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# Maintenance of Whole Muscle Strength and Size Following Resistance Training in Older Men

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Following a progressive resistance training (PRT) program of 3 days per week, we sought to examine how effective a resistance training maintenance program of 1 day per week would be to preserve muscle strength and size in older men. Each subject's whole muscle strength (1 repetition maximum, or 1RM) and whole muscle size (determined by computed tomography scan) were measured before (T1) and after (T2) 12 weeks of PRT and again following 6 months (T3) of training (TR) or detraining (DT). During the 12-week PRT, older men ($N = 10$; age 70 ± 4 years) trained their knee extensors 3 days per week at 80% of their 1RM. The maintenance program consisted of older men ($n = 5$; TR; 75 ± 1 years) who completed 3 sets of 10 repetitions at 80% of their 1RM 1 day per week (this was equivalent to a single training session that was performed 3 days per week during the 12-week PRT). The other group of older men ($n = 5$; DT; 69 ± 1 years) resumed their normal lifestyle (no regular physical activity) following the 12-week PRT. From T1 to T2, muscle strength increased ($p < .05$) 45% (66 ± 10 to 94 ± 10 kg) in the TR group and 53% (50 ± 6 to 74 ± 7 kg) in the DT group. From T2 to T3, whole muscle strength of the TR group was unchanged (96 ± 11 kg), whereas strength decreased ($p < .05$) in the DT group by 11% (66 ± 6 kg). Muscle size demonstrated a similar pattern with a 7% increase ($p < .05$) in both groups from T1 to T2. No change in muscle size was found in the TR group from T2 to T3, whereas the DT group had a 5% reduction ($p < .05$). These data indicate that resistance training 1 day per week was sufficient to maintain muscle strength and size in these older men following a 12-week PRT program. Furthermore, the men who resumed their normal lifestyle (no regular physical activity) experienced significant losses in muscle strength and size.

PRESERVING muscle strength and size with aging has become a critical issue for older adults attempting to maintain independent living and quality of life (1). Several resistance training studies in older men and women have proven effective in reversing sarcopenia-related problems (2–5). Most of these investigations have been 2–6 months in duration, with the resistance training occurring 2 to 3 days per week, and they have been successful for promoting muscle hypertrophy and strength (2–5). Of practical importance for the elderly and health care communities is how much (or little) training is necessary to maintain skeletal muscle function and size. Minimizing the frequency and time commitment may lead to increased participation of older adults engaging in resistance training types of activities.

The intent of this investigation was to determine if high-intensity resistance training performed once per week would be sufficient to maintain skeletal muscle strength and size in older men following resistance training. This once a week program was implemented for 6 months following a 12-week progressive resistance training (PRT) program with exercise sessions performed 3 days per week. We hypothesized that (i) the skeletal muscle strength gains achieved during the 12-week PRT program would be maintained by resistance training once per week, (ii) skeletal muscle size (as determined from computed tomography) increases with the 12-week PRT would be maintained by resistance training once per day, and (iii) both skeletal muscle strength and size would be significantly reduced when the subjects returned to their normal free-living lifestyles.

## Methods

### *Experimental Design*

All subjects underwent a health history questionnaire and physical exam (see the following subsection) prior to being admitted into the investigation. Following physician clearance, all subjects ($N = 10$) engaged in a 12-week PRT program. After the PRT program, the volunteers were divided into two groups. Group 1 (trained, or TR; $n = 5$) performed strength training 1 day per week. Group 2 (detrained, or DT; $n = 5$) returned to a free-living lifestyle (similar to that before PRT) with no regular physical activity. All volunteers were evaluated for one-repetition maximum (1RM) leg strength and whole muscle size (computed tomography) before any resistance training was performed (T1), following 12 weeks of PRT (T2), and after 6 months of free-living or resistance training 1 day per week (T3).

*Subjects*

Ten older male adults participated in this investigation. Their age, height, and mass are shown in Table 1. Each participant underwent a thorough physical examination, which included a medical history, resting and exercise electrocardiogram, blood pressure, and orthopedic evaluation prior to initiation of the resistance training program. These volunteers were nonobese (less than 28 $kg/m^2$), normotensive, nonsmokers, nonmedicated, and healthy as judged by a physical examination. The volunteers were sedentary and had not performed resistance training for at least 1 year prior to this study. The experimental protocol was approved by the Human Research Committees of Ball State University and Ball Memorial Hospital prior to data collection.

