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A Longitudinal Trial of Weight Training in the Elderly: Continued Improvements in Year 2

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We conducted a 2-year (42 weeks of consecutive training in each year, separated by 10 weeks of testing and vacation time) randomized, controlled trial of weight training in 142 healthy male and female subjects, aged 60 to 80 years. Measurements included dynamic strength, symptom-limited endurance in cycling, treadmill walking and stair climbing, muscle size, and bone mineral density and content of the lumbar spine and whole body. One hundred and thirteen subjects completed the study (57 exercise, 56 control), with a mean attendance of 85% among the exercisers. Muscle strength was unchanged in the control subjects but increased (collapsed across age and gender) from 32% (leg press) to 90% (military press) in the exercisers. Symptom-limited endurance in cycling, treadmill walking, and stair climbing increased in the exercisers by (mean ± SE) 6.2 ± 0.8%, 29.2 ± 7.3%, and 57 ± 12%, respectively; the only change in the controls was an unanticipated 33% increase in stair climbing performance during the first year. These values were unchanged in the controls. Cross-sectional area of the knee extensors increased by 8.7 ± 0.9% in the trained subjects and was unchanged in controls. Measures of whole body, lumbar spine bone mineral density, and lumbar spine bone mineral content were unchanged in the exercisers, but whole body bone mineral content decreased by 1%. In contrast, there were small increases (<4.0%) in bone mineral density among the controls. Long-term weight training proved to be a safe and well-tolerated mode of exercise for the elderly. Increased strength was associated with muscle hypertrophy in each year, and with increased endurance in cycling, walking, and stair climbing. There were no changes in bone mineral density but a small reduction in whole body bone mineral content.

STRATEGIES to promote and prolong independent living among the growing numbers of the elderly in society are receiving widespread attention (Fiatarone et al., 1993. The declines in muscle strength with aging (Larsson et al., 1979) are closely correlated with reductions in muscle mass (Grimby and Saltin, 1983) and may be related to the incidence of falls (Tinetti et al., 1988) and dependency (Hyatt et al., 1990). Young (1986) has suggested that relatively modest increases in strength may delay the dependency threshold for several years, but this has yet to be demonstrated. What has been established is that short-term weight training programs result in notable increases in dynamic strength and muscle hypertrophy in the young elderly (Frontera et al., 1988; Brown et al., 1990), and even among the very old and frail (Fiatarone et al., 1990, 1994).

Despite these encouraging findings from short-term studies, there is little available information about the adaptations to prolonged training. Whether strength and muscle mass can continue to increase, if there are associated improvements in functional tasks such as walking and stair climbing, and if there can be improvements in measures of bone health, are all important unresolved questions. We have previously reported mid-point findings from a 2-year (42 weeks of consecutive training in each year, separated by 10 weeks of testing and vacation time) randomized, controlled trial of weight training in 119 healthy males and females aged 60–80 years (McCartney et al., 1995). The present work describes the final results. Measurements included dynamic strength, symptom-limited endurance in cycling, treadmill walking and stair climbing, muscle size, and bone mineral density and content of the lumbar spine and whole body.

METHODS

Subjects

One hundred and ninety-three apparently healthy men and women aged 60–80 years, who had never weight-trained, volunteered for the study. The investigation was approved by the President's Committee on Ethics of Research on Human Subjects, McMaster University, and each subject gave written informed consent to participate. Inclusion in the study was confirmed after the approval of the family physician, and satisfactory completion of a maximum progressive incremental cycle ergometer test to screen for cardiac or pulmonary disease (Jones, 1988). In addition to cardiopulmonary disorders, exclusion criteria included osteoporosis, orthopaedic disability which limited the ability to train, smoking, and a body mass greater than 130% of ideal (Metropolitan Life Insurance Co., 1959). One hundred and forty-two subjects satisfied the inclusion and exclusion criteria and formed the initial study population. The peak oxygen uptake of these subjects during maximum progressive cycle ergometry was 100 ± 20% of that predicted for their age, height, and gender (Jones et al., 1985; see McCartney et al., 1995, for details).

Study Design

The study design required 30 males and 30 females from each of the two decades to be assigned at random to either an exercise or control group. This sample size was calculated based on an expected increase in bone mineral density among the experimental subjects which would yield a between-group difference of .60 of one standard deviation. With an α of .05 and β of .20, the required sample size per group for a onetailed test would be 34 (we deemed it highly improbable that the intervention would have a negative impact on outcome). Thus our two groups of 60 each should have been entirely adequate to detect main effects, even allowing for a dropout rate of 25%. Due to the likelihood of comorbidity in this older population, and to account for nonadherence and dropouts, there were 76 subjects entered into the intervention group compared to 66 controls. Initially, the only subgroup with less than 15 participants was the male controls aged 70–80, in which there were 8 subjects.

