Short-Term Heavy Resistance Training Eliminates Age-Related Deficits in Muscle Mass and Strength in Healthy Older Males

Darren G. Candow,[1] Philip D. Chilibeck,[2] Saman Abeysekara,[3] and Gordon A. Zello[3]

[1]Faculty of Kinesiology and Health Studies, University of Regina, Regina, Saskatchewan, Canada; [2]College of Kinesiology, University of Saskatchewan, Saskatoon, Saskatchewan, Canada; and [3]College of Pharmacy and Nutrition, University of Saskatchewan, Saskatoon, Saskatchewan, Canada

Abstract

Candow, DG, Chilibeck, PD, Abeysekara, S, and Zello, GA. Short-term heavy resistance training eliminates age-related deficits in muscle mass and strength in healthy older males. *J Strength Cond Res* 25(2): 326–333, 2011—The objective of this investigation was to determine whether short-term heavy resistance training (RT) in healthy older men could eliminate deficits in muscle mass and strength (ST) compared with healthy younger men. Seventeen older men (60–71 yr) performed supervised RT for 22 weeks. Before and after RT, measurements were made for lean tissue mass (LTM), muscle thickness (MT), and ST (leg and bench press 1 repetition maximum) and were compared with values of younger men ($n =$ 22–60 for the different measures, 18–31 yr). Before training, older men had significantly lower ($p < 0.05$) LTM (58.4 ± 7.0 kg), MT (3.4 ± 0.7 cm), and ST (leg press = 168 ± 33 kg; bench press = 75 ± 18 kg) compared with younger men (LTM 64.3 ± 7.1 kg; MT 4.0 ± 0.8 cm; leg press = 231 ± 54 kg; bench press = 121 ± 31 kg). All deficits were eliminated after 22 weeks of RT (LTM = 60.5 ± 7.6 kg; MT = 4.0 ± 0.7 cm; leg press = 222 ± 48 kg; bench press = 107 ± 19 kg). Short-term, heavy RT in healthy older men is sufficient to overcome deficits in muscle mass and ST when compared with healthy younger men. The practical application from this research is that healthy older men can be prescribed a whole-body heavy RT program to substantially increase muscle mass and ST to levels similar to young, active individuals.

Key Words aging, sarcopenia, hypertrophy, muscle protein

Address correspondence to Dr. Darren G. Candow, Darren.Candow@uregina.ca.

25(2)/326–333

Journal of Strength and Conditioning Research

Introduction

Sarcopenia, defined as the age-related loss of muscle mass (33), has a negative effect on strength, which subsequently decreases the ability to perform tasks of daily living (e.g., carrying groceries, climbing stairs). Approximately 5% of skeletal muscle mass is lost per decade after 40 years of age, with accelerated deterioration after 65 years of age (37). Contributing factors to age-related muscle atrophy include reductions in neuromuscular function (29), satellite cell activity and content (38), muscle fiber number and size (24), muscle protein kinetics (1), anabolic hormone production (36), mitochondrial function (30) and physical activity (9), and increases in oxidative stress (21), catabolic cytokine levels (2), and cellular apoptosis (25).

We have shown on numerous occasions that resistance training is an effective strategy to increase aging muscle mass and strength (7,8,11,13); however, no study has determined the effectiveness of resistance training in older adults to eliminate muscle size and strength deficits compared with younger adults. We have previously shown that healthy older men had lower lean tissue mass, muscle thickness of the elbow flexors, knee flexors and extensors, and ankle dorsi and plantar flexors compared with healthy younger men (5) and that lower-body muscle groups were more negatively affected than upper-body muscle groups, which is in agreement with the work of others (20,23). Reviews of studies of master athletes, older adults of different physical activity levels, and previously sedentary older adults who were put on intense resistance training programs conclude that much of the age-associated muscle atrophy and weakness can be eliminated with resistance training; however, some of the atrophy and weakening cannot be abolished with training (14,16). Therefore, the purpose of this study was to determine the extent to which supervised heavy resistance training in healthy older males could eliminate deficits in lean tissue mass, muscle thickness, and strength when compared with healthy younger reference groups. We hypothesized that resistance training would increase lean tissue mass and size of the muscles surrounding the elbow, knee, and ankle, as well as leg press and bench press strength.

We also hypothesized that resistance training in older men would eliminate most of the muscle and strength deficits when compared with measures in younger men. These findings may have application for the design of effective resistance training strategies (i.e., whole body, multiple sets, and repetitions) for healthy older adults, which will lead to significant muscle accretion and strength. Potentially, results from this study may encourage healthy older adults to initiate and maintain a regular resistance training program because improvements in muscle mass and strength should be expected in a relatively short period of time (i.e.,10–22 wk).

Methods

Experimental Approach to the Problem

To determine whether short-term resistance training in healthy older men could eliminate muscle and strength deficits compared with measures in healthy younger men, a group of older men were prescribed a whole-body heavy resistance training program for 22 weeks and compared with reference groups of younger males for lean tissue mass, muscle thickness, and strength.