Subject selection for the groups was based upon two main criteria: (a) willingness to participate in the PRT program and the maintenance resistance training program, and (b) availability to come to the laboratory for 9 months. The latter proved to be the greater limitation because of the travel schedules of some of the volunteers (some of our volunteers moved south for the winter). As a result, all subjects participated in the 12-week PRT program, but some of the subjects were in the DT group by default as a result of their travel schedules.

*Resistance Training Program*

All volunteers performed a 12-week PRT program designed to strengthen the quadriceps femoris muscle group (3,5,6). This PRT program consisted of bilateral isotonic leg extension at 80% of their concentric 1RM leg extension. Subjects raised the weight using 2- to 3-second interval and used this same interval for lowering the weight. The 1RM was reevaluated every 2 weeks and the weight adjusted accordingly to ensure that intensity was maintained at 80%. Subjects performed the PRT 3 days per week (for a total of 36 training sessions) with at least 24–48 hours between training sessions. Each training session consisted of 2 sets of 10 repetitions and a third set to failure. There was a 2-minute rest period between each set. Each PRT session was preceded by a warmup and cooldown period of 10 minutes of stationary cycling at low resistance (50 W) and slow speed, as well as stretching of the muscle groups involved in the strength measurements.

*Maintenance Program*

Following the 12-week PRT program, the TR group continued resistance training. However, the resistance training sessions were reduced to 1 day per week. The maintenance program had the volunteers complete 3 sets of 10 repetitions at 80% of the 1RM (this was equivalent to a single training session that was performed 3 days per week during the 12-week PRT). Once every 4 weeks, the 1RM was reassessed.

Table 1. Subject Characteristics for the TR and DT Groups

| Group | Age (y) | Height (cm) | Weight (kg) T1 | Weight (kg) T2 | Weight (kg) T3 |
|---|---|---|---|---|---|
| TR ($n$ = 5) | 75 ± 1 | 175 ± 3 | 74.1 ± 3.3 | 73.5 ± 3.5 | 70.8 ± 4.0 |
| DT ($n$ = 5) | 69 ± 1 | 183 ± 5 | 88.1 ± 7.2* | 88.8 ± 7.2* | 88.1 ± 7.7* |

*Notes*: Body weights are shown for all three testing sessions. TR = trained; DT = detrained; T1 and T2 = before and after the 12-wk progressive training program, respectively; T3 = 6 mo after the program (maintenance or detraining phase).

*$p < .05$ between groups.

*1RM*

Whole muscle strength was assessed by using a bilateral isotonic knee extensor device (Cybex Eagle, New York, NY). The resistance was increased in 2.6-kg to 5.2-kg increments, until the subject was unable to lift the load to full knee extension or maintain lower back stability against the back pad on the knee extensor device. The amount lifted with the above criteria was recorded as the 1RM. Three minutes was allotted between 1RM attempts. This evaluation was T1; every 2 weeks during the 12-week progressive strength-training program, T2, once a month during the maintenance phase (TR group only), and T3. Each testing session was supervised (one on one) by a member of the investigative team.

*Maximal Voluntary Contraction*

Unilateral maximal voluntary isometric strength of the right knee extensor was evaluated by using a Cybex 340 Dynamometer (Ronkonkama, NY). While seated (85° hip flexion), each volunteer applied force to a cushioned lever arm positioned anteriorly on the ankle. The axis of the dynamometer lever arm was aligned with the knee joint axis. Restraints were applied on the thigh, lower leg (proximal to the right lateral malleolus), pelvis, and shoulders. Range of motion was individually determined with full knee extension (~0°) and flexion (~110°). A gravity correction factor was calculated by the instrumentation to account for leg mass and weight of the lever arm.

Maximal torque was measured with each subject's knee angle fixed at 60° (with neutral representing 90°). Each subject performed two maximal voluntary contractions (MVCs), with the subject applying as much torque as possible for 5 seconds at the test angle. Two trials were performed for each maximal effort with the best effort for the maximal test being utilized for analysis. Coefficient of variation for MVC measurements in these older men in our laboratory was 2.2%.

