, Fleg JL, Fletcher B, Limacher M, Pina IL, Stein RA, Williams M, and Bazzarre T.** AHA Science Advisory. Resistance exercise in individuals with and without cardiovascular disease: benefits, rationale, safety, and prescription: an advisory from the Committee on Exercise, Rehabilitation, and Prevention, Council on Clinical Cardiology, American Heart Association; position paper endorsed by the American College of Sports Medicine. *Circulation* 101: 828–833, 2000.
26. **Pratley R, Nicklas B, Rubin M, Miller J, Smith A, Smith M, Hurley B, and Goldberg A.** Strength training increases resting metabolic rate and norepinephrine levels in healthy 50- to 65-yr-old men. *J Appl Physiol* 76: 133–137, 1994.
27. **Sahn DJ, DeMaria A, Kisslo J, and Weyman A.** Recommendations regarding quantitation in M-mode echocardiography: results of a survey of echocardiographic measurements. *Circulation* 58: 1072–1083, 1978.
28. **Sugawara J, Miyachi M, Moreau KL, Dinenno FA, DeSouza CA, and Tanaka H.** Age-related reductions in appendicular skeletal muscle mass: association with habitual aerobic exercise status. *Clin Physiol Funct Imaging* 22: 169–172, 2002.
29. **Tanaka H, Dinenno FA, Monahan KD, Clevenger CM, DeSouza CA, and Seals DR.** Aging, habitual exercise, and dynamic arterial compliance. *Circulation* 102: 1270–1275., 2000.
30. **US Department of Health and Human Services** *Physical Activity and Health: A Report of the Surgeon General.* Atlanta, GA: US Department of Health and Human Services, Center for Disease Control and Prevention, National Center for Chronic Disease Prevention and Health Promotion, 1996.
31. **Wahren J, Saltin B, Jorfeldt L, and Pernow B.** Influence of age on the local circulatory adaptation to leg exercise. *Scand J Clin Lab Invest* 33: 79–86, 1974.
32. **Williams MA, Fleg JL, Ades PA, Chaitman BR, Miller NH, Mohiuddin SM, Ockene IS, Taylor CB, Wenger NK; and American Heart Association Council on Clinical Cardiology Subcommittee on Exercise, Cardiac Rehabilitation, and Prevention.** Secondary prevention of coronary heart disease in the elderly (with emphasis on patients > or =75 years of age): an American Heart Association scientific statement from the Council on Clinical Cardiology Subcommittee on Exercise, Cardiac Rehabilitation, and Prevention. *Circulation* 105: 1735–1743, 2002.

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Effect of aging on carotid artery stiffness and baroreflex sensitivity during head-out water immersion in man

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Abstract

To examine the possible age-related blood pressure (BP) deregulation in response to central hypervolemia, we measured spontaneous baroreflex sensitivity (SBRS), carotid arterial compliance (CC), and R-R interval coefficient of variation (RRICV) during basal and thermoneutral resting head-out-of-water immersion (HOWI) in 7 young (YG = 24.0 ± 0.8 years) and 6 middle-aged/older (OL = 59.3 ± 1.3 years) healthy men. Compared with basal conditions (YG = 19.6 ± 4.0 *vs* OL = 6.1 ± 1.5 ms/mmHg, $P < 0.05$), SBRS remained higher in YG than OL during rest HOWI (YG = 23.6 ± 6.6 *vs* OL = 9.3 ± 2.1 ms/mmHg, $P < 0.05$). The RRICV was significantly different between groups (YG = 6.5 ± 1.4 *vs* OL = 2.8 ± 0.4%, $P < 0.05$) under HOWI. The OL group had no increase in CC, but a significant increase in systolic BP (basal = 115.3 ± 4.4 *vs* water = 129.3 ± 5.3 mmHg, $P < 0.05$) under HOWI. In contrast, the YG group had a significant increase in CC (basal = 0.16 ± 0.01 *vs* water = 0.17 ± 0.02 mm^2/mmHg, $P < 0.05$) with no changes in systolic BP. SBRS was positively related to CC ($r = 0.58$, $P < 0.05$ for basal *vs* $r = 0.62$, $P < 0.05$ for water). Our data suggest that age-related vagal dysfunction and reduced CC may be associated with SBRS differences between YG and OL groups, and with BP elevation during HOWI in healthy older men.