The dependent variables measured at baseline and after 12 and 22 weeks of heavy resistance training in older men were (1) body composition (body mass, lean tissue, fat mass), (2) muscle thickness of the elbow, knee, and ankle flexors and extensors, and (3) strength (leg press and bench press 1 repetition maximum [1RM]). The same measures were made in our young reference groups and compared with the older men's values at baseline and after 12 and 22 weeks of training of the older men. Before and after the 22 weeks of training in older men, urinary 3-methylhistidine, an indicator of muscle protein catabolism, was also assessed. This was assessed to determine whether reduced protein catabolism with training influenced increases in lean tissue mass and strength. Older men also completed dietary records for 3 days at baseline and after 12 and 22 weeks of training to assess whether diet (energy, macronutrient content) changed over time. Detailed procedures for strength (11), body composition and muscle thickness (5), 3-methylhistidine (6), and the resistance training program and diet (7) have been previously described. Therefore, only an overview of the procedures is presented.

Subjects

Twenty healthy older men (age = 64.7 ± 5.0 yr, range: 60–71 yr; mass = 85.0 ± 18.9 kg, height = 171 ± 15 cm) who were not performing resistance training for at least 15 months volunteered for the study, which occurred between January and May, through advertising in a local newspaper. This study was approved by the ethics review board and the subjects signed an informed consent document after having the risks and benefits explained. We chose to recruit adults 60 years of age or older because this is the approximate time where significant decreases in physical activity, muscle mass, and strength occur (15). Three groups of young males were used for comparisons with the older men: 1 for comparison of lean tissue mass ($n = 57$; age = 24.5 ± 4.5 yr; mass = 81.6 ± 13.5 kg; height = 178 ± 8 cm), 1 for comparison of muscle thicknesses ($n = 22$; age = 22.0 ± 3.3 yr; mass = 80.8 ± 11.8 kg; height = 179 ± 5 cm (5), and 1 for comparisons of bench press and leg press strength ($n = 60$; age = 26.6 ± 6.2 yr; mass = 80.9 ± 14.7 kg; height = 178 ± 8 cm).

Baseline physical activity was assessed by having the older men fill out a leisure time exercise questionnaire (17) in which the number of times per week, on average, was determined for strenuous exercise (e.g., running, jogging, bicycling), moderate exercise (e.g., fast walking, tennis, badminton), and mild exercise (e.g., yoga, gardening). The younger males who had muscle thickness measurements ($n = 22$) also filled out baseline physical activity questionnaires. All the young subjects were physically active but not currently involved in resistance training.

The older subjects were instructed not to change their diet or engage in physical activity that was not part of their normal daily routine during the study. Subjects were required to fill out a Physical Activity Readiness Questionnaire, which assesses an individual's readiness for participation in exercise programs and includes questions related to heart conditions, angina at rest or during physical exercise, balance, and bone or joint problems that may affect exercise performance. Subjects were classified as healthy if they did not indicate any of these health problems. Subjects were informed of the experimental risks and signed an informed consent document before the investigation. The investigation was approved by an institutional review board for use of human subjects.

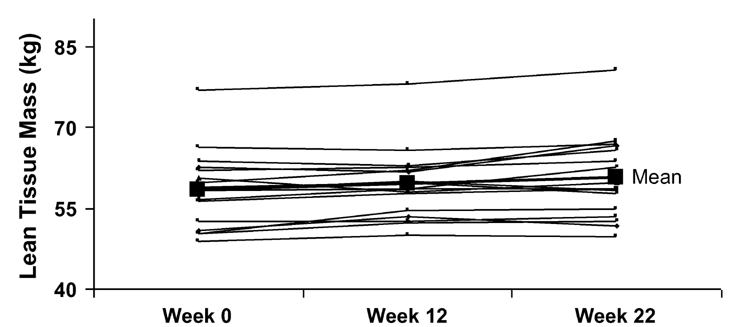

Figure 1. Lean tissue mass (kg) at week 0, 12, and 22 for older subjects ($n = 17$).

Procedures

Resistance Training Program. Before the start of the study, each older subject familiarized himself with the resistance training equipment by participating in supervised training sessions

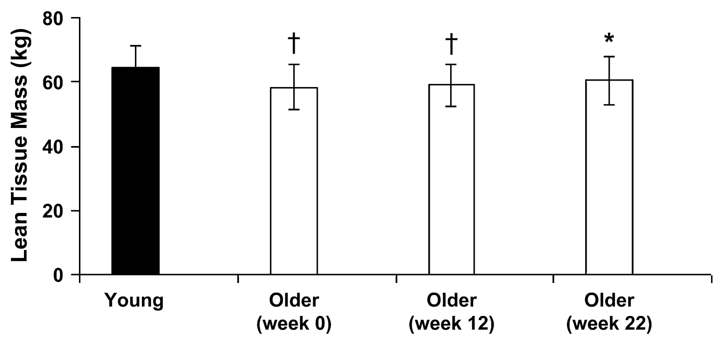

Figure 2. Lean tissue mass (kg) at baseline (week 0) and after 12 and 22 weeks of resistance training in older men ($n = 17$) compared with younger men ($n = 57$). Values are means ± *SD*. *Week 22 significantly different than pretraining values ($p < 0.05$). †Significantly different compared with younger men ($p < 0.05$).