The exercise intervention comprised two weight-training sessions per week for 42 consecutive weeks in each of Year 1 and Year 2. The training periods were followed by 2 weeks of performance testing, and in the first year there was an additional 8 weeks of vacation. This design was chosen because many of the subjects took an extended vacation, which could thus be accommodated. We also believed this was more representative of a real-life situation. Subjects were allowed to miss 4 weeks of training in either year for reasons of illness or vacation, and the missed sessions were added at the end. Anyone who did not complete either period of training in a consecutive 11-month period was deemed a dropout. Many control subjects continued to walk on their own, and they were encouraged to pursue normal daily activities without restriction but to refrain from weight training. Tests of dynamic muscular strength, exercise capacity, and body composition were administered to both groups before and after each 42-week intervention period. Tests of strength and exercise performance were repeated in the training group after the 2 months of vacation at the end of Year 1. Subjects did not train during the 2-week intense testing periods due to logistical reasons (in particular that the program staff were involved in various aspects of the testing and could not supervise the exercise sessions).

Training

Weight training was done twice each week, with one or two days of recovery in between sessions. Unilateral military press, leg press, ankle plantarflexion, and bilateral bench press exercises were performed on a multistation weight training machine (Global Gym, Downsview, Ontario). Unilateral arm curls were completed on a custom-built apparatus (Rubicon Industries, Stoney Creek, Ontario), and the ankle dorsiflexors were also trained on another specially made device. Modified abdominal curls were done on a padded board on the floor. The military press was done from a seated position on a high stool. The movement was initiated with the arm flexed and the hand at shoulder level, proceeded to full overhead extension of the arm to lift the weight, and returned to the starting position. Subjects were seated during the leg press maneuver with the back supported and the foot resting on a foot plate. The movement began with the leg flexed and the knee at a 90° angle, proceeded to full extension to raise the weight, and then reassumed the starting position. In the ankle plantarflexion exercise the leg was fully extended with the foot at an initial angle of 90°. The weight was lifted through full plantarflexion and then returned to the starting position. To train the dorsiflexors, subjects were seated in a chair with the foot strapped into a foot plate apparatus designed to rotate in the vertical plane. The initial angle of the foot was 110° (20° of plantarflexion), and the knee joint angle was maintained at 90°. The weight was lifted by full dorsiflexion of the ankle and then returned to the starting position. The bench press was done supine, as a bilateral arm press beginning and ending close to the chest. Exercises were done using a circuit set approach, with 2-min rest intervals between sets; each set comprised either 10 (arms) or 12 (legs) repetitions. Training initially consisted of 2 sets of each exercise at 50% of the one repetition maximum (1 RM) and progressed to 3 sets at 80% of 1 RM after a few weeks. The 1 RM was reassessed at 6-week intervals, and the training loads were adjusted accordingly. After the weights were adjusted, not all of the subjects could initially complete the desired 10 or 12 repetitions, but they could before the weights were adjusted again.

Measurement of Dynamic Strength

Dynamic strength was designated as the heaviest weight that could be lifted once throughout a complete range of movement (1 RM). During testing, the subjects did successive sets of single repetitions with progressively heavier weights until the 1 RM was established. Three-minute rest periods were interspersed between sets to reduce the likelihood of fatigue. The testing was repeated on another day and the greater of the 1 RMs was taken as the pretraining value. On each day the sequence of exercises was selected at random, to obviate any effects of testing order. All tests were administered by the same individual throughout the study. Movements tested were unilateral arm curl, military press and leg press, and bilateral bench press.

Maximum Cycle Ergometry

Peak cycling power output was measured in an incremental progressive test (Jones, 1988) on an electrically braked cycle ergometer (Siemans Elema 370). Initial power output was 100 kpm/min and was increased by the same amount at the end of each minute until exhaustion, or until the subject could no longer maintain a pedaling frequency of 60 rpm. Heart rate was monitored continuously using a 12-lead electrocardiogram (1515-B Automatic Cardiograph, Hewlett Packard), and arterial blood pressure was recorded during alternate workloads by sphygmomanometry. Symptoms of leg effort and dyspnea were rated independently at the end of each minute using the Borg (0–10) scale (Borg, 1982).

Treadmill Endurance

Subjects did 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 criterion for ending the test was not made known to the subjects. During the first 2 minutes the walking speed was 2.0 mph and the elevation was 10%. This was increased to 2.5 mph and 12% grade for mins 2 to 4, and in each additional 2-minute interval the speed remained constant and the grade was increased by a further 2%. Symptoms of leg effort and dyspnea were rated separately at the end of each minute.

Stair Climbing Ergometry

Stair climbing was done on a revolving staircase ergometer (Model 6000, Stairmaster Sports/Medical Products, Newburgh, NY) at a cadence of 55 steps/min. A separate RPE for leg effort and breathing was recorded at the end of each minute, and the test was stopped when a level of 7 (very severe) was reported. During the test, subjects were not allowed to grip the handrail, but one-hand fingertip contact to assist with balance was permitted.

Muscle Cross-sectional Area

Cross-sectional areas of the thigh, and individual constituent muscles, were measured from computerized tomography scans using either a planimetry method (MacDougall et al., 1984) or a semi-automated computer analysis (unpublished). Individual subject data were analyzed with the same technique on both occasions. For the computer analysis, single-slice CT scans were transferred digitally to a network of SUN SPARC stations, and the areas of fat (including blood), muscle, and bone were calculated from determination of their respective Hounsfield densities. Both thighs were scanned together either 10 cm (females) or 12 cm (males) proximal to the superior border of the patella.

