Journal of Gerontology: BIOLOGICAL SCIENCES
1995, Vol. 50A, No. 2, B97–B104

Long-term Resistance Training in the Elderly: Effects on Dynamic Strength, Exercise Capacity, Muscle, and Bone

Neil McCartney,[1,2] Audrey L. Hicks,[1] Joan Martin,[1] and Colin E. Webber[2]

Departments of [1]Kinesiology and [2]Medicine, McMaster University, Ontario, Canada.

We examined the effects of 42 weeks of progressive weight-lifting training on dynamic muscle strength, peak power output in cycle ergometry, symptom limited endurance during progressive treadmill walking and stair climbing, knee extensor cross-sectional areas, and bone mineral density and content in healthy males and females aged 60–80 years, currently enrolled in a 2-year resistance training program. Subjects were randomized into either exercise (EX) or control (CON) groups (60–70 years: 38 males and 36 females; 70–80 years: 25 males and 43 females). EX trained several muscle groups twice per week for 42 weeks at intensities ranging from 50–80% of the load that they could lift once only (1 RM); CON did usual daily activities. After the 10 months there was no change in 1 RM strength in CON, but significant gains (mean increases up to 65%) in EX (no independent age or gender effects); 30% and 47% of the increase in 1 RM had occurred by 6 and 12 weeks, respectively. In EX, the 7.1% increase in peak cycling power output was significantly greater than in CON (+1.1%). The 17.8% improvement in symptom limited treadmill walking endurance was also greater than in CON (+3.4%), but the difference between groups during stair climbing was not significant (EX + 57%, CON + 33%). The cross-sectional areas of the knee extensors increased significantly by 5.5% in EX but were unchanged in CON. There were no changes in bone mineral density or content in either group. We conclude that long-term resistance training in older people is feasible and results in increases in dynamic muscle strength, muscle size, and functional capacity.

BEYOND the age of 50 years there are progressive declines in exercise performance (Jones et al., 1985; Makrides et al., 1985) and muscle strength (Larsson et al., 1979). Reductions in muscle strength may compromise activities of daily living and bring individuals close to, or beyond, the threshold for dependency (Young, 1986). In the frail elderly there is a strong association between muscle weakness and falls, and the resulting fractures are a common source of disability in this group (Tinetti et al., 1988). Interventions to increase muscle strength in the elderly would be potentially very useful, but it is only in recent years that systematic techniques of progressive resistance overload training have been applied to this population.

In earlier studies using calisthenics to train the knee extensors (Aniansson and Gustafsson, 1981), and a short-term weight-lifting program to train the elbow flexors (Moritani and de Vries, 1980), there were notable gains in strength but no evidence of muscle hypertrophy. This suggested that the mechanism(s) responsible for the improvement was contained within the nervous system. More recent work in 60–70-year-old males (Frontera et al., 1988; Brown et al., 1990) demonstrated that 12 weeks of progressive resistance weight-lifting training resulted in large gains in dynamic strength, and in whole muscle and individual muscle fiber cross-sectional areas. Fiatarone and colleagues (1990) have reported similar findings in institutionalized subjects with an average age of 90 years. While these results from short-term studies are encouraging, the willingness of older individuals to participate in a prolonged period of training, and the results of such training, are unknown. Whether increases in muscle strength are associated with improvements in daily tasks such as walking and stair climbing is also an important question.

The present report describes the midpoint findings from a 2-year study of weight-lifting training in 142 healthy male and female volunteers aged from 60 to 80 years (76 exercise, 66 controls). The purpose(s) of the investigation was: (a) to examine the pattern of change in dynamic strength over a long period of training; (b) to measure the effects of the training on muscle size and bone mineral density and content; and (c) to evaluate whether increases in dynamic leg strength would lead to increased maximum power output in cycle ergometry, and to increased symptom-limited endurance in treadmill walking and stair-climbing ergometry.

METHODS

Subjects

One hundred and ninety-three apparently healthy subjects aged from 60 to 80 years, with no prior resistance training experience, volunteered to take part in the study. Subjects freely gave their written informed consent, and the study was approved by the appropriate University Research Review Committee. Listed among the criteria for inclusion in the study were the approval of the family physician and the satisfactory completion of a maximum progressive incremental cycle ergometer exercise test to detect cardiac or pulmonary impairment (Jones, 1988). Exclusion criteria included: evidence of coronary artery disease; chronic obstructive or restrictive lung disease;

osteoporosis; major orthopedic disability; smoking; a body weight greater than 130% of ideal (Metropolitan Life Insurance Co., 1959). After the medical reviews and the exercise testing, the study population was reduced to 142 subjects who met the inclusion and exclusion criteria (Table 1). The maximum oxygen uptake of these subjects was as predicted (100 ± 20%) for their age, height, and gender (Jones et al., 1985).

Study Design

The study was designed so that there would be 30 males and 30 females from each decade assigned at random to either the exercise or control groups. In order to account for the likelihood of comorbidity in this age group, and to allow for nonadherence and dropouts, a total of 76 subjects were entered into the exercise group, compared to 66 controls. At the outset of the study, the only group which included less than the required 15 individuals was male controls aged 70–80, in which there were 8 subjects.

The exercise subjects took part in two resistance training sessions per week for 10 months. Control subjects were offered a supervised, twice weekly, low-intensity walking program, but it was not heavily utilized after the onset of cold weather. Control subjects were also instructed to pursue their normal daily activities without restriction, and many continued to walk on their own. Tests of dynamic strength, exercise capacity, and body composition were administered to both groups before and after the 10-month intervention period. Subjects were allowed to miss one month of training during the 10 months for reasons of illness or vacation, and the sessions missed were added at the end. A dropout was defined as someone who could not complete the 10 months of training in a consecutive 11-month period.