(3 times/wk for 2 wk) to reduce the amount of learning that may occur during the initial stages of resistance training (10). Older subjects followed the same high-volume supervised resistance training program for 22 weeks (i.e., 66 training sessions). They trained 3 days/week for 3 sets of 10 repetitions to muscle fatigue with 2 minutes of rest between sets for each exercise (5 upper body, 4 lower body) at an intensity corresponding to approximately 70% 1RM for the leg press and bench press and a weight corresponding to their 10RM for other exercises. Machine-based resistance exercises performed in order were horizontal leg press, flat bench press, lat pull down, shoulder press, leg (knee) extension, leg curl (knee flexion), biceps curl, triceps press down, and horizontal calf press. We chose to use machine--based exercise equipment for our training program in older adults because they are considered safer to use and easier to learn than free weights (31), and the use of machine-based equipment lead to greater improvements in machine-based strength tests (3). Leg press and calf press exercises were performed using Hammer Strength equipment (Life Fitness, Franklin Park, IL, USA), bench press, shoulder press, lat pull down and biceps curl exercises were performed using Lever equipment (Pulse Fitness Systems, Winnipeg, Canada), and triceps extension was performed using Paramount Fitness equipment (Apple Fitness, Edmonton, Canada). Resistance was increased by 2 to 5 kg once a subject completed 3 sets of 10 repetitions to muscle fatigue for an exercise.

Body Composition. Body composition (body mass, lean tissue, fat mass) was assessed by air-displacement plethysmography (Bod Pod, Life Measurement, Inc., Concord, CA, USA). Reproducibility of the Bod Pod was assessed by testing 17 older subjects (60–71 yr) 1 week apart. The coefficients of variation for body mass, lean tissue mass, and fat mass were 0.3%, 1.7%, and 2.5% respectively. The intraclass correlation coefficients (ICC) for these measurements were all 0.99.

Muscle Thickness. Muscle thickness of the elbow and knee flexors and extensors and ankle dorsiflexors and plantar

Table 1. Muscle thickness measurements (cm) for elbow and knee flexors and extensors and ankle dorsiflexors and plantar flexors in older men ($n = 17$) over 22 weeks of heavy resistance training compared with younger men ($n = 22$).*

		Older men			
	Younger men	Baseline	Week 12	Week 22	Effect size
Muscle group					
Elbow flexors	3.2 ± 0.5	2.8 ± 0.4†	3.3 ± 0.8§	3.3 ± 0.4§	1.3
Elbow extensors	4.0 ± 0.5	4.1 ± 0.4	4.8 ± 0.8‡§	4.9 ± 0.8‡§	2.0
Knee flexors	5.5 ± 0.5	4.7 ± 0.8†	5.1 ± 0.8†§	5.1 ± 0.8§	0.5
Knee extensors	4.2 ± 1.0	3.6 ± 0.8†	3.9 ± 0.8†§	4.0 ± 0.8§	0.5
Ankle plantar flexors	4.4 ± 1.4	3.2 ± 0.8†	3.7 ± 0.8§	4.1 ± 0.8§	1.1
Ankle dorsiflexors	2.7 ± 0.5	2.2 ± 0.4†	2.4 ± 0.4†	2.5 ± 0.4§	0.8
Total	24.0 ± 0.5	20.6 ± 0.4†	23.2 ± 0.8†§	27.2 ± 0.8§	

*Values are means (cm) ± *SD*. Effect size: small (<0.5), moderate (0.5–0.8), or large (>0.8).
†Indicates values for older men are less than values for younger men ($p < 0.05$).
‡Indicates older men had greater elbow extensor muscle thickness compared with younger mean men ($p < 0.05$).
§Indicates muscle thickness was greater than baseline values ($p < 0.05$).

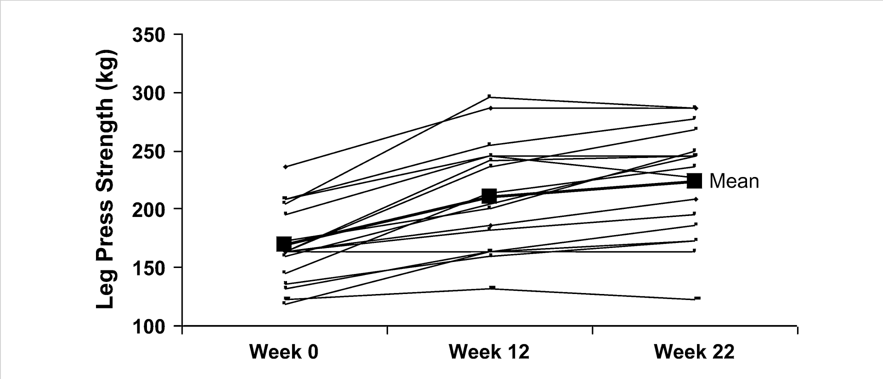

Figure 3. Leg press strength (kg) at week 0, 12, and 22 for older subjects ($n = 17$).

flexors was measured using B-Mode ultrasound (Aloka SSD-500, Tokyo, Japan). Reproducibility of muscle thickness measurements was determined by testing 16 subjects (60–76 yr) 1 week apart. The coefficients of variation for muscle thickness measurements were 2.5% (elbow flexors), 2.2% (elbow extensors), 3.6 % (knee flexors), 2.1% (knee extensors), 3.3% (ankle plantar flexors), and 4.0% (ankle dorsiflexors) (5). The ICCs for each measure were 0.96 (elbow flexors), 0.88 (elbow extensors), 0.99 (knee flexors), 0.99 (knee extensors), 0.98 (ankle plantar flexors), and 0.87 (ankle dorsiflexors).