*Whole Muscle Size (Computed Tomography)*

Whole muscle cross-sectional area (CSA) of the right thigh was determined by using computed tomography (CT) (CTI helical scanner, General Electric, Milwaukee, WI). The circumference of the anatomical midpoint of the femur was used as the point of the CT measurement. Subjects were supine with the legs in an anatomical position for 15 minutes prior to any scanning to minimize the influence of fluid shifts on the CSA measurement (7). An initial lower body scout scan of the right leg was taken to determine the length of the femur from the top of the greater trochanter to the articular surface of the tibia at an angle of 0° (using a computer software interface). From this established femur length, the halfway point was used for the acquisition of the actual scan. These values were recorded by the technician and used during the T2 and T3 measurements to ensure that the measured femur length from the T1 session was consistent across all time points. The scan width was set at 5 mm with an exposure time of 3 seconds. The image and its associated scale were then printed on a standard imaging transparency and were transferred to a computer by using a flatbed scanner. The CSA of the thigh minus the area of the bone and subcutaneous fat was determined by using computerized planimetry (NIH Image Program v. 1.61, National Institutes of Health, Bethesda, MD). To help ensure the accuracy of the CT measurement, bone area was analyzed and recorded for all subjects (T1, T2, and T3). This allowed us to objectively ascertain the before to after location on the right thigh. Our results indicated that there was less than 0.1% difference in the bone area between the two scans. This was under the assumption that there was no change in bone size as reported by others (8). The CSA measurements were utilized in conjunction with the MVC measurement (torque/CSA) to estimate a specific tension (ST) of the musculature involved. The CT scans were made on each subject before any strength testing measurements were performed. Each CT scan analysis was blinded to the investigator performing the measurements.

### *Statistical Analysis*

Differences in muscle strength (1RM and MVC), muscle size (CT scan), and ST were examined by using a general linear model (analysis of variance) with repeated measures (SPSS v. 10.0.1, Chicago, IL). The dependent variables (1RM, MVC, CT scan, and ST) for both groups (TR and DT) were compared over the three time points (T1, T2, and T3). A Bonferroni post hoc test was used to assess differences found with the repeated measures analysis. Significance for all statistical procedures was set at the $p < .05$ level. All data are reported as means ± standard error.

## Results

### *Whole Muscle Strength (1RM)*

The 1RM knee extensor strengths for T1, T2, and T3 are shown in Table 2. From T1 to T2 there was an increase ($p < .05$) of 53% and 45% for the DT and TR groups, respectively. Six months after the training program (T3), the 1RM for the DT group decreased ($p < .05$), on average 11%. In contrast, the TR group maintained its 1RM strength over the 6 months of resistance training 1 day per week.

Figure 1 shows the progression in strength gains (1RM) for both groups (TR and DT) every 2 weeks during the 12-week PRT program and 6 months (36 weeks) after the PRT program. No differences were observed between groups from baseline (week 0) through the end of PRT (week 12). However, after 6 months the DT group declined ($p < .05$) compared with the TR group, which was unchanged.

### *MVC*

MVC measurements followed a similar pattern as the 1RM data for both groups. The DT group improved ($p < .05$) MVC 25% from 148 ± 14 N m to 186 ± 22 N m with the 12-week PRT program. Following 6 months (T3) of no resistance training, MVC declined 9% from after PRT to 169 ± 20 N m. Similarly, the TR group increased ($p < .05$) MVC 20% from 185 ± 18 N m to 221 ± 22 N m with the PRT program. However, 1 day per week of resistance training for 6 months (T3) was sufficient to maintain MVC (226 ± 28 N m) in the TR men.