Training

Resistance training took place two times each week, interspersed with a day or two of recovery. Unilateral leg press, ankle plantar flexion, military press, and bilateral bench press exercises were done on a multistation weight-lifting apparatus (Global Gym, Downsview, Ontario). Single-arm curls were performed on a custom-built weight-lifting device (Rubicon Industries, Stoney Creek, Ontario), and ankle dorsiflexors were also exercised on a specially constructed apparatus. Abdominal curls were done on a padded station on the floor. During single-arm curls the subjects were seated, with the arm in a fully extended position and the palm facing up. The elbow was flexed to lift the weight through a full range of movement, before resuming full extension. The military press was performed in a seated position on a high stool. The movement began with the hand at shoulder level, proceeded to full overhead extension of the arm to lift the weight, and returned once again to shoulder level. The bench press exercise was done supine, as a bilateral arm press beginning and ending close to the chest. During the leg press exercise, subjects were seated with the back supported and the foot resting on a footplate. The movement began with the knee at an angle of 90°, proceeded to full extension to lift the weight, and then resumed the starting position. Ankle plantar flexion was done in the same position as the leg press during full extension. The movement began with the foot at an angle of 90°, proceeded to full plantarflexion, and returned to the starting position. To train the dorsiflexors, subjects were seated in a chair with their foot strapped into a footplate apparatus that could rotate in the vertical plane. The knee joint angle was maintained at 90°, and the initial angle of the foot at approximately 110° (20° of plantar flexion). Subjects lifted the weight by dorsiflexion of the ankle through a complete range of movement, and then lowered it to the starting position. The exercises were completed using a circuit set system, with 2-min rests between sets; each set comprised either 10 (arms) or 12 (legs) repetitions. Training progressed from two sets of each exercise at 50% of the initial one-repetition maximum (1 RM) to three sets at 80% 1 RM over the course of the study. The 1 RM was reevaluated every 6 weeks, and the training loads were adjusted accordingly.

Measurement of dynamic strength. — Dynamic strength was measured as the heaviest weight that could be lifted once throughout a complete range of movement (1 RM). Testing was repeated on two different days, and the greatest 1 RM was recorded as the pretraining value. The movements tested were unilateral arm curl, military press and leg press, and bilateral bench press.

Maximum cycle ergometry. — Maximum cycling capacity was measured in a progressive incremental test (Jones, 1988) using an electrically braked cycle ergometer (Siemans Elema 370). Initial power output, 100 kpm/min, increased by the same amount at the end of each minute until exhaustion, or until the subject could no longer maintain the required pedaling frequency of 60 rpm. There was continuous monitoring of heart rate using a 12-lead electrocardiogram (1515-B Automatic Cardiograph, Hewlett Packard), and arterial blood pressure was measured by auscultation during alternate work loads. Symptoms of leg effort and dyspnea were rated at the end of each minute using the Borg scale (0–10) (Borg, 1982).

Table 1. Descriptive Details of Subjects Who Completed the Pretesting Evaluations

	Age (Mean ± *SD*)	Height (cm) (Mean ± *SD*)	Weight (kg) (Mean ± *SD*)
Females 60–70 yrs			
Exercise (*n* = 17)	65 ± 2.4	160.8 ± 5.9	62.5 ± 9.5
Control (*n* = 19)	65 ± 2.8	162.6 ± 5.5	67.1 ± 9.3
Females 70–80 yrs			
Exercise (*n* = 20)	71 ± 1.8	162.2 ± 5.7	67.1 ± 8.6
Control (*n* = 23)	73 ± 3.5	157.4 ± 5.1	60.0 ± 6.8
Males 60–70 yrs			
Exercise (*n* = 22)	64 ± 2.4	175.2 ± 5.8	81.3 ± 8.5
Control (*n* = 16)	63 ± 2.4	177.1 ± 6.4	83.1 ± 10.3
Males 70–80 yrs			
Exercise (*n*= 17)	73 ± 3.1	173.5 ± 4.7	75.9 ± 6.6
Control (*n* = 8)	72 ± 2.8	177.0 ± 3.2	82.9 ± 10.1

Treadmill testing. — Subjects performed a progressive treadmill (Quinton Q55xt) walking test until they reported a Borg rating of perceived exertion (RPE) of 7 (very severe), at which time the test was terminated by the attending investigator. The subjects were unaware that an RPE rating of 7 was the criterion for ending the test. In the first 2 minutes the walking speed was 2.0 mph, and the grade was 10%. This was increased to 2.5 mph and 12% grade for mins 2 to 4; in each subsequent 2-minute interval the speed remained constant and the grade was increased by a further 2%. Symptoms of leg effort and dyspnea were rated at the end of each minute.

Stair climbing ergometry. — Subjects walked on a Stairmaster 6000 ergometer at a stepping rate of 55 steps/min. An RPE for leg effort and breathing was obtained at the end of each minute, and the test was terminated when a level of 7 (very severe) was reported. During the test, subjects were allowed one-hand fingertip contact with the rail to assist balance, but they were not allowed to grip it.

Muscle cross-sectional area. — The cross-sectional areas of the thigh and individual constituent muscles were measured from computerized tomography scans using either a previously reported planimetry method (MacDougall et al., 1984) or a newly developed semi-automated computer analysis (unpublished). Individual subject data were analyzed on both occasions using the same technique. In the computer analysis, single slice scans were transferred digitally from the CT scanner on to a network of SUN SPARC stations, and the areas of fat (including blood), muscle, and bone were calculated according to their respective Hounsfield densities. Both thighs were scanned simultaneously at a point 10 cm (females) or 12 cm (males) proximal to the superior border of the patella.