Muscular Strength. Leg press and bench press strength was assessed using a 1RM standard testing procedure (11). These 2 exercises were chosen as an index of muscular strength because they involve the major muscle groups in the lower and upper body. Reproducibility of the strength measures was assessed on 10 subjects (60–84 yr) 1 week apart. The leg press and bench press strength measures had coefficients of variation of 3.8% and 3.1%, respectively (11). The ICC for both measures was 0.99.

3-Methylhistidine. For the measurement of 3-methylhistidine, an index of muscle protein catabolism, urine was collected during the last 24 hours of a 72-hour meat-free diet immediately before and immediately after the study. A meat-free diet was implemented because meat consumption increases urinary 3-methylhistidine values and may falsely represent an increase in muscle protein turnover (27). The concentration of 3-methylhistidine was determined by high-performance liquid chromatography using the methods of Wassner et al. (40) with modification for sample volumes. The intra-assay coefficient of variation from duplicate samples from 27 subjects (60–71 yr) was 5.1% (7), and the ICC was 0.99. The daily amount of 3-methylhistidine excreted by each subject was determined by multiplying the concentration by the 24-hour urine volume. This amount of 3-methylhistidine was then expressed relative to lean tissue mass (μmol/kg) (7).

Diet. Dietary intake was recorded using 3-day food records in which subjects recorded what they ate during 2 weekdays and 1 weekend day. Subjects were instructed to record all food items, including portion sizes consumed for the 3 designated days. The Interactive Healthy Eating Index (Center for Nutrition Policy and Promotion, United States Department of Agriculture) was used to analyze 3-day food records for the amounts of nutrients and energy consumed. Food records were completed on days that were separate from the meat-free diet imposed for the 3-methylhistidine assessment. A portion of the younger males ($n = 19$) who had lean tissue mass and strength measurements completed dietary intake questionnaires that were used for comparison with the older group.

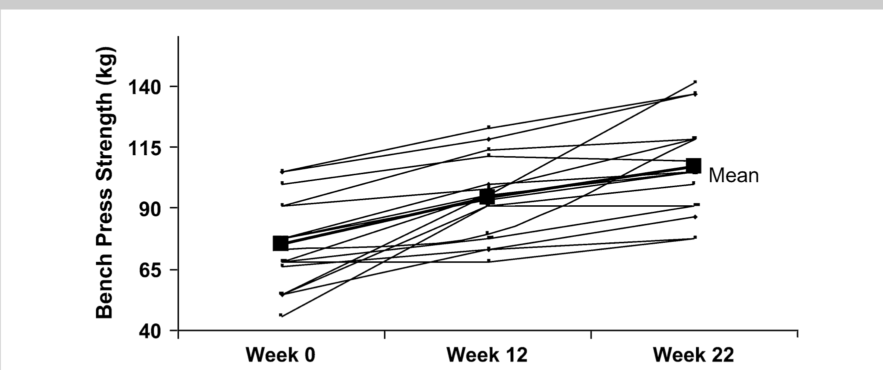

Figure 4. Bench press strength (kg) at week 0, 12, and 22 for older subjects ($n = 17$).

Statistical Analyses

Repeated measures analysis of variance (ANOVA) (pre, wk 12, wk 22) was used to assess changes in body composition (body mass, lean tissue, fat mass), muscle thickness, strength, 3-methylhistidine, and diet in older men over time. Effect sizes (ES) were determined for these changes and classified as small (<0.5), moderate (0.5–0.8), or large (>0.8) according to Cohen (12). Separate 1-factor ANOVAs were used to compare physical

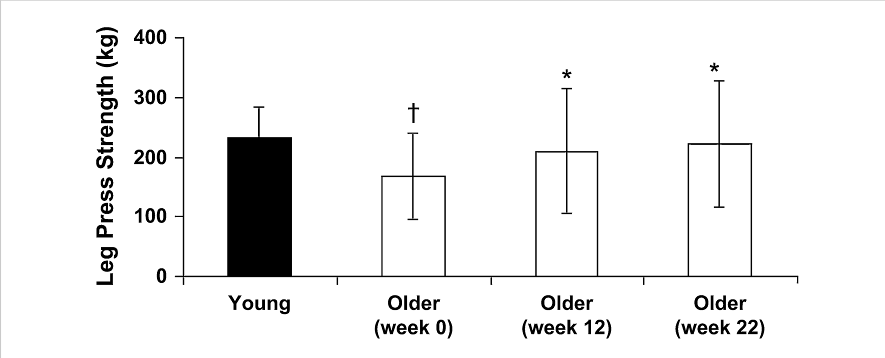

Figure 5. Leg press strength (kg) at baseline (week 0) and after 12 and 22 weeks of resistance training in older men ($n = 17$) compared with younger men ($n = 22$). Values are means ± *SD*. *Significantly different than pretraining values ($p < 0.05$). †Significantly different compared with younger men ($p < 0.05$).

activity levels at baseline and lean tissue mass, muscle thicknesses, strength and dietary variables at baseline, after 12 weeks, and after 22 weeks of resistance training in the older men compared with younger reference groups. When main effects were found, a least squared difference post hoc test was used to determine differences between means. All of our results were normally distributed, and Levine's test was used to confirm homogeneity of variance for our comparisons between young and old groups. The Greenhouse-Geisser adjustment was used to adjust for any violations in sphericity in our repeated measures ANOVAs. All results are expressed as mean ± *SD*. Significance was set at $p \leq 0.05$.