Table 2. 1RM Knee Extensor Strength for T1, T2, and T3

| Subject | T1 | T2 | T3 | %Δ T1 vs T2 | %Δ T2 vs T3 |
|---|---|---|---|---|---|
| Detraining | | | | | |
| A | 28.8 | 54.6 | 48.9 | 90.0 | −10.5 |
| B | 57.5 | 86.3 | 80.5 | 50.0 | −6.7 |
| C | 54.6 | 86.3 | 74.7 | 57.9 | −13.3 |
| D | 46.0 | 63.3 | 57.5 | 37.5 | −9.1 |
| E | 63.3 | 80.5 | 69.0 | 27.3 | −14.3 |
| Mean | 50.0 | 74.2* | 66.1*,** | 52.5 | −10.8 |
| *SE* | 6.0 | 6.5 | 5.8 | 10.7 | 1.4 |
| Training | | | | | |
| F | 69.0 | 106.4 | 109.3 | 54.2 | 2.7 |
| G | 46.0 | 77.6 | 80.5 | 75.0 | 0.0 |
| H | 63.3 | 94.9 | 97.8 | 54.6 | 0.0 |
| I | 100.6 | 120.8 | 129.4 | 20.0 | 7.1 |
| J | 51.8 | 63.3 | 63.3 | 22.2 | 0.0 |
| Mean | 66.1 | 93.7* | 96.0* | 45.2 | 2.0 |
| *SE* | 9.5 | 10.0 | 11.4 | 10.5 | 1.4 |

*Note*: T1 and T2 = before and after the 12-wk progressive training program, respectively; T3 = 6 mo after the program; 1RM = one repetition maximum; *SE* = standard error.

*$p < .05$ compared with T1; **$p < .05$ compared with T2.

### *Whole Muscle Size*

Whole muscle size of the right midthigh is shown in Table 3. With the 12-week PRT program, the DT and TR groups had a 6.5% and 7.4% increase ($p < .05$), respectively, in muscle size. Following 6 months of no resistance training, the DT group had a 5% decline ($p < .05$) in muscle size. The TR group had no change in muscle size from the T2 to T3 measurement.

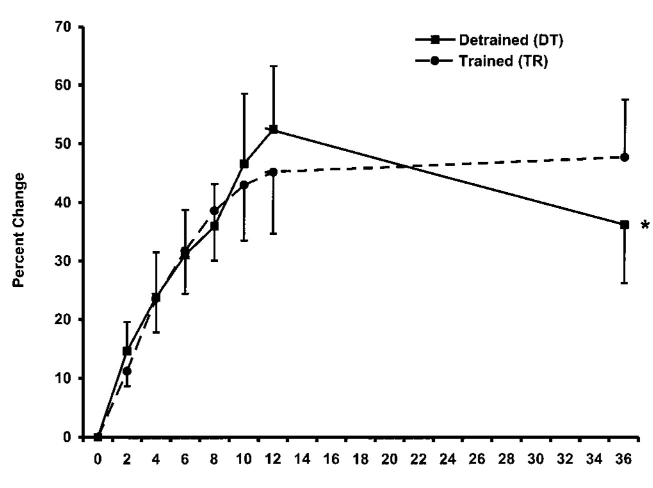


Figure 1. Rate of progression in one-repetition maximum (1RM) knee extensor strength every 2 weeks during the 12-week progressive resistance training program and at week 36 (6 months after the 12-week program). The statistical difference in 1RM strength was based on absolute values; *$p < .05$ from week 12 to week 36.

Table 3. Whole Muscle Size of the Right Thigh as Determined From CT for T1, T2, and T3

| Subject | T1 | T2 | T3 | %Δ T1 vs T2 | %Δ T2 vs T3 |
|---|---|---|---|---|---|
| Detraining | | | | | |
| A | 105.9 | 116.5 | 108.5 | 10.1 | −6.9 |
| B | 124.6 | 134.0 | 127.1 | 7.5 | −5.1 |
| C | 160.7 | 167.1 | 159.1 | 4.0 | −4.8 |
| D | 107.0 | 111.3 | 108.9 | 4.1 | −2.2 |
| E | 135.3 | 144.8 | 136.1 | 7.0 | −6.0 |
| Mean | 126.7 | 134.8* | 127.9** | 6.5 | −5.0 |
| *SE* | 10.2 | 10.1 | 9.4 | 1.1 | 0.8 |
| Training | | | | | |
| F | 133.9 | 142.9 | 142.2 | 6.7 | −0.5 |
| G | 142.8 | 148.8 | 148.0 | 4.2 | −0.5 |
| H | 141.6 | 160.2 | 153.8 | 13.1 | −3.9 |
| I | 175.2 | 177.3 | 179.2 | 1.2 | 1.1 |
| J | 115.5 | 129.1 | 129.5 | 11.8 | 0.3 |
| Mean | 141.8 | 151.6* | 150.5* | 7.4 | −0.7 |
| *SE* | 9.7 | 8.1 | 8.2 | 2.3 | 0.9 |