Bone mineral density and content. — Lumbar spine and total body bone mass were measured using dual photon absorptiometry (^{153}Gd based Norland 2600 dichromatic densitometer). Data obtained with this instrument have been shown to be accurate and precise for both total body (Galea et al., 1990) and local (Webber, 1989) measurement. At the lumbar spine, bone mineral density and bone mineral mass were assessed for L2, L3, and L4.

Statistical analyses. — The effects of training were analyzed with a 4-way mixed ANOVA: a 2 (Age) × 2 (Gender) × 2 (Group) × 2 (Time) design, with repeated measures on the last factor. The interaction of most interest to determine training effects was the Group × Time interaction, but significant interactions involving gender and/or age are mentioned where appropriate. The level for statistical significance was $p \leq .05$.

RESULTS

Immediately after the pretesting and randomization to groups, 7 control subjects were lost from the study population: 3 would not participate as control subjects, 1 subject moved away, and 3 were found to have serious medical problems. There were no injuries as a result of the training, but during the course of the 10 months a total of 16 exercise subjects dropped out of the study (11 males and 5 females). Seven of the exercise dropouts were in the male 60–70-year-old group. The reasons for dropout included illness (9; 1 death from cancer), moved away (2), time commitment (3), family problems (1), no reason given (1). In those who completed the study, adherence to the training regimen was excellent, with a mean attendance at all possible sessions of 88%. The results reported here are from the 119 subjects who completed the intervention; baseline results from subjects who dropped out of the study are not included.

Weight-lifting capacity. — In all 4 exercises men were significantly stronger than women; age was also associated with reduced capacity, but to a lesser extent. In the arm exercises the females' 1 RMs were approximately half those of the males, whereas in the leg press their capacity was reduced by one-third (Figures 1–4). There was no change in the 1 RMs of the control subjects after 10 months, but the increases in the training group (20–65%) were highly significant ($p < .01$) (Figures 1–5). Overall there was no effect of age or gender on the response to

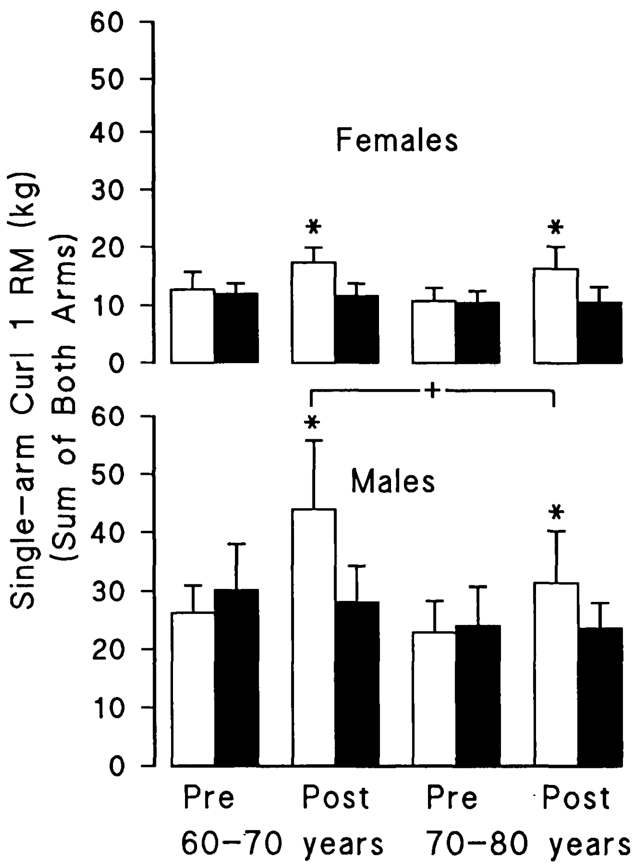

Figure 1. Single-arm curl 1 RM in male (lower) and female (upper) subjects before and after 42 weeks of resistance training (open bars) or control (solid bars). *Significant difference between the exercise and control groups post-training; + significant difference between the two age groups post-training.

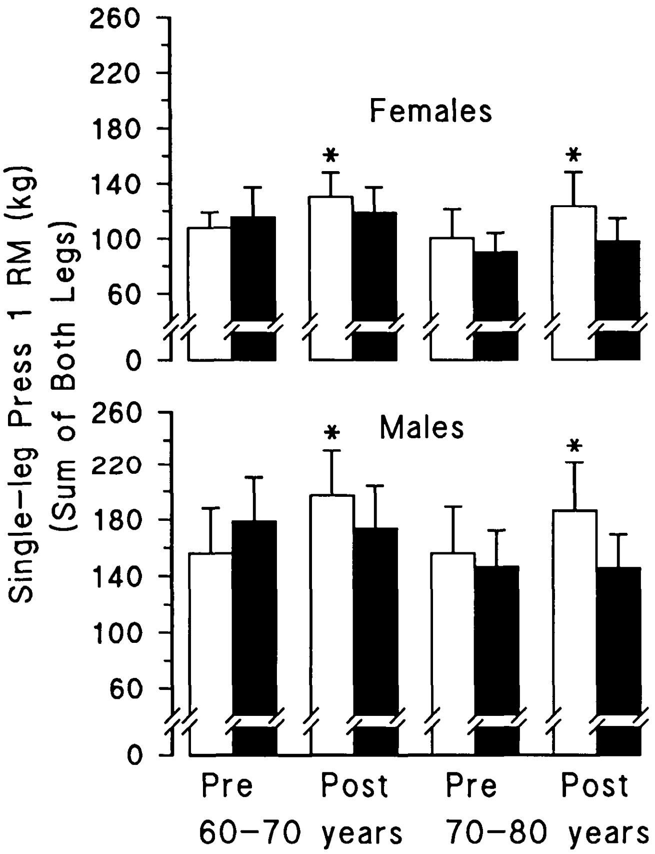

Figure 2. Single-leg press 1 RM in male (lower) and female (upper) subjects before and after 42 weeks of resistance training (open bars) or control (solid bars). *Significant difference between the exercise and control groups post-training.