To assess whether we had adequate power to determine whether mean values between the older and younger groups were equivalent after training of the older group, we first determined theoretical differences in lean tissue mass and strength between younger and older groups that would constitute a clinically significant difference (i.e., that would lead to functional impairment in the older group) (22). We then performed power calculations using our subject numbers, the mean for the younger group, the theoretical mean for the older group if they were to have functional deficiencies (i.e., deficiencies in the ability to perform tasks of daily living), the *SD* of the younger group (which we considered the "control" group), and an alpha of 0.05. Power was considered acceptable at 80% or greater.

Results

Lean tissue mass was significantly lower at baseline in older compared with younger subjects ($p < 0.05$). Lean tissue mass progressively increased over the 22 weeks of resistance training in the older men (+2.0 ± 7.3 kg, $p < 0.05$, ES: 0.3 = small) (Figure 1).

At week 12, older men still had lower lean tissue mass compared with younger men ($p < 0.05$). However, after 22 weeks of training, lean tissue mass in the older men was similar to the younger group (Figure 2).

All muscle thickness measurements, except for the elbow extensors, were significantly lower at baseline in the older compared with younger subjects ($p < 0.05$) (Table 1). Muscle thickness significantly increased in all muscle groups with 22 weeks of training in the older men ($p < 0.05$) (Table 1). At week 12, muscle thickness of the elbow and knee flexors and extensors and ankle plantar flexors was greater than pretraining values. After 22 weeks of training, ankle dorsiflexor muscle thickness was greater than pretraining values. There was no greater increase in elbow and knee flexor and extensor and ankle plantar flexor muscle thickness from weeks 12 to 22. After 12 weeks of training, muscle thickness of the elbow flexors and ankle dorsiflexors was similar between younger and older men, with elbow extensor muscle thickness actually being greater in the older men ($p < 0.05$). After 22 weeks of training, the older men no longer differed from the younger men for muscle thickness of the knee flexors and knee extensors and ankle plantar flexors (Table 1).

At baseline, bench press and leg press strength were significantly lower in the older compared with the younger subjects ($p < 0.05$). A progressive

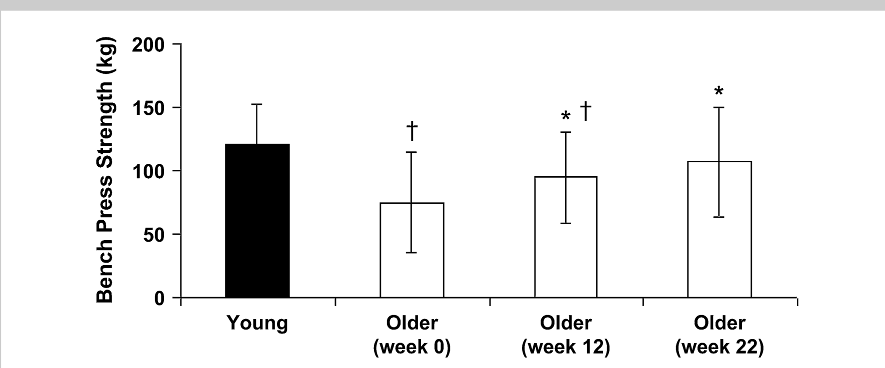

Figure 6. Bench press strength (kg) at baseline (week 0) and after 12 and 22 weeks of resistance training in older men ($n = 17$) compared with younger men ($n = 22$). Values are means ± *SD*. *Significantly different than pretraining values ($p < 0.05$). †Significantly different companed with younger men ($p < 0.05$).

Table 2. Total calories (kcal/d) and macronutrient (g/d) content for 3 days at baseline for younger men ($n = 19$) and at baseline and following 12 and 22 weeks of heavy resistance training in older men ($n = 13$).*

	Younger men baseline	Older men baseline	Older men week 12	Older men week 22
Kilocalories per day	2,423 ± 620	2,290 ± 649	2,148 ± 590	2,333 ± 553
Carbohydrates	296 ± 95	245 ± 69	230 ± 78	247 ± 101
Fat	89 ± 28	93 ± 40	82 ± 31	97 ± 26
Protein	110 ± 36	115 ± 42	103 ± 37	109 ± 26

*Values are means ± *SD*. Data are based on daily average from 3-day food records. No differences were evident in any measures over time, or between younger and older groups.

increase in leg press strength (+55.0 ± 40.5 kg, $p < 0.05$, ES: 1.6 = large) (Figure 3) and bench press (+32.0 ± 18.8 kg, $p < 0.05$, ES: 1.8 = large) (Figure 4) was evident with 22 weeks of training of the older group. At week 12, leg press strength was similar between younger and older men (Figure 5), but bench press strength was still lower for older men (Figure 6). However, after 22 weeks of training in the older men, bench press strength was similar to the younger group (Figure 6).