Bone Density and Content

Bone mass of the lumbar spine and the whole body was measured using dual photon absorptiometry (^{153}Gd based Norland 2600 dichromatic densitometer). At the lumbar spine, bone mineral density and bone mineral content were calculated for L2, L3, and L4. Whole body (Galea et al., 1990) and regional measurements (Webber, 1989) obtained with this instrument have been shown to be both accurate and precise.

Statistical Analyses

The data were analyzed using a 4-way mixed analysis of variance (ANOVA): a 2 (Age) × 2 (Gender) × 2 (Group) × 3 (Time) design, with repeated measures on the last factor. Two analyses were done. The first included only the subjects who completed the 2-year protocol (efficacy); the second included mid-point data (as final data) for those subjects who dropped out in the second year (effectiveness). The interaction of greatest interest to determine training effects was Group × Time, but significant interactions involving gender and/or age are mentioned where appropriate. The location of specific differences among groups was investigated using the Tukey A procedure. Differences in the profile of the strength gains in each year were investigated using least squares linear regression analysis. Statistical significance was established at $p \leq .05$.

RESULTS

In the first year of the investigation, 23 subjects were lost from the study cohort, as reported previously (McCartney et al., 1995). An additional 6 subjects (5 exercise and 1 control) were lost in Year 2. The reasons for dropout were illness in 4 cases, and moving away from the area (2 subjects). Among those who completed the study, compliance with the training schedule was very high, with a mean attendance of 85%. The majority of results reported here are from the 113 individuals who completed the 2-year program (57 exercise and 56 control). In the 60–70-year-old participants there were 15 exercise and 14 control males, and 14 exercise and 15 control females; the corresponding numbers in the 70–80-year-old subjects were 14, 7, 14, and 20. The effectiveness of the intervention (including mid-point data from the 6 dropouts in Year 2) is also reported.

Weight Training Capacity

In each of the 4 exercises, males were significantly stronger than females, and individuals in the older decade were weaker than the younger subjects; however, within each gender there were no significant differences in 1 RM at baseline associated with age (Figures 1–4).

There was no change in the 1 RMs of the control subjects over the 2-year period, but the training group (collapsed across age and gender) demonstrated substantial gains (85%, 90%, 53%, and 32% in the arm curl, military press, bench press, and leg press, respectively; group × time × $p < .0005$; Figures 1–5). Among the female exercisers there was no effect of age on the response to training, but the younger males progressed beyond their older counterparts at various times during the first year and remained higher thereafter (Figures 1–4). Following the 2-month layoff at the end of Year 1 there was an overall decrease in 1 RM strength of 8% (range from 4.3% in the leg press to 10.1% in the arm curl), with slightly greater losses in the older subjects (7% in the younger decade vs 9.2% in the older). This mid-point reduction in strength resulted in the proportion of the total change (over 94 weeks) that occurred in each year being quite similar (63% in Year 1 vs 61% in Year 2; Figure 6). Within each exercise, linear regression analysis revealed no difference in the slopes of the relative increase in either year (Figure 5), and the values for r^2 ranged from .90 to .98.

An analysis which included the mid-point measurements from the 6 dropouts in Year 2 as final data yielded the same result; the increases in 1 RM were highly significant compared to control values.

Maximum Cycle Ergometry

Overall, the maximum power output of males was 70–80% greater than the females and there was a lesser, but significant, inverse relation to age ($p < .0005$). Nevertheless, there were no independent effects of age or gender on the response to training. The performance of the control group did not change during the 2 years; however, the small increase which occurred in Year 1, and was then maintained, in the weight-trained subjects resulted in significant differences between the groups (Group × Time $p = .045$; Figure 7). Repeat testing did not take place after the 2-month layoff due to logistical problems. Once the mid-point data from the 6 dropouts in Year 2 were included in the analysis, the Group × Time interaction was no longer significant ($p = .072$).

Treadmill Walking

Overall, the mean treadmill time for males (18.1 min) was 53% greater than for females (11.8 min), but there was no effect of age ($p = .16$). There was no change in the performance of control subjects over the 2 years, but the exercise group improved significantly by the end of the

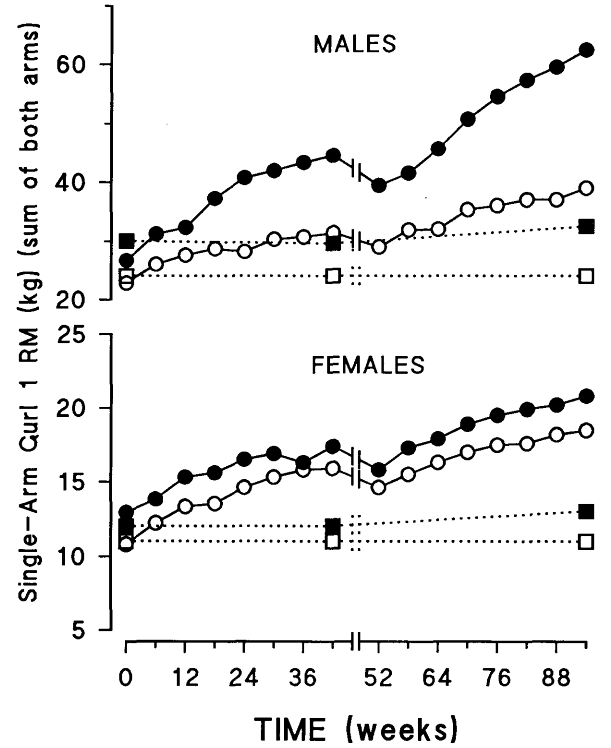

Figure 1. Single-arm curl 1 RM in exercising (circles) and control (squares) 60–70-year-old (filled symbols) and 70–80-year-old (open symbols) males and females.