*Notes*: Whole muscle size is in cubic centimeters. CT = computed tomography; T1 and T2 = before and after the 12-wk progressive training program, respectively; T3 = 6 mo after the program; *SE* = standard error.

*$p < .05$ compared with T1; **$p < .05$ compared with T2.

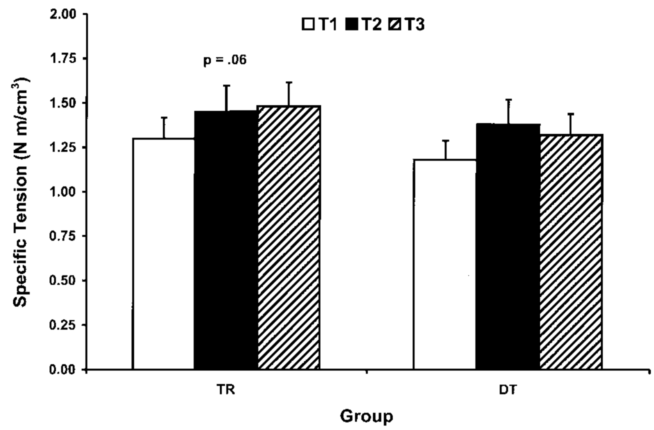


Figure 2. Whole muscle specific tension, i.e., knee extensor maximal voluntary contraction and cross-sectional area measurements (torque/cross-sectional area) to estimate a specific tension, before the 12-week progressive resistance training program (T1), after the 12-week program (T2), and following 6 months (T3) of training 1 day per week (trained, or TR) or no training (detrained or DT); *$p < .05$ from T1.

### *ST*

The ST of the right knee extensors for T1, T2, and T3 are shown for both groups (DT and TR) in Figure 2. The DT men improved ($p < .05$) ST by 17% from T1 to T2 (1.18 ± 0.12 to 1.38 ± 0.14 N m/cm$^3$). This remained unchanged from T2 to T3 (T3 = 1.32 ± 0.13 N m/cm$^3$; −4%). The TR men improved ($p = .06$) ST 11% from 1.30 ± 0.07 to 1.45 ± 0.09 N m/cm$^3$ from T1 to T2. As with the DT men, the RT men's ST was unchanged from T2 to T3 (1.48 ± 0.11 N m/cm$^3$; +2%). It should be pointed out that the small number of subjects ($n = 5$ per group) and the relatively small changes in ST limited the statistical power and contributed to the nonstatistical significance in the TR group.

## Discussion

The goal of this project was to determine if resistance training 1 day per week for 6 months was sufficient to maintain skeletal muscle strength and size following a 12-week PRT program. To test this hypothesis, we resistance trained 10 older men 3 days per week and then divided them into two equal groups, one that returned to their normal, free-living lifestyle, and one that participated in resistance training 1 day per week for 6 months. The main findings from this study were that 6 months after the 12-week PRT, the men who resistance trained once per week were able to maintain the muscle strength and size gained during the 12-week PRT program. Conversely, the men who did not perform any resistance training activities for the 6 months following the 12-week PRT program had a significant decline in their thigh muscle strength and size.

Our findings of an ∼50% increase of 1RM strength during the initial 12 weeks of PRT are consistent with other resistance training studies in older adults (2,3,5). During the 24-week detraining phase, 1RM strength declined 11% in the free-living men, which is in agreement with other detraining studies in young (9–11) and old (12,13) adults. We found no change in 1RM strength in the men who resistance trained once per week for 24 weeks, which is similar to the findings of Lexell and colleagues (14) for the upper body (elbow flexion) and lower body (knee extension). Interestingly, the 11% decline over 24 weeks in 1RM strength was relatively minor compared with the 53% increase found after 12 weeks of PRT. Worth noting was the fact that all men increased their 1RM strength (range 20–90%) during the 12-week PRT program. Additionally, all men ($n = 5$) that ceased resistance training for 24 weeks had a decline (range from −6% to −14%) in 1RM strength. Likewise, all men ($n = 5$) that continued training were able to maintain 1RM strength (range from 0 to +7%). The fact that all men responded in a similar manner to the detraining and maintenance phases of the program suggests a uniform response to these types of inactivity or activity patterns in this older population.