Measurement of usual physical activity showed that younger men performed more strenuous exercise (younger: 3.1 ± 4.2, older: 1.1±1.9 times/wk; $p < 0.05$) and moderate exercise (younger: 3.5 ± 3.7, older: 2.0 ± 2.4 times/wk; $p < 0.05$) compared with the older men. Younger and older men participated in similar levels of mild exercise (younger: 4.6 ± 3.1, older: 3.8 ± 4.3 times/wk). Thirteen older subjects were able to provide 3-day food records at baseline and after 12 and 22 weeks of resistance training. Total energy (Kcal) and macronutrient intake did not change over the study time period and did not differ from values for younger men (Table 2). Twelve older subjects were able to provide 24-hour urine samples at baseline and after 12 and 22 weeks of resistance training. 3-methylhistidine was significantly reduced over the 22 weeks of training (baseline: 4.5 ± 1.4 μmol/kg lean tissue, wk 22: 3.1 ± 2.1 μmol/kg lean tissue, $p < 0.05$; ES: 1.0 = large), with no other differences.

Discussion

As expected, heavy resistance training in the older men increased muscle mass (ES: 0.3 = small) and strength (ES: 1.7 = large). However, a unique and important finding from this study was that only 12 weeks of resistance training in healthy older men was sufficient to eliminate deficits in muscle size of the elbow flexors (ES: 1.25 = large) and ankle dorsiflexors (ES: 0.75 = moderate) and leg press strength (ES: 1.6 = large) when compared with measures in healthy younger men. An additional 10 weeks of resistance training eliminated remaining deficits in lean tissue mass (ES: 0.3 = small), muscle thickness of the elbow extensors (ES: 2.0 = large), knee flexors (ES: 0.5 = moderate), and extensors (ES: 0.5 = moderate), ankle plantar flexors (ES: 1.1 = large) and bench press strength (ES: 1.8 = large). Before the resistance training program, most of the differences between the younger and older group in lean tissue mass, muscle thickness, and strength were of clinically significant levels; that is, they would predict a decrease in physical functioning during activities of daily living (4,26,28).

A decrease in lean tissue mass of approximately 10% from young to older age leads to a clinically significant reduction in muscular strength of 20% (i.e., a level that might result in functional impairment) (26,28). With our subject numbers, the power to detect a 10% difference for lean tissue mass between the younger and older groups was 90%. As shown in Figure 2, the approximate difference between younger and older groups for lean tissue mass at baseline was 9%, approaching a level of clinical/biological significance. After 22 weeks of training of the older group, the difference was only 6% and no longer of clinical significance.

A decrease of arm muscle mass of 8% and leg muscle mass of 12% from young to older age leads to a clinically significant reduction in muscular strength of 20% (28). With our subject numbers, the power to detect these differences for muscle thickness between the younger and older groups was inadequate (i.e., 19–44%) except for knee flexors (99%). As seen in Table 1, the approximate differences between younger and older groups for muscle thicknesses at baseline was at a clinically significant level for all muscle groups except the elbow extensors, with deficits ranging from 13% to 27%. After resistance training, none of the differences were at a clinically significant level, with upper-body muscle size slightly higher in the older group and with deficits in lower-body muscle thicknesses ranging from 5% to 7%.

A decrease in leg press and bench press strength of approximately 20% from young to older age leads to a significant increase in functional limitations (4); therefore, we considered this decrease to represent a clinically significant level. With our subject numbers, the power to detect a 20% difference between the younger and older groups was 80% for the bench press and 86% for the leg press. As seen in Figures 5 and 6, the approximate differences between younger and older groups for bench press and leg press at baseline were 38% and 27%, respectively, which could be considered clinically significant. After 22 weeks of training in the older group, these differences were 12% and 4%, which would no longer be considered clinically significant.

Mechanistically, muscle accretion from resistance training in older adults may be caused by an increase in muscle protein synthesis (35), satellite cell activity and content (38), anabolic hormone production (36), mitochondrial quality and function (30), and a decrease in catabolic cytokine activity (13). We found that 22 weeks of heavy resistance training reduced a urinary indicator of muscle protein catabolism (3-methylhistidine) by 31% (ES: 1.0 = large) compared with baseline values. 3-methylhistidine is an amino acid found in actin and the heavy chain of myosin in skeletal muscle (32), and when measured in urine is considered to be an indicator of muscle protein catabolism (27). This reduction in muscle protein catabolism, coupled with significant muscle hypertrophy, suggests that healthy older adults experienced net muscle protein retention as a result of resistance training.

The only muscle thickness measurement that did not differ between younger and older men at baseline was for the elbow extensors (young: 4.0 ± 0.5cm, older: 4.1 ± 0.4 cm) (Table 1). This is in agreement with 1 other study that assessed muscle thickness of the elbow extensors in younger and older individuals (23). An explanation of why elbow extensor muscle size and not elbow flexor muscle size would be better maintained with age may be related to changes in the ability to activate the flexors and extensors with age. Jakobi and Rice (19) found that elbow extensor muscle activation was maintained to a greater degree than the ability to activate the elbow flexors in older versus younger males. These differences between muscle groups may be the result of a greater age-related decrease in motor unit discharge rates in the elbow flexors compared with the elbow extensors (19) because suboptimal discharge rates may be a possible factor leading to a decrease in muscle activation (18).