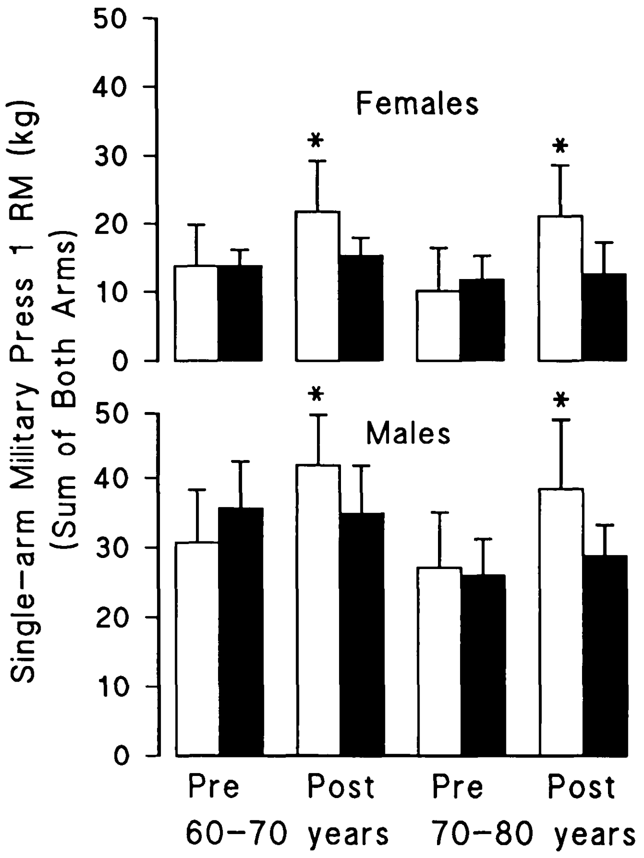

Figure 3. Single-arm military press 1 RM in male (lower) and female (upper) subjects before and after 42 weeks of resistance training (open bars) or control (solid bars). *Significant difference between the exercise and control groups post-training.

training, but in the single-arm curl exercise the younger male subjects improved their 1 RM significantly more than the others (Figures 1, 5). Collapsing the data across age, gender, and exercise type, 30% of the increase in dynamic strength occurred in the initial 6 weeks, or 15% of the total training time; 47% of the increase had developed by 12 weeks, or 30% of the training time (Figure 6).

Maximum cycle ergometry. — As in the measures of 1 RM, males had significantly higher values of maximum power output than females, and there was an additional main effect for age (Table 2). After training, there was a 7.1% increase in maximum power output in the exercise group, which was significantly greater than the 1.1% gain in the controls ($p < .05$). There were no independent effects of age or gender on the response to training.

Treadmill performance. — The performance of the males in the treadmill walking test (overall average of 17.1 mins at the time of pretesting) was significantly higher than the females (overall average of 11.3 mins), but there was no effect of age ($p = .08$) (Table 2). After training, the increase in treadmill endurance in the exercise group (17.8%) was greater ($p < .05$) than in the controls (3.4%) (Figure 7). There were no independent effects of age or gender on the response to training.

Stair climbing. — At the time of pretesting, the stair climbing endurance of the males (overall average of 565 sec, or 32 flights) was significantly greater than the females (overall average of 247 sec, or 14 flights), and there was a main effect for age (younger males and females 37% and 16% better than their older counterparts, respectively). After the intervention period there was a 57% increase in performance in the resistance-trained subjects, but also a 33% gain in the controls (Figure 7). The difference between groups was not significant.

Muscle cross-sectional area. — The cross-sectional area of the knee extensors was greater in males than females, and it was also greater in the 60–70-year-old subjects of both genders than in the older individuals (Table 2). After the intervention there was a mean increase of 5.5% in the resistance-trained subjects, compared to an increase of 1.7% in controls ($p < .05$). There were no independent effects of age or gender on the training response.

Bone mineral density and content. — The bone mineral density and content of the whole body, and the lumbar spine, was lower in females than in males and decreased with age; the range in values (Cottreau et al., in press) was compatible with other published data on elderly subjects. There were no changes as a result of the training program.