Key words
- Aging
- Baroreflex sensitivity
- Carotid compliance
- Water immersion
- Hypertension
- Vascular stiffness

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Introduction

Orthostatic hypotension is prevalent with aging (1) and a proposed underlying mechanism is associated with impaired arterial baroreflex sensitivity (BRS; 2,3). It has been reported that in hypovolemic stress induced by head-up-tilt, the fluid shifts from the upper to the lower part of the body, unloading cardiopulmonary and arterial baroreceptors. In contrast, head-out-of-water immersion (HOWI) results in a significant increase in cardiac filling accompanied by loading of cardiopulmonary and arterial baroreceptors (4). Arterial baroreceptors are sensory nerve endings that innervate large arteries (carotid sinuses and aortic arch) and appear to contribute importantly to the regulation of blood pressure (BP) by the withdrawal of cardiac vagal tone (the immediate increase in heart rate (HR) determined by the acceleration of the electrocardiographic (ECG) R-R interval) during orthostatic challenge (5).

Age-related changes seem to provoke autonomic changes with impairment of vagal baroreflex and increases of baseline muscle sympathetic nerve activity (2). Shi et al. (6) demonstrated that age-related cardiac vagal dysfunction is associated with an attenuated response of BP regulation during hypovolemic stress. Their study showed that the elderly experienced orthostatic hypotension at the onset of orthostatic challenge because of a diminished HR response, but the increased vasoconstriction helped maintain their BP during a hypovolemic stress.

It has long been believed that aging leads to progressive structural and functional changes within the arterial walls, which are associated with increased vascular stiffness (7). In association with structural alterations, the elastic properties of the carotid arterial wall are reduced, blunting the baroreceptor response to increases in BP (8). Studies have revealed that the reduced carotid artery compliance (9,10) plays an important role in the age-associated decrease in cardiac BRS. On the other hand, studies (11,12) using hypovolemic circulatory stress have not detected changes in cardiovascular reflex responses with aging. Thus, the inconclusive findings concerning baroreflex responsiveness in young and older men, as well as its physiological consequences, provide a compelling rationale for the study of hemodynamic changes associated with BP regulation with advancing age.

The primary goal of the present study was to investigate age-related changes in cardiac autonomic control and elastic properties of the carotid artery related to BP regulation during resting hemodynamic stress. We used water immersion to load arterial and cardiopulmonary baroreceptors and hypothesized that: i) BP deregulation is prevalent in older adults and an underlying mechanism may be the result of impaired BRS, and ii) age-related vagal dysfunction and elastic properties of the carotid artery could be related to BP changes and BRS responses during hemodynamic stress.

Material and Methods

Subjects

Thirteen healthy males, 7 young (YG, 24 ± 0.8 years) and 6 middle-aged/older men (OL, 59.3 ± 1.3 years), volunteered for the study. All signed an informed consent form released prior to participation. The experiments were carried out with the approval of the Ethics Committee of Kyoto University, Graduate School of Human and Environmental Studies. The subjects studied are normotensive (BP <140/90 mmHg) with no evidence of renal or cardiovascular disease as indicated on the basis of medical history and of a resting electrocardiogram.

Experimental design

All of the experimental procedures were performed in two randomized sessions (resting basal conditions and during resting HOWI) on separate days at the same time each day. The following randomized measurements were made: anthropometric parameters, carotid artery diameter (CD), echocardiography measures, beat-to-beat HR, and BP. All measurements were made with the subject in the upright-seated position.