The greatest deficits for muscle size in older compared with younger men were for lower-body muscle groups (Table 1). These deficits may have been too large to overcome with 12 weeks of resistance training. Despite the deficits in lower-body muscle groups, older men were able to increase leg press strength to a similar degree as younger men after only 12 weeks of training. The rapid increase in leg press strength after 12 weeks of training may be the result of neural adaptations (10). For example, leg press strength was significantly increased after 10 weeks of resistance training in young women, with no concurrent gain in leg muscle mass (10). Multijoint exercises such as the leg press may involve a longer initial neural adaptation compared with single-joint exercises such as biceps curl, resulting in delayed muscle hypertrophy (10). Rutherford and Jones (34) have suggested that, during the leg press exercise, learning and coordination play a greater role early in training compared with the arm curl exercise. The authors further state that with complex exercises such as the leg press, support muscles may have to increase in strength or improve their ability to activate muscle contraction. Therefore, longer training periods (i.e., >12 wk) may be required to increase lower-body muscle mass. Our results suggest that 22 weeks of resistance training in older adults is sufficient in duration to increase muscle hypertrophy and overcome age-related deficits in lower-body muscle groups.

Practical Applications

The results of this research suggest that structured, supervised resistance training in healthy older men is sufficient to eliminate differences in muscle mass and strength between younger and older men. These findings have application for the design of resistance training programs for healthy older adults. Specifically, performing 3 sets of 10 repetitions to muscle fatigue with 2 minutes of rest between sets for 9 whole-body machine-based exercises 3 days per week for up to 22 weeks is effective for increasing muscle mass and strength of older men to levels found in young healthy individuals.

Acknowledgments

This study was supported by a research grant from Experimental and Applied Sciences and the Natural Sciences and Engineering Research Council of Canada. Training equipment was supplied with a grant from the Saskatchewan Health Research Foundation.

References

1. Balagopal, P, Rooyackers, OE, Adey, DB, Ades PA, and Sreekumaran Nair, K. Effects of ageing on in vivo synthesis of skeletal muscle myosin heavy-chain and sarcoplasmic protein in humans. *Am J Physiol Endocrinol Metab* 273: 790–800, 1997.
2. Bautmans, I, Njemini, R, Vasseur, S, Chabert, H, Moens, L, Demanet, C, and Mets, T. Biochemical changes in response to intensive resistance exercise training in the elderly. *Gerontology* 51: 253–65, 2005.
3. Boyer, BT. A comparison of the effects of three strength training programs on women. *J Appl Sports Sci Res* 4: 88–94, 1990.
4. Brill, PA, Macera, CA, Davis, DR, Blair, SN, and Gordon, N. Muscular strength and physical function. *Med Sci Sports Exerc* 32: 412–416, 2000.
5. Candow, DG and Chilibeck, PD. Differences in size, strength, and power of upper and lower body muscle groups in young and older men. *J Gerontol Biol Med Sci* 60: 148–156, 2005.
6. Candow, DG, Chilibeck, PD, Burke, DG, Davison, KS, and Palmer, TS. Effect of glutamine supplementation combined with resistance training in young adults. *Eur J Appl Physiol* 86*:* 142–149, 2001.
7. Candow, DG, Chilibeck, PD, Facci, M, Abeysekara, S, and Zello, GA. Protein supplementation before and after resistance training in older men. *Eur J Appl Physiol* 97: 548–556, 2006.
8. Candow, DG, Little, JP, Chilibeck, PD, Abeysekara, S, Zello GA, Kazachkov, M, Cornish, SM, and Yu PH. Low-dose creatine combined with protein during resistance training in older men. *Med Sci Sports Exerc*, 40: 1645–1652.
9. Carmeli, E, Coleman, R, and Reznick, AZ. The biochemistry of aging muscle. *Exp Gerontol* 37: 477–48, 2002.
10. Chilibeck, PD, Calder, AW, Sale, DG, and Webber, CE. A comparison of strength and muscle mass increases during resistance training in young women. *Eur J Physiol* 77: 170–175, 1998.
11. Chrusch, MJ, Chilibeck, PD, Chad, KE, Davison, KS, and Burke, DG. Creatine supplementation combined with resistance training in older men. *Med Sci Sports Exerc* 33: 2111–2117, 2001.