Similar to the increases in 1RM strength, muscle size measurements (CT scans) of the midthigh increased 6–7% (range from +1% to +13%) for all men with the 12-week PRT program, which is in agreement with other studies of this duration and age population (3,5). Following 24 weeks of detraining, all men had a 5% decline (range from −2% to −7%), whereas the men who engaged in training 1 day per week had no overall change in their muscle size (range from −4% to +1%). The one individual that had a decline in muscle size with the 6-month maintenance program was the same individual that had the greatest increase in muscle size during the 12-week PRT program (+13%; T2). Thus, despite a 4% decline in muscle size following the 6-month maintenance program (T3), this individual's muscle size was still 9% above his pretraining (T1) muscle size. Ivey and colleagues (12) found knee extensor muscle volume to return to pretraining values following 31 weeks of detraining. This is similar to the current investigation that found muscle mass to be within 1–2% of pretraining values with the 24 weeks of detraining.

To our knowledge, this is the first study to assess muscle size by using CT with a maintenance program in an elderly population. The maintenance of muscle mass is a critical component for the elderly population for several reasons. First, there is a strong relationship between muscle mass and strength in humans (15). Second, muscle is a metabolic tissue, providing physiological control related to glucose metabolism (16), protein kinetics (17), and resting metabolic rate (18). Thus, while preserving strength in the elderly population may be important for locomotion, maintaining muscle mass may be a key component to help regulate metabolism and to prevent potential disease states (e.g., insulin resistance).

Maximal force production per unit of muscle mass (ST) has been used to assess muscle quality at the whole muscle (19) and single fiber level (20) with aging and resistance training (6,21). The measurement of whole muscle ST is a noninvasive way to assess the relative contribution of muscle mass to muscle strength. In the current study, ST increased in all men with 12 weeks of PRT, and it remained elevated in all men despite training or detraining for 26 weeks. Similarly, Ivey and colleagues (12) found ST to increase with resistance training and to remain elevated following 31 weeks of detraining. The most likely explanation for these findings is that the neurological system does not have the same rate of decline compared with changes in muscle mass. Support for this theory comes from the present study, and others (12,14), that have shown strength to decline to a lesser degree than muscle size. In the current investigation, 1RM strength declined 11% in the detrained men, which was still ∼40% above the pretraining values. However, muscle size was reduced by 5% with detraining, accounting for more than 80% of the loss in size that was gained during the initial 12 weeks of the PRT program. Hakkinen and Komi (22) and Narici and collegues (23) have shown that neural activation increases observed with resistance training can be maintained for several weeks of detraining. Thus, it appears that the rates of decline in muscle strength and size with detraining in older men do not parallel one another.

A reduction in muscle strength and size, often referred to as sarcopenia, is commonly associated with aging (1). As a result, sarcopenia-related problems (falls that lead to injury and loss of independent living) have cost the health care industry millions of dollars annually (24). Resistance training programs, in contrast, have been effectively used in research for more than 15 years to increase muscle strength and size in older men and women (3,5). In fact, older men and women that are over 90 years of age have responded positively to resistance training by increasing their muscle mass and overall strength (4). However, most of the resistance training programs that are performed with older adults are short term (∼12 weeks) in nature. What is not known is how little resistance training is necessary to maintain muscle mass and strength gains in older people following a typical resistance training program. The current investigation suggests that training at 80% of the 1RM is sufficient to preserve both muscle mass and strength characteristics in older adults following 12 weeks of PRT. This has important social implications for time management and cost for the elderly population and the health care community. Given that 1 day per week seems to be effective to prevent the advancement of sarcopenia, older adults could engage in a low volume, high-intensity resistance training program and still maintain independence and reduce their chances for falls and injuries.

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