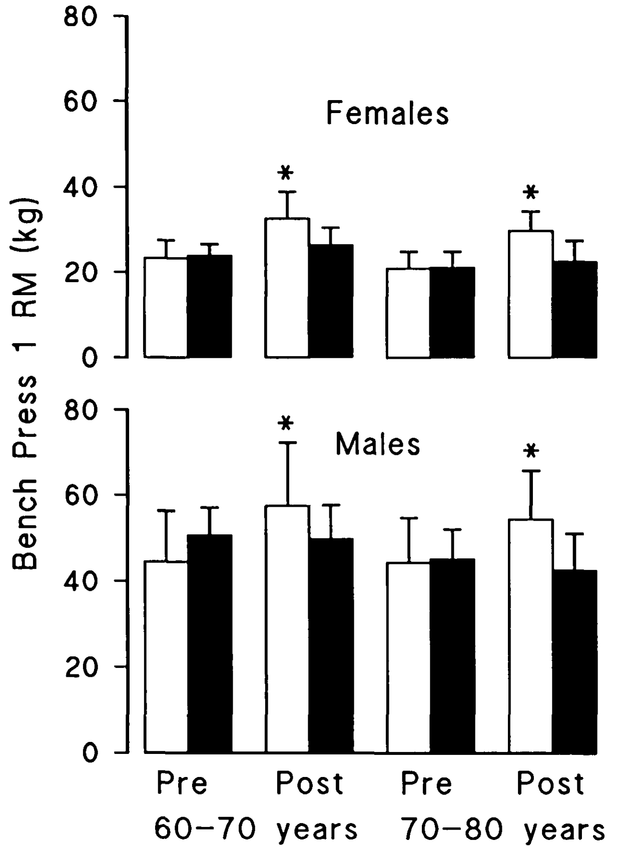

Figure 4. Bench press 1 RM in male (lower) and female (upper) subjects before and after 42 weeks of resistance training (open bars) or control (solid bars). *Significant difference between the exercise and control groups post-training.

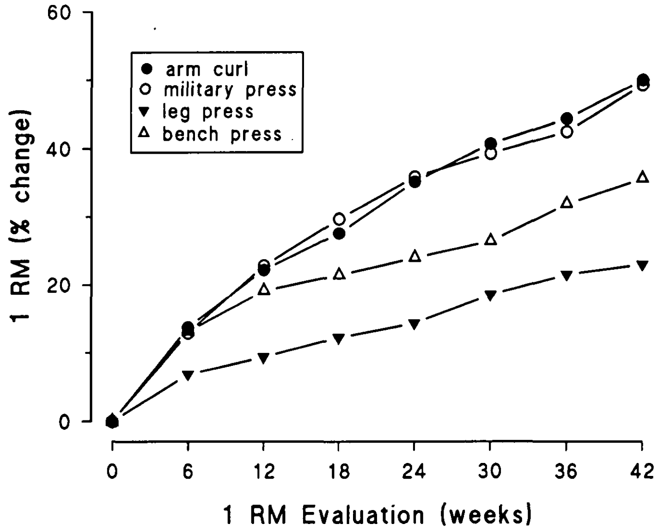

Figure 5. Relative (%) increases in 1 RMs among resistance-trained subjects over 42 weeks.

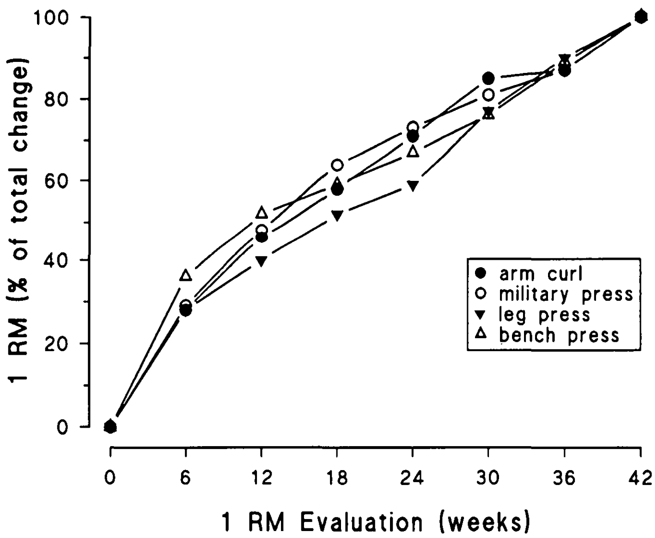

Figure 6. The evolution of relative change in 1 RMs among resistance-trained subjects over 42 weeks.

Discussion

Adherence and dropout. — Over the course of the year, 16 out of 135 subjects (12%) who progressed beyond the pretesting were lost from the study due to illness and personal reasons. The 88% completion rate is comparable to an 8-month aerobic training program in this age group (McMurdo and Burnett, 1992), and substantially better than in a 2-year study (Morey et al., 1991). It is also considerably better than the dropout rate from studies of exercise in coronary artery disease (Oldridge, 1979) and in older subjects with health problems (Morey et al., 1989). In subjects who completed the year, the average attendance rate of 88% demonstrated that acceptance of the training regimen was very high. The absence of injury confirmed the findings from previous short-term studies (Frontera et al., 1988; Brown et al., 1990), which concluded that resistance training is safe and appropriate for older people.

Dynamic muscle strength and muscle cross-sectional area. — The 1RM data confirmed that the females were approximately 30% and 50% weaker than the men in leg and arm exercises, respectively. This proportionality is similar to findings in young subjects (Wilmore, 1974), and indicates that the decline in dynamic strength with aging is not affected by gender. Nevertheless, with a much lower level of strength, it seems likely that older women would experience greater difficulties in many strength-related activities of daily living, particularly those which involve the arms. This being the case, they may also have the most to gain from interventions which result in increased strength.