12. Cohen, J. *Statistical Power Analysis for the Behavioral Sciences* (2nd ed.) Hillside, NJ: Erlbaum, 1988.
13. Cornish, SM and Chilibeck, PD. Alpha-linolenic acid supplementation and resistance training in older adults. *Appl Physiol Nutr Metab* 34: 49–59, 2009.
14. Doherty, TJ. Aging and sarcopenia. *J Appl Physiol* 95: 1717–1727, 2003.
15. Doherty, TJ, Vandervoort, AA, Taylor, AW, and Brown, WF. Effects of motor unit losses on strength in older men and women. *J Appl Physiol* 74: 868–874, 2003.
16. Faulkner, JA, Larkin, LM, Claflin, DR, and Brooks, SV. Age-related changes in the structure and function of skeletal muscles. *Clin Exp Pharmacol Physiol* 34: 1091–1096, 2007.
17. Godin, G and Shephard, RJ. A simple method to assess exercise behavior in the community. *Can J Appl Sport Sci* 10: 141–146, 1985.
18. Herbert, RD and Gandevia, SC. Twitch interpolation in human muscles: mechanisms and implications for measurement of voluntary activation. *J Neurophysiol* 82: 2271–2283, 1999.
19. Jakobi, JM and Rice, CL. Voluntary muscle activation varies with age and muscle group. *J Appl Physiol* 93: 457–462, 2002.
20. Janssen, I, Heymsfield, SB, Wang, A, and Ross, R. Skeletal muscle mass and distribution in 468 men and women aged 18–88 yr. *J Appl Physiol* 89: 81–88, 2000.
21. Johnston, AP, De Lisio, M, and Parise, G. Resistance training, sarcopenia, and the mitochondrial theory of aging. *Appl Physiol Nutr Metab* 33: 191–199, 2008.
22. Kirshner, B. Methodological standards for assessing therapeutic equivalence. *J Clin Epidemiol* 44: 839–849, 1991.
23. Kubo, K, Kanehisa, H, Azuma, K, Ishizu, M, Kuno, SY, Okada, M, and Fukunaga, T. Muscle architectural characteristics in young and elderly men and women. *Int J Sports Med* 24: 125–130, 2003.
24. Larsson, L, Yu, F, Hook, P, Ramamurthy, B, Marx, JO, and Pircher, P. Effects of aging on regulation of muscle contraction at the motor unit, muscle cell, and molecular levels. *Int J Sport Nutr Exerc Metab* 11(Suppl): S28–S43, 2001.
25. Leeuwenburgh, C. Role of apoptosis in sarcopenia. *J Gerontol A Biol Sci Med Sci* 58: 999–1001, 2003.
26. Lindle, RS, Metter, EJ, Lynch, NA, Fleg, JL, Fozard, JL, Tobin, J, Roy, TA, and Hurley, BF. Age and gender comparisons of muscle strength in 654 women and men aged 20–93 yr. *J Appl Physiol* 83: 1581–1587, 1997.
27. Lukaski, HC, Mendez, J, Buskirk, ER, and Cohn, SH. Relationship between endogenous 3-Methylhistidine excretion and body composition. *Am J Physiol* 240: E302–E307, 1981.
28. Lynch, NA, Metter, EJ, Lindle, RS, Fozard, JL, Tobin, JD, Roy, TA, Fleg, JL, and Hurley, BF. Muscle quality. I. Age-associated differences between arm and leg muscle groups. *J Appl Physiol* 86: 188–194, 1999.
29. Marcell, TJ. Sarcopenia: causes, consequences, and preventions. *J Gerontol A Biol Sci Med Sci* 58: M911–M916, 2003.
30. Melov, S, Tarnopolsky, MA, Beckman, K, Felkey, K, and Hubbard, A. Resistance exercise reverses aging in human skeletal muscle. *PLoS ONE* 23: e465, 2007.
31. Ratamess, NA, Alvar, BA, Evetoch, TK, Housh, TJ, Kibler, WB, Kraemer, WJ, and Triplett, NT. American College of Sports Medicine position stand. Progression models in resistance training for healthy adults. *Med Sci Sports Exerc* 41: 687–708, 2009.
32. Rennie, MJ and Millward, DJ. 3-Methylhistidine excretion and the urinary 3-methylhistidine/creatinine ratio are poor indicators of skeletal muscle protein breakdown. *Clin Sci (London)* 65: 217–225, 1983.
33. Rosenberg, IH. Sarcopenia: origins and clinical relevance. *J Nutr* 127: 990S–991S, 1997.
34. Rutherford, OM and Jones, DA. The role of learning and coordination in strength training. *Eur J Appl Physiol* 55: 100–105, 1986.
35. Schulte, JN and Yarasheski, KE. Effects of resistance training on the rate of muscle protein synthesis in frail elderly people. *Int J Sport Nutr Exerc Metab* 11: S111–S118, 2001
36. Smilios, I, Pilianidis, T, Karamouzis, M, Parlavantzas, A, and Tokmakidis, SP. Hormonal responses after a strength endurance resistance exercise protocol in young and elderly males. *Int J Sports Med* 28: 401–406, 2007.
37. Tzankoff, SP and Norris, AH. Effect of muscle mass decrease on age-related BMR changes. *J Appl Physiol* 43: 1001–1006, 1977.
38. Verdijk, LB, Gleeson, BG, Jonkers, RA, Meijer, K, Savelberg, HH, Dendale, P, and van Loon, LJ. Skeletal muscle hypertrophy following resistance training is accompanied by a fiber type-specific increase in satellite cell content in elderly men. *J Gerontol A Biol Sci Med Sci* 64: 332–339, 2009.
39. Verdijk, LB, Koopman, R, Schaart, G, Meijer, K, Savelberg, HH, and van Loon, LJ. Satellite cell content is specifically reduced in type II skeletal muscle fibers in the elderly. *Am J Physiol Endocrinol Metab* 292: E151–E157, 2007.
40. Wassner, SJ, Schlitzer, JL, and Li, JB. A rapid, sensitive method for the determination of 3-methylhistidine levels in urine and plasma using high-pressure liquid chromatography. *Anal Biochem* 104: 284–289, 1980.