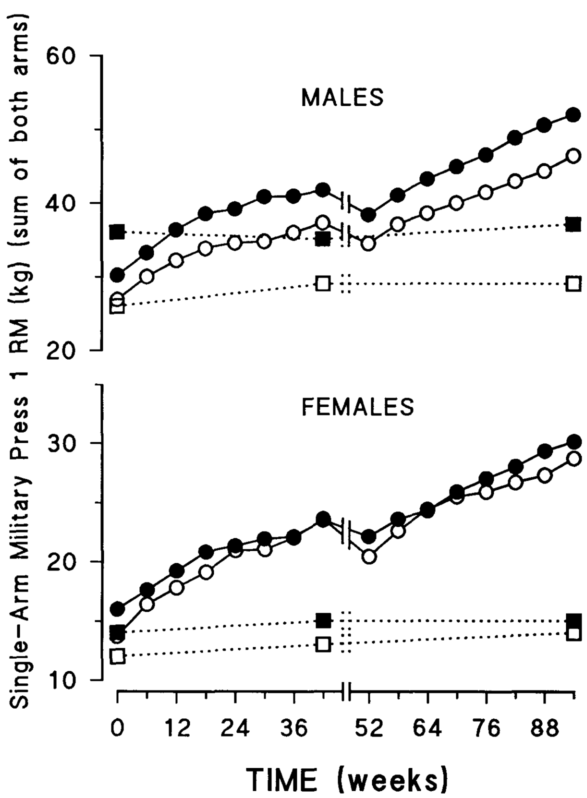

Figure 2. Single-arm military press 1 RM in exercising (circles) and control (squares) 60–70-year-old (filled symbols) and 70–80-year-old (open symbols) males and females.

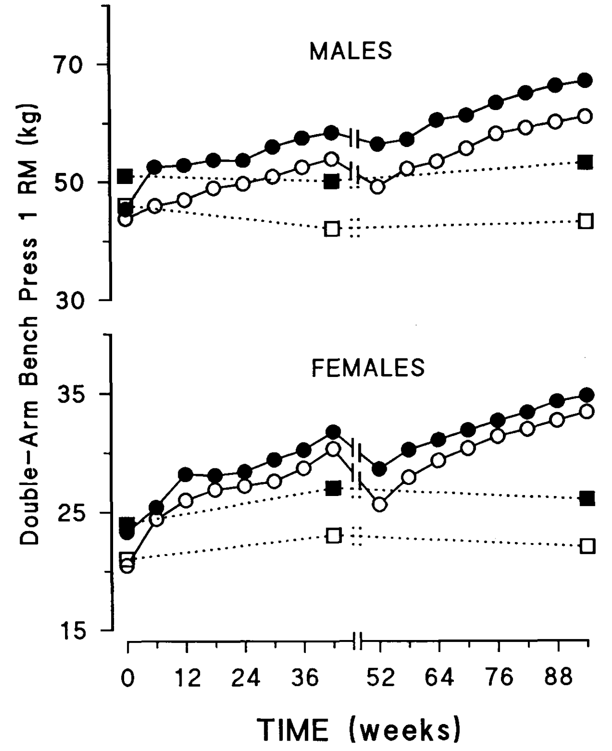

Figure 3. Double-arm bench press 1 RM in exercising (circles) and control (squares) 60–70-year-old (filled symbols) and 70–80-year-old (open symbols) males and females.

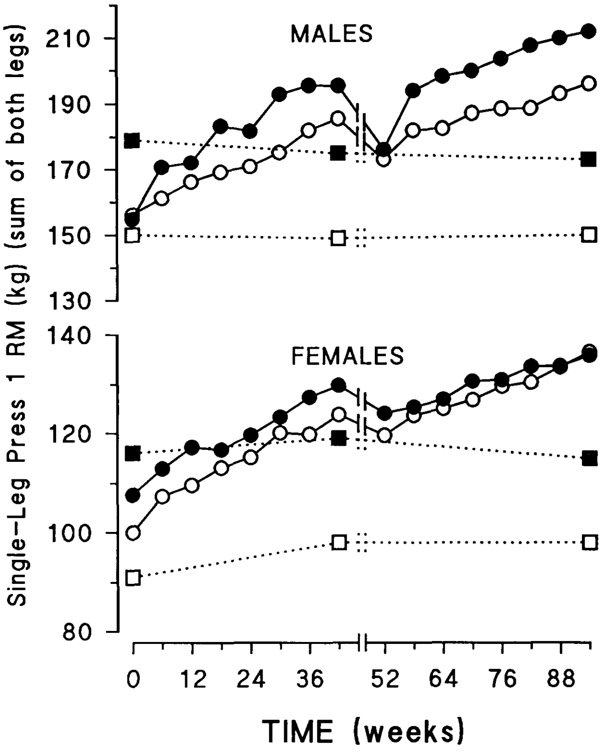

Figure 4. Single-leg press 1 RM in exercising (circles) and control (squares) 60–70-year-old (filled symbols) and 70–80-year-old (open symbols) males and females.