The 10 months of resistance training resulted in significant mean increases in 1 RM ranging from 20 to 65% (Figures 1–6). The absence of any Age × Time, or Gender × Time interactions in three of the exercises confirmed that males and females of both age groups were equally responsive to training. Only in the single-arm curl exercise was there an exception, as the 60–70-year-old males improved more than the others. The overall similar responsiveness to

Table 2. Peak Cycling Power Output, Treadmill and Stair Climbing Endurance Time, and Cross-Sectional Area of the Knee Extensors Before and After 42 Weeks of Resistance Training or Control

	Treadmill Time(s)		Cycling Power Output (kpm/min)		Stair Climbing Time (Flights)		Knee Extensors Cross-sectional Area (cm²) (Sum of Both Legs)	
	Pre	Post[a]	Pre	Post[a]	Pre	Post	Pre	Post[a]
Males 60–70								
Exercise	1019 ± 123	1070 ± 96	943 ± 47	985 ± 45	35 ± 7	52 ± 10	124.8 ± 5.1	133.4 ± 6.0
Control	1327 ± 165	1244 ± 192	1116 ± 58	1057 ± 41	38 ± 6	63 ± 11	128.2 ± 5.5	128.2 ± 5.6
Males 70–80								
Exercise	705 ± 62	935 ± 136	863 ± 36	862 ± 31	22 ± 5	33 ± 8	116.8 ± 4.5	123.4 ± 5.3
Control	1060 ± 413	1030 ± 422	875 ± 82	888 ± 52	32 ± 17	42 ± 17	124.4 ± 3.9	127.4 ± 3.6
Females 60–70								
Exercise	793 ± 116	875 ± 137	590 ± 38	633 ± 32	13 ± 2	30 ± 7	78.3 ± 2.4	82.7 ± 2.6
Control	606 ± 89	636 ± 74	596 ± 34	620 ± 47	17 ± 4	17 ± 3	79.4 ± 3.8	81.8 ± 4.3
Females 70–80								
Exercise	807 ± 176	785 ± 138	504 ± 24	547 ± 17	16 ± 4	20 ± 6	70.2 ± 1.7	72.9 ± 1.9
Control	517 ± 57	530 ± 66	462 ± 20	467 ± 23	9 ± 1	11 ± 1	72.4 ± 2.8	73.3 ± 2.5

Note. Treadmill time and stair climbing time were the times until subjects reported a Borg (1–10) rating of 7 (very severe) for either leg effort or breathing.

[a]Significant group (collapsed across age and gender × time interactions).

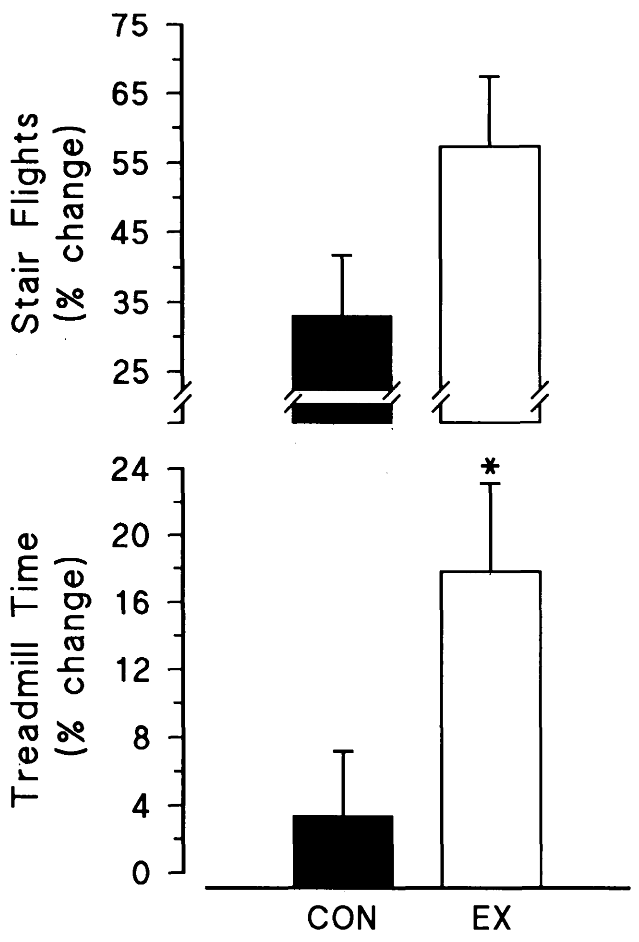

Figure 7. Relative change in stair climbing (upper) and treadmill (lower) symptom-limited endurance after 42 weeks of resistance training (open bars) or control (solid bars). *Significant difference between the exercise and control groups.

resistance training appears to be the case even in subjects up to 96 years of age (Fiatarone et al., 1990).

Collapsing the 1 RM data across age, gender, and exercise type (Figure 6), it is clear that the most rapid rate of strength gain was in the first 6 weeks of training (15% of the training time), when 30% of the total increase had taken place. Another 17% of the total increase occurred by 12 weeks (30% of the training time), and then the rate slowed down. However, at no time was there a plateau in the strength gain; it continued to increase slowly over the remaining 7 months. This pattern of adaptation is of considerable practical importance, as it suggests that even a short period of moderate resistance training will promote increases in strength that may enable seniors to take part in strenuous activities of daily living that might otherwise have proved difficult or even impossible. Such benefits have recently been demonstrated in the frail elderly (Fiatarone et al., 1990). The fact that the dynamic strength continued to increase over the 10 months is also important, as it suggests that long-term resistance training may help to ameliorate the reductions in strength that are commonly associated with aging.

The early, rapid increases in strength with resistance training may be attributed more to neural adaptations (Sale, 1988), such as learning and coordination (Rutherford and Jones, 1986), than to muscle hypertrophy. We (Brown et al., 1990) and others (Vandervoort and McComas, 1986) have previously demonstrated that older individuals are able to achieve complete motor unit activation during maximum voluntary effort, so enhanced motor unit activation is an unlikely mechanism to account for the strength changes. Muscle hypertrophy was probably a contributing factor to the strength gains over 10 months, as indicated by the significant increase in knee extensor cross-sectional areas, but we have no data relating to the time course of change. Previous short-term resistance training studies in 60–70-year-old men have documented hypertrophy of the knee extensors after 12 weeks (Frontera et al., 1988; Brown et al., 1990), but in those studies the training took place on three occasions each week and was more aggressive than in the present work.