Experimental procedures

All measurements were made with the subjects sitting on a chair under resting basal conditions (air temperature of 27°C) and in a similar position during rest thermoneutral water immersion. An adjustable chair was placed in the swimming pool to adjust the water to heart level in all subjects evaluated. The subject, wearing only swim shorts, was instrumented with cuffs around the left upper arm and right finger for the determination of brachial and peripheral arterial BP, respectively. Simultaneously, a beat-to-beat HR signal was recorded using a bipolar lead (CM5 lead). The noninvasive peripheral BP wave was recorded using an automatic sphygmomanometer (Finapress 2300, Ohmeda, Englewood, CO, USA) connected to a finger cuff containing a plethysmographic transducer. The noninvasive beat-to-beat BP recording device was fitted to the middle finger of the hand. The arm was placed at the level of the heart and adjusted for similar brachial BP values in all subjects under basal conditions and during rest HOWI. Then, the analog output of the ECG (with a band pass filter between 0.5 and 100 Hz) and BP signals were digitized via a 13-bit analog-to-digital converter (Trans Era Corporation, South Orem, UT, USA) at a sampling rate of 1 kHz. The beat-to-beat ECG and BP signals collected under basal conditions and during rest HOWI were stored on a computer hard disk for later analysis. To analyze spontaneous BRS (SBRS) and HR variability (HRV) the beat-to-beat ECG and BP signals were collected for 300 s.

Our beat-to-beat ECG and BP data collection procedures have been described in detail (13,14). The standard time domain analysis of HRV was performed by calculating the beat-to-beat ECG R-R interval coefficient of variation [RRICV = (R-R interval standard deviation x 100)/mean R-R interval]. In addition, the systolic (SBP) and diastolic blood pressure (DBP) was measured at the 5th and 10th min in the left brachial artery with a standard sphygmomanometer. Arterial pulse pressure (PP) was calculated from arterial SBP minus DBP, and mean arterial blood pressure (MBP) was calculated from DBP + 1/3 PP.

Left ventricular vessel size

Subjects were studied under quiet resting basal conditions while they were sitting on a chair and in a similar position during rest HOWI. Our procedures to measure left ventricular size have been described in detail elsewhere. Briefly, left ventricular end-diastolic diameter (LVEDD) and left ventricular end-systolic ascending aortic diameter (LVESD) were measured by M-mode echocardiography with a model SSD 870 apparatus (Aloka, Tokyo, Japan) with the 2.5-MHz sector probe as previously reported (15). LVEDD and LVESD were measured during end respiration as an average of measurements from 3 M-mode pictures obtained from parasternal long axis views. All measurements were performed in a blind fashion and analyzed by the same investigator. Stroke volume (SV) was derived from measurements of LVEDD minus LVESD volumes. Cardiac output (CO) and total peripheral resistance were calculated from HR x SV and MBP/CO, respectively, using brachial MBP and HR values obtained before the measurements of M-mode echocardiography, as described previously (16).

Carotid artery measurements

Subjects were studied in a sitting position under resting basal conditions and during rest HOWI. Common CD was measured from the images derived from an ultrasound machine (Shimadzu SSD 350, Tokyo, Japan) equipped with a high-resolution linear array transducer (7.5 MHz) as previously described by Miyachi et al. (17). A longitudinal image of the cephalic portion of the common carotid artery was acquired 1 to 2 cm proximal to the carotid bulb, with the transducer placed at a 90° angle to the vessel so that near and far wall interfaces were clearly discernible. These images were recorded using a VHS videocassette recorder and analyzed with computerized image analysis software (NIH Image). The same investigator who was blind to the group of the subjects performed all image analysis. Measurements of maximal (systolic) and minimal (diastolic) lumen diameters from the media adventitia border of the near wall to the intima-lumen interface of the far wall were made for analysis. The ΔCD was calculated using the difference between systolic (CD_{sys}) minus diastolic (CD_{dia}) CD. For the determination of arterial compliance under basal conditions and during rest HOWI, we used the combination of common CD with peripheral BP measurements obtained under basal conditions and during rest HOWI, respectively, using the following equation previously described (18):

$$\text{Arterial compliance} = [(CD1 - CD0)/CD0]/[2(P1 - P0)] \times \pi \times (CD0)^2$$

where arterial compliance is reported in $mm^2/mmHg$; CD1 = maximal CD (mm); CD0 = minimal CD (mm); P1 = highest BP (mmHg); P0 = lowest BP (mmHg).