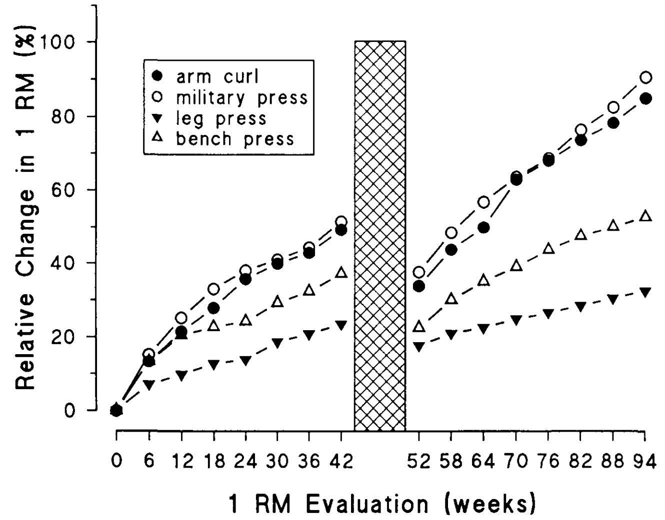

Figure 5. Relative (%) increases in 1 RMs among resistance-trained subjects in each year of training.

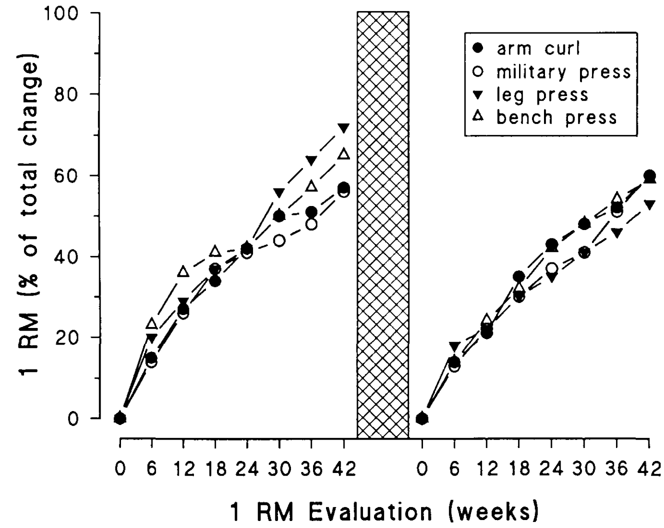

Figure 6. The proportion of the total relative change in 1 RMs occurring in each year.

second year (Group × Time $p = .043$; Figure 7). There were no independent effects of age or gender on the response to training. Losses in treadmill endurance during the 2-month layoff at the end of Year 1 amounted to only 3% in the males and 5% in the females. An analysis that included dropout data confirmed the effectiveness of the intervention (Group × Time $p = .035$).

Stair Climbing

The stair-climbing endurance of the males was more than twice that of the females at the time of initial testing (589 vs 241s), and this difference widened over the 2-year intervention period (904 vs 278s; Gender × Time $p < .0005$). The reason for the Gender × Time interaction was a greater increase among the male exercisers, and an unexplained

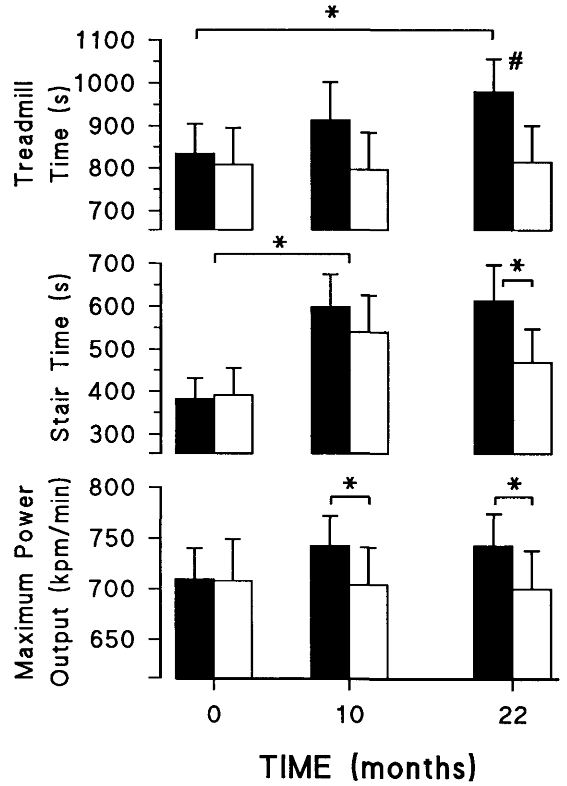

Figure 7. Change in treadmill and stair climbing symptom-limited endurance, and maximum cycling power output in resistance-trained (filled bars) and control subjects (open bars). *$p < .05$; # significantly different from all control values.