Maximum cycle ergometry. — Maximum power output during progressive cycle ergometry showed the well-established declines with age and gender (Jones et al., 1985). The small but significant increase in peak power of 7.1% in the resistance-trained subjects was approximately half the improvement that we previously noted in patients with coronary artery disease (McCartney et al., 1991). In that study a similar, 21% gain in knee extensor 1 RM was associated with a 15% increase in maximum cycling power output. This may suggest that initial dynamic leg strength was not such a major limiting factor among the healthy subjects in the present study; this appears unlikely, however, as the initial 1 RM values were similar between the groups.

Treadmill walking. — The increase in dynamic leg strength after training was associated with a 17.8% increase in treadmill endurance until subjects reported an RPE of 7 (very severe) for either the legs or dyspnea. In previous work we have demonstrated that endurance measured in this manner is strongly associated with increases in knee extensor 1 RM, and is more sensitive to change than tests of peak exercise performance (McCartney et al., 1991). We believe that it is also more likely to reflect the impact of increased strength on strenuous activities of daily living which involve the trained muscles. Other investigators have reported a 12% increase in treadmill endurance time after only 10 weeks of weight-lifting training in patients with coronary artery disease (Kelemen et al., 1986). Our data do not allow us to identify the mechanism(s) responsible for the increased endurance, although we speculate that it may be quite simple; any absolute muscle force after training will require less relative effort from stronger muscles, and will thus be perceived as less demanding and may be tolerated for longer.

Stair climbing. — Although the strength-trained subjects improved by 57%, there was a concurrent increase of 33% in the control subjects, and the difference between groups was not significant. It was only the male control subjects who improved, especially the younger age group, and we are unable to explain this increase. Perhaps, despite repeated practice before the pretesting took place, there was a large learning component to the task, or perhaps the effort during initial testing was submaximal. Despite the lack of significance, it could be argued that the 73% greater relative increase in the trained subjects was meaningful, and may result in improved stair climbing tolerance during daily life.

Bone mineral density and content. — In cross-sectional studies there often appears to be a positive association between muscle strength and bone mineral density (Bevier et al., 1989; Snow-Harter et al., 1990; 1992b). There is also a report of small increases in lumbar spine bone mineral density after resistance training in young females (Snow-Harter et al., 1992a), but results in postmenopausal women are equivocal (Pruitt et al., 1992; Smidt et al., 1992). In the present study there was no change in whole body, or lumbar spine bone mineral density or bone mineral mass after training. What increases we did observe were actually slightly greater in the control subjects. Perhaps the training frequency and intensity were not sufficient, or the training time was too short. Seasonal variation in bone mineral may be a problem in longitudinal studies (Bergstrahl et al., 1990), especially when not all subjects begin the intervention at exactly the same time, which was the case in the present work. Even under ideal conditions, exercise training may not promote large increases in bone mass (Dalsky, 1989). Whatever the reason, it seems clear that a resistance training program such as the one in the present study does not cause measurable bone remodeling in healthy seniors.

In summary, we have demonstrated that long-term resistance training is feasible and well tolerated in men and women up to 80 years of age. Training resulted in large gains in dynamic strength, and associated increases in knee extensor cross-sectional areas, peak cycling power output, and treadmill endurance capacity. There were large increases in endurance during stair climbing ergometry, but control subjects showed increases also. Bone mineral density and bone mass were unchanged. Regular weight-lifting training in the elderly may be an excellent method of preserving independent functional capacity and improving quality of life.

Acknowledgments

This work was supported by a grant from the Ontario Ministry of Health.

Address correspondence to Dr. Neil McCartney, Department of Kinesiology, McMaster University, 1280 Main Street West, Hamilton, Ontario, Canada L8S 4K1.

References

Aniansson, A.; Gustafsson, E. Physical training in elderly men with special reference to quadriceps muscle strength and morphology. Clin. Physiol. (Oxford) 1:87–98; 1981.

Bergstrahl, E.J.; Sinaki, M.; Offord, K.P.; Wahner, H.W.; Melton, L.J. Effect of season on physical activity score, back extensor muscle strength, and lumbar bone mineral density. J. Bone Min. Res. 5:371–377; 1990.

Bevier, W.C.; Wiswell, R.A.; Pyka, G.; Kozak, K.C.; Newhall, K.M.; Marcus, R. Relationship of body composition, muscle strength, and aerobic capacity to bone mineral density in older men and women. J. Bone Min. Res. 4:421–432; 1989.

Borg, G.A.V. Psychophysical bases of perceived exertion. Med. Sci. Sports Exer. 14:377–381; 1982.

Brown, A.B.; McCartney, N.; Sale, D.G. Positive adaptations to weight-lifting training in the elderly. J. Appl. Physiol. 69:1725–1733; 1990.

Cottreau, M.; Chambers, L.F.; Gordon, C.L.; Martin, J.; Hicks, A.L.; McCartney, N.; Webber, C.E. Lumbar spine and total body bone mass in healthy elderly men and women. Can. J. Aging, in press.

Dalsky, G.P. The role of exercise in the prevention of osteoporosis. Comp. Therapy 15:30–37; 1989.

Fiatarone, M.A.; Marks, E.C.; Ryan, N.D.; Meredith, C.N.; Lipsitz, L.A.; Evans, W.J. High intensity strength training in nonagenarians: Effects on skeletal muscle. JAMA 263:3029–3034; 1990.