Spontaneous baroreflex sensitivity

The spontaneous baroreflex modulation of HR was assessed using the sequence method. Details of this analysis have been previously described (19). Briefly, sequences of three or more consecutive beats, characterized by either a progressive rise in SBP and lengthening of R-R interval (+RR/+SBP sequences) or by a progressive decrease in SBP and shortening of the ECG R-R interval (-RR/-SBP sequences) with a correlation higher than 0.80 were identified. A linear regression was applied to each sequence and the mean individual slope of the significant SBP/R-R interval relationship obtained by averaging all slopes computed within the test period was calculated and taken as a measure of the SBRS.

Table 1. Cardiovascular parameters at rest during basal conditions and during head-out water immersion of young and older subjects.

	Young group		Older group	
	Basal	Water	Basal	Water
Heart rate (bpm)	58.4 ± 3.5	57.1 ± 3.1	62.9 ± 4.6	63.4 ± 5.6
RRICV (%)	4.8 ± 0.8	6.5 ± 1.4	2.3 ± 0.4	2.8 ± 0.4‡
Systolic BP (mmHg)	106.9 ± 2.5	105.9 ± 3.6	115.3 ± 4.4*	129.3 ± 5.3‡
Diastolic BP (mmHg)	63.7 ± 2.4	58.4 ± 2.6	70.5 ± 4.5	72.0 ± 5.3‡
Mean BP (mmHg)	78.0 ± 2.2	74.2 ± 2.1	85.7 ± 3.8	91.0 ± 4.6‡
Pulse pressure (mmHg)	43.1 ± 2.1	47.4 ± 4.5	44.8 ± 5.0	57.3 ± 5.3*
LVESD (mm)	3.1 ± 0.1	3.1 ± 0.2	3.2 ± 0.2	3.2 ± 0.2
LVEDD (mm)	4.7 ± 0.1	4.9 ± 0.2	4.7 ± 0.2	4.9 ± 0.1
Cardiac output (l/min)	4.5 ± 0.2	5.2 ± 1.3*	4.6 ± 0.6	5.5 ± 1.1*
Stroke volume (ml)	80.3 ± 7.5	94.7 ± 3.7*	72.7 ± 7.5	85.7 ± 4.6*
TPR (mmHg per l/min)	17.3 ± 0.9	14.4 ± 2.2	20.4 ± 3	17.8 ± 2

Data are reported as means ± SEM. Young group (24 ± 0.8 years, N = 7); older group (59.3 ± 1.3 years, N = 6); RRICV = ECG R-R interval coefficient of variation; BP = blood pressure; LVESD = left ventricular end-systolic diameter; LVEDD = left ventricular end-diastolic diameter; TPR = total peripheral resistance.
*P < 0.05 basal *vs* water (two-way ANOVA).

Statistical analysis

Data are reported as means ± SEM. The unpaired Student *t*-test was used to assess statistical differences in anthropometric characteristics. Two-way analysis of variance for repeated measures was used to analyze differences between conditions (basal condition; water) and groups (YG; OL). When a significant effect was found, the Scheffé test for multiple comparisons was applied for condition and group. An alpha level of 0.05 was used to determine statistical significance. The relationships between SBRS and CD measured during rest HOWI were determined by linear regression analysis. The correlation coefficient (r) was calculated for the product-moment equation. All calculations were performed using the Statistica statistical program (version 5.0 for windows; StatSoft Inc., Tulsa, OK, USA).

Results

There was a significant difference in age between the YG and OL groups (24.0 ± 0.8 *vs* 59.3 ± 1.3 years, P < 0.01), but no significant difference in height (171.5 ± 1.4 *vs* 169.0 ± 2.9 cm, P > 0.05), weight (71.1 ± 4.6 *vs* 68.9 ± 4.1 kg, P > 0.05), or body fat