53% increase in the younger male controls. After the first year there was a significant 56% increase in stair-climbing endurance among the resistance-trained subjects, less than a 7% reduction during the 2 months of inactivity, and 57% overall improvement from baseline by the end of Year 2. The control subjects also improved by 33% in the first year, but this was reduced to 14% at the end of the study (Figure 7). Including dropout data in the final analysis did not detract from the effectiveness of the intervention (Group × Time $p = .034$).

Muscle Cross-sectional Area

At baseline the cross-sectional area of the knee extensors was significantly greater in males than females ($p < .0005$), and was inversely related to age group ($p = .016$). Training resulted in an overall increase in cross-sectional area of 8.7%, almost two thirds occurring by the end of Year 1; control values remained similar throughout the study (Figure 8). Age did not affect the training response, and although the absolute gains among female exercisers were less than 60% of those among the males, the Gender × Group × Time interaction did not attain significance ($p = .068$). When expressed as relative (%) change there was no difference between the genders. Analysis that included dropout data confirmed the effectiveness of the training program (Group × Time $p < .0005$), and also indicated greater gains in males vs females (Gender × Group × Time $p = .028$).

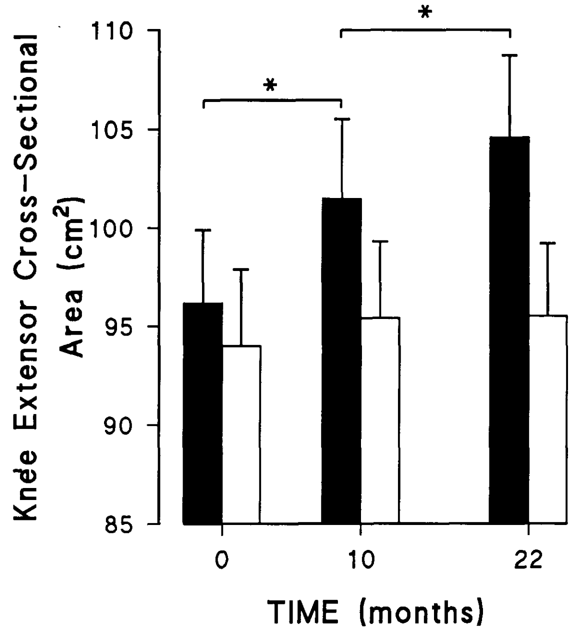

Figure 8. Change in knee extensor cross-sectional area in resistance-trained (filled bars) and control subjects (open bars). $*p < .05$.

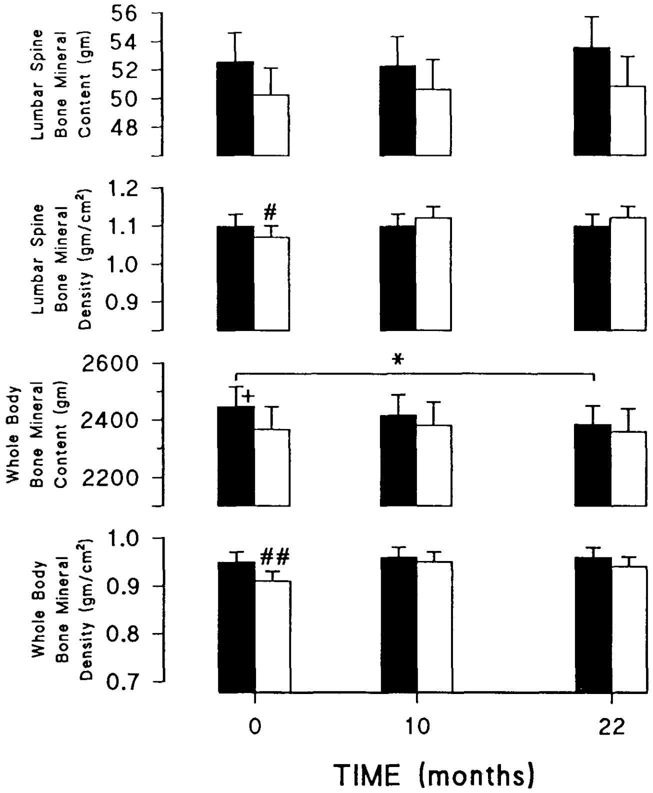

Figure 9. Lumbar spine and whole body bone mineral density and content in resistance-trained (solid bars) and control subjects (open bars). $*p < .05$; + significantly greater than all control values; # significantly different from other 2 control values; ## significantly different from all exercise and other control values.

Bone Mineral Density and Content

At the time of baseline testing the bone mineral density and content of the whole body, and the lumbar spine, were higher in males than in females ($p < .0005$) and decreased with age. After the intervention there were significant Group × Time interactions ($p < .01$) for both measures of bone mineral density and for total body bone mineral. Post hoc analysis of the bone mineral density data revealed significant increases among control subjects during the first year and no change in the resistance-trained subjects. The whole body bone mineral content measured at the start of the study was greater in the exercise group than any other value recorded during the 2 years. This initial high value was reduced significantly by the end of Year 2 (Figure 9). Although these findings were statistically significant, the absolute differences between groups were small (the exercise and control groups changed by +1.6% and +3.6% in whole body bone mineral density, −1.0% and +1.1% in total body bone mineral, +0.9% and +3.8% in lumbar spine bone mineral density, respectively). An analysis which included the mid-point data from the second-year dropouts yielded the same findings.