Frontera, W.R.; Meredith, C.N.; O'Reilly, K.P.; Knuttgen, H.G.; Evans, W.J. Strength conditioning in older men, skeletal muscle hypertrophy, and improved function. J. Appl. Physiol. 64:1038–1044; 1988.

Galea, V.; Ormerod, S.; White, N.; MacDougall, J.D.; Webber, C.E. Body composition by photon absorptiometry. Can. J. Appl. Sport Sci. 15:143–148; 1990.

Jones, N.L. Clinical exercise testing. Philadelphia: W.B. Saunders, 1988.

Jones, N.L.; Makrides, L.; Hitchcock, C.; Chypchar, T.; McCartney, N. Normal standards for an incremental progressive cycle ergometer test. Am. Rev. Resp. Dis. 131:700–708; 1985.

Kelemen, M.H.; Stewart, K.J.; Gillilan, R.E.; Ewart, C.K.; Valenti, S.A.; Manley, J.D.; Kelemen, M.D. Circuit weight training in cardiac patients. J. Am. Coll. Cardiol. 7:38–42; 1986.

Larsson, L.; Grimby, G.; Karlsson, J. Muscle strength and speed of movement in relation to age and muscle morphology. J. Appl. Physiol. 46:451–456; 1979.

MacDougall, J.D.; Sale, D.G.; Alway, S.E.; Sutton, J.R. Muscle fiber number in biceps brachii in body builders and control subjects. J. Appl. Physiol. 57:1399–1403; 1984.

Makrides, L.; Heigenhauser, G.J.F.; McCartney, N.; Jones, N.L. Maximal short-term exercise capacity in healthy subjects aged 15–70 years. Clin. Sci. 69:197–205; 1985.

McCartney, N.; McKelvie, R.S.; Haslam, D.R.S.; Jones, N.L. Usefulness of weightlifting training in improving strength and maximal power output in coronary artery disease. Am. J. Cardiol. 67:939–945; 1991.

McMurdo, M.E.; Burnett, L. Randomized controlled trial of exercise in the elderly. Gerontology 38:292–298; 1992.

Metropolitan Life Insurance Co. Statistical bulletin of the Metropolitan Life Insurance Co. New York: Author, 1959:40.

Morey, M.C.; Cowper, P.A.; Feussner, J.R.; DiPasquale, R.C.; Crowley, G.M.; Kitzman, D.W.; Sullivan, R.J. Jr. Evaluation of a supervised exercise program in a geriatric population. J. Am. Geriatr. Soc. 4:348–354; 1989.

Morey, M.C.; Cowper, P.A.; Feussner, J.R.; DiPasquale, R.C.; Crowley, G.M.; Samsa, G.P.; Sullivan, R.J. Jr. Two-year trends in physical performance following supervised exercise among community-dwelling older veterans. J. Am. Geriatr. Soc. 10:986–992; 1991.

Moritani, T.; DeVries, H.A. Potential for gross muscle hypertrophy in older men. J. Gerontol. 35:672–682; 1980.

Oldridge, N.B. Compliance of post myocardial infarction patients to exercise programs. Medi. Sci. Sports 11:373–375; 1979.

Pruitt, L.S.; Jackson, R.D.; Bartels, R.L.; Lehnhard, H.J. Weight-training effects on bone mineral density in early postmenopausal women. J. Bone Min. Res. 7:179–185; 1992.

Rutherford, O.M.; Jones, D.A. The role of learning and coordination in strength training. Eur. J. Appl. Physiol. 55:100–105; 1986.

Sale, D.G. Neural adaptation to resistance training. Med. Sci. Sports Exerc. 20(Suppl.):S135–S145; 1988.

Smidt, G.L.; Lin, S.Y.; O'Dwyer, K.D.; Blanpied, P.R. The effect of high-intensity trunk exercise on bone mineral density of postmenopausal women. Spine 17:280–285; 1992.

Snow-Harter, C.; Bouxsein, M.; Lewis, B.; Charette, S.; Weinstein, P.; Marcus, R. Muscle strength as a predictor of bone mineral density in young women. J. Bone Min. Res. 5:589–595; 1990.

Snow-Harter, C.; Bouxsein, M.L.; Lewis, B.T.; Carter, D.R.; Marcus, R. Effects of resistance and endurance exercise on bone mineral status of young women: a randomized exercise intervention trial. J. Bone Min. Res. 7:761–769; 1992a.

Snow-Harter, C.; Whalen, R.; Myburgh, K.; Arnaud, S.; Marcus, R. Bone mineral density, muscle strength, and recreational exercise in men. J. Bone Min. Res. 7:1291–1296; 1992b.

Tinetti, M.E.; Speechley, M.; Ginter, S.F. Risk factors for falls among elderly persons living in the community. N. Engl. J. Med. 319: 1701–1707; 1988.

Vandervoort, A.A.; McComas, A.J. Contractile changes in opposing muscles of the human ankle joint with aging. J. Appl. Physiol. 61: 361–367; 1986.

Webber, C.E. Some factors which influence the evaluation of a dual photon measurement of lumbar spine bone mineral mass. J. Can. Assoc. Radiol. 40:87–91; 1989.

Wilmore, J.H. Alterations in strength, body composition and anthropometric measurements consequent to a 10-week weight training program. Med. Sci. Sports 6:133–138; 1974.

Young, A. Exercise physiology in geriatric practice. Acta Med. Scand. 711(Suppl.):227–232; 1986.

Received December 20, 1993
Accepted May 3, 1994