DISCUSSION

This study demonstrated that long-term weight training in older men and women resulted in large increases in dynamic strength, with associated improvements in laboratory tests of cycling, walking, and stair climbing. The intervention promoted progressive muscle hypertrophy but did not effect increases in whole body, or lumbar spine bone mineral density and content.

Adherence, Dropout and Injury

We previously reported (McCartney et al., 1995) that 16/135 subjects (12%) who progressed beyond the pretesting were classified as dropouts during the first year of the study. The six additional dropouts in Year 2 yielded an overall completion rate of 84%, which is substantially higher than in many other studies of elderly subjects undergoing exercise training programs (Morey et al., 1989, 1991; McMurdo and Burnett, 1992). The high attendance rate of 85% also attests to the acceptable nature of weight training as an intervention in older subjects. It is possible that the reduced training frequency of twice per week, compared to the usual regimen of 3 times each week in many studies, was an important factor underlying the high completion and attendance rates.

The reduced frequency of training may also have contributed to the lack of musculoskeletal injuries. The extent of "injury" that we noted was when an individual subject may not have completed a given exercise for one or two sessions due to muscle or joint soreness, but there were no long-term problems.

Dynamic Muscle Strength and Muscle Size

Most published investigations of weight training in older subjects have been less than 16 weeks in duration, have conducted training thrice weekly, and included relatively small sample sizes of predominantly males. From some of these studies it is now established that short-term, progressive weight training in the elderly results in large increases in dynamic strength in addition to notable muscle hypertrophy (Frontera et al., 1988; Brown et al., 1990; Charette et al., 1991). Nevertheless, the pattern of strength gains has not been investigated extensively and the results are equivocal. In general, the greatest rate of strength gain is during the first few weeks of training, and this has been ascribed to one or more neural adaptations rather than significant muscle hypertrophy (Rutherford and Jones, 1986; Sale, 1988). Thereafter, strength has either continued to increase (Frontera et al., 1988; Fiatarone et al., 1990) or to demonstrate a plateau (Hakkinen and Pakarinen, 1994; Nichols et al., 1995).

In a previous report describing our findings after 10 months of training (McCartney et al., 1995), we noted that 30% of the increase in 1 RM had occurred by 6 weeks and almost half was evident by 12 weeks (30% of the training time), but there was no defined plateau. The present study extends these observations to 94 weeks, and still there was no evidence of a plateau in the strength gains. Indeed, the proportion of the total change (over the entire 94-week intervention period) in each year (63% vs 61%) was almost identical (Figure 6). One possible explanation for the apparent plateau in other short-term studies could be that the slowing of strength gains was actually a transient phase, and strength may have continued to increase if the subjects had been followed for longer. This cannot account for the findings of Pyka and colleagues (1994), however, who trained 4 male and 4 female subjects for one year and noted approximately 60% of the strength gains after just 8 weeks. Perhaps other methodological factors such as differences in sample sizes, or a training frequency of twice weekly in our study compared to 3 times a week in the study by Pyka et al. (1994), may have contributed to the difference. In any event, it is encouraging to note that even after 2 years of twice weekly weight training strength was still increasing in our subjects, and thus they had not yet realized their maximum strength potential. This pattern of adaptation suggests that ongoing weight training in the elderly may be an excellent method of counteracting the losses in strength normally associated with aging. Such improvements may be very important. For example, Young (1986) has suggested that a 10 to 20% increase in quadriceps muscle strength among the elderly may serve to delay the threshold for dependency by one or two decades.

Our data also extend the observations from short-term studies on the effects of age and gender. Although at the time of baseline testing dynamic strength was greater among the males and the younger subjects, men and women of both decades were similarly responsive to training. Within each age group, the female to male ratio of mean 1 RM capacity during the initial evaluation was approximately 0.5 to 0.6 for arm exercises, and 0.6 to 0.7 for the leg press. These ratios were unchanged at the end of each year except in the case of the single-arm curl exercise, where the ratio of female to male 1 RM decreased from .50 to .34 in the 60- to 70-year-old subjects by the end of Year 2; we are unable to account for the greater improvement shown by the males. Similarly, the increase in the single-arm curl 1 RMs of the younger men was greater than in their older male counterparts. Other than these two exceptions, the training responses of men and women of both decades were comparable. It appears that this similar responsiveness to weight training may even extend to the 10th decade of life (Fiatarone et al., 1990).

In cross-sectional studies strength declines by 10 to 15% per decade after the age of 60 years (Doherty and Vandervoort, 1993). This being the case, we might have expected a 2 to 3% reduction in 1 RM among our control subjects. The fact that there was no reduction after 2 years, even in the older subjects, suggests that caution be advised in the interpretation of cross-sectional data.

Another important observation was that following the 2-month layoff at the end of Year 1 there was an overall decrease in 1 RM strength of only 8%. The losses in leg press 1 RM were less than half those seen in the arms, perhaps because of the relatively greater use of the legs in everyday activities. These small reductions in dynamic strength are appreciably less than the 32% loss in quadriceps strength reported by Fiatarone et al. (1990) after only 4 weeks of detraining. The physical frailty and advanced age of the subjects (mean age 90 years), and the brief training period (8 weeks) in the study by Fiatarone and colleagues (1990) may account for the differences.

While the initial, rapid gains in strength with weight training may be related to neural mechanisms, later improvements are generally believed to be more dependent on muscle hypertrophy (McDonagh and Davies, 1984; Rutherford and Jones, 1986; Sale, 1988). In this study we noted significantly increased cross-sectional areas of the knee extensors in each year of training, which would be consistent with continued muscle hypertrophy. Nevertheless, the 8.7% mean increase in knee extensor cross-sectional areas was appreciably less than the 32% increase in leg press 1 RM. This suggests that neural adaptations such as learning, and improved coordination, may have contributed significantly to the gains in dynamic strength, even over such a long period of training. We suggest that long-term weight training may also be an effective method to ameliorate the reductions in lean tissue mass that are commonly present in the elderly.

Cycling, Treadmill Walking, and Stair Climbing

The strength-trained subjects showed overall improvements in each of the endurance tasks, compared to only a mid-point temporary increase in stair-climbing performance among the controls. Thus, an added benefit of weight training in the elderly may be increased endurance in functional tasks involving the trained muscles. These data both confirm, and extend, previous observations from short-term training studies in the very old (Fiatarone et al., 1990, 1994), in patients with coronary artery disease (Kelemen et al., 1986; McCartney et al., 1991), and those with obstructive lung disease (Simpson et al., 1992). The mechanism(s) responsible for the increased endurance has not been identified. One plausible explanation is that stronger muscles may generate a given force more easily, resulting in a reduced perception of effort; when exercise is perceived as less demanding it can be tolerated for longer (Killian, 1988). As the treadmill and stair-climbing tests in our study were stopped when the subjects reported a Borg (1–10) rating of perceived exertion of 7 (very severe), our data support this hypothesis, i.e., the subjects could exercise for a longer time before symptoms of effort became limiting.

Bone Mineral Density and Content

Whether exercise training can make a significant contribution to bone mineral density and content seems equivocal (Gutin and Kasper, 1992). Cross-sectional data often suggest positive, potentially causal associations between muscle strength, muscle mass, and bone mineral density (Bevier et al., 1989; Snow-Harter et al., 1990, 1992). As discussed by Gutin and Kasper (1992), however, the issue of self-selection in cross-sectional studies prevents any definite conclusions about causation. Prospective training studies in older individuals have produced more variable results. Weight-bearing (Dalsky et al., 1988) and walking (Nelson et al., 1991) programs have been associated with improved bone mineral density of the spine in postmenopausal women. Strength training programs have resulted in either modest improvements (Ayalon et al., 1987; Gleeson et al., 1990; Nelson et al., 1994), no change (Nichols et al., 1995), or even a decrease in bone mineral density (Rockwell et al., 1990).

One common feature in most of the studies that demonstrated improvements in bone mineral density was a study population of previously sedentary subjects. In the present investigation the participants were healthy, reasonably active volunteer subjects, although none had ever taken part in weight training. Perhaps it was for this reason that there was no improvement in either bone mineral density or content after 2 years of training. A nonsedentary study population was suggested as the possible cause of null findings in a recent 12-month weight-training study in older women (Nichols et al., 1995). On the other hand, there were small but statistically significant increases in both whole body and lumbar spine bone mineral density among our control subjects, similar to the findings of Rockwell and colleagues (1990). This result is difficult to explain. It may be due to the dual photon measuring technique, but any problems associated with the method would have been common to both the intervention and control groups. Nevertheless, we cannot discount the possibility that a more precise measurement technique, such as dual x-ray absorptiometry (DEXA), may have yielded different findings. Nor can we ignore the likelihood that there may have been site-specific changes as a result of the training program which we did not detect. Perhaps, as suggested by Gutin and Kasper (1992), weight training alone may be an insufficient osteogenic stimulus, and programs designed to improve bone health should also include a significant component of aerobic, weight-bearing activities.

Efficacy and Effectiveness

Efficacy is established when a positive outcome is evident in those who comply with the intervention. As already discussed, this was clearly established in the present study for all measures except those relating to bone. If an intervention has high efficacy but few subjects complete the requirements, then it is likely to be ineffective; that is, when the most recent data from dropouts are included, the results are no longer significant, and thus it is a poor strategy to adopt in any given population. We tested the effectiveness of our weight-training program by including the mid-point data from the second-year dropouts in a separate final analysis. Including those data made no difference to the significance attached to any outcome measure except the cycle ergometry, so we conclude that long-term, supervised weight training in the elderly is a suitable program for widespread adoption.

In summary, we have presented the findings from the largest and longest duration, prospective randomized trial of weight training in elderly men and women. After two 42-week periods of twice-weekly training during a 2-year period, dynamic strength was still increasing in our subjects. Increased strength was associated with muscle hypertrophy in each year, and with increased endurance in cycling, walking, and stair climbing. There was a significant, 1% decrease in whole body bone mineral content among the training group, and increases in bone mineral density only among the control subjects. We conclude that weight training is an appropriate mode of exercise for elderly men and women, with significant potential to help extend the years of independent living.

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