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The Interrelationship Among Muscle Mass, Strength, and the Ability to Perform Physical Tasks of Daily Living in Younger and Older Women

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The purpose of this study was to objectively compare the difficulty and determine the contribution of strength and muscle mass to the performance of physical tasks of daily living in a group of younger and older women. A cross-sectional design was used. Volunteer participants were from the community of Birmingham, AL; there were 21 older (aged 60–75 years) and 20 younger (23–34 years) healthy women in the study. Subjects were matched for height and weight. Their testing included total and regional body composition evaluation by use of dual-energy x-ray absorptiometry, isometric strength tests of elbow flexors and knee extensors, and integrated electromyography (IEMG) evaluation while the subjects were standing from and sitting into a chair, and while they were carrying a small load (weight relative to strength). A two-way analysis of variance and a two-way analysis of covariance with repeated measures, Pearson product correlation, and first-order partial correlations were used to analyze the data. A significant inverse correlation was observed between age and isometric strength of both the knee extensors and elbow flexors. Adjusting for upper leg lean tissue did not change the significant inverse correlation between age and knee extensor strength. However, after an adjustment for arm lean tissue, there was no significant correlation between elbow flexor strength and age. Older women experienced significantly greater difficulty in standing than younger women as measured by quadriceps normalized IEMG (i.e., IEMG during task/IEMG during maximum isometric strength test). This difference persisted even after the covariate upper leg lean tissue was added to the model. No significant difference was observed between younger and older women for difficulty (biceps normalized IEMG) during the carry task after the covariate arm lean tissue was added to the model. The older women in this study had less strength in the knee extensors and experienced greater difficulty standing from a chair than the younger women, even after the covariate upper leg lean tissue was added to the model. This suggests that other factors, in addition to loss of lean tissue, contribute to the age-related decline of muscular strength and the ability to perform tasks with the legs. In contrast, although elbow flexor strength declined, this appeared to be largely due to decreased arm lean tissue mass.

MUSCLE size, strength, and the ability to perform physical tasks of daily living (PTDL) reach a peak in a person's early thirties and then decline with age (1–3). This decline occurs regardless of physical fitness or amount of training (1,4). Schultz and Curnow have documented the progressive performance decrements of highly trained athletes as they age (4). Cross-sectional studies suggest varying rates of skeletal muscle atrophy, from 20% in the biceps brachii to 33% in the quadriceps femoris, when sedentary young (20–35 years) and old (68–86 years) adults are compared (1,5,6). The decline in muscle strength appears to follow the decline in muscle mass closely (6–9). However, some controversy exists as to whether the decline in strength is solely due to a decline in (quantitative) muscle mass (1,5,6,10) or to whether changes in muscle quality also occur, such as alterations in the activation of motor units or contractile properties of the muscle (5,8,11). Compromised task performance with age may result from a variety of factors, including muscle weakness and decreased muscle mass in relation to fat mass (12,13).

The relationship of muscle mass and strength to the difficulty of performing daily tasks such as standing from and sitting into a chair or carrying a box of groceries is not known. Although muscle cross-sectional area and thus quantity of limb lean tissue are related to strength and effort in performing daily tasks, it is not known whether this relationship is the same in younger and older adults. A comparison of the relationship between the quantity of muscle mass and muscle function between young and old adults should improve our understanding of the age-related decline in the ability to perform PTDL.

To our knowledge, few studies have examined objective physiological measurements of difficulty, while the subjects are performing daily tasks, in young and old persons. The physiological effort required to do tasks can be evaluated by using integrated electromyography (IEMG; 14). The electrical activity of the muscle recorded as IEMG is normalized by dividing the IEMG recorded while the subject is performing a task (or gradation of maximum strength) by the maximum IEMG recorded from the same muscle group during a maximum effort. Higher normalized IEMG (nIEMG) values indicate greater muscular effort or intensity of contraction. When combined with a measure of lean tissue, nIEMG during task performance can provide objective comparisons between the muscle function of older and younger individuals.

Using younger and older women matched for body mass index (BMI), this study was designed to test the following hypotheses: (1) older women have lower strength and lean tissue mass in the arms and legs than younger women; (2) an age-related decline in the strength of the knee extensors is independent of limb lean tissue mass, whereas the age-related decline in elbow flexor strength is dependent on limb lean tissue mass; (3) an age-related decline in the ability to stand from a chair is independent of limb lean tissue and strength; and (4) older and younger women have similar muscle function for a carrying task that is proportional to each woman's maximal strength.

METHODS

Subjects

Twenty-one healthy older women (60–75 years of age) and 20 younger women (23–34 years of age) participated in the study. Subjects were pooled from two separate research projects that were concurrently conducted. A physician screened potential subjects by history and physical exam. Subjects were excluded from the study if they had evidence of diabetes, significant renal or hepatic disease, hypothyroidism, or musculoskeletal problems that would hinder participation. None of the subjects performed resistance weight training, and none were training for improved aerobic fitness. Estrogen replacement therapy was not an exclusion factor. Methods and procedures were approved by the Institutional Review Board of the University of Alabama at Birmingham. All subjects gave signed informed consent.

Design

All subjects were evaluated between the hours of 7 AM and 10 AM after an overnight fast. Subjects were evaluated one time for the following: (1) body composition by dual-energy x-ray absorptiometry (DXA) scan; (2) maximum voluntary isometric contraction (MVIC) of the right elbow flexors and right knee extensors; (3) nIEMG of the right rectus femoris while standing from and sitting into a chair; and (4) nIEMG of the right biceps while carrying a weighted box and walking on a treadmill. The nIEMG was used to objectively observe electrical activity of the muscle.

DXA

A DXA total body scan was performed on each subject (Lunar Model DPX-L, software version 1.5g, Lunar Radiation Corporation, Madison, WI). Scans were conducted in the adult medium mode (8 cm/s). A DXA analysis provided fat mass percentage of total body weight, fat mass, and lean tissue mass (excluding bone mineral content). Regions of interest were used to separate right arm and upper right leg from total body lean tissue mass (LTM). This procedure allowed the measure of LTM of the extremity, including the predominant muscle or muscle group used to perform the MVICs and tasks of daily living completed in this study. The LTM of the upper leg provided a surrogate measure of the knee extensors. The LTM of the total arm served as the surrogate measure for the elbow flexors because elbow flexors lie in both the upper and lower arm.

Isometric Strength Tests

Maximum isometric strength of the knee extensors and elbow flexors was evaluated while the IEMG of the rectus femoris and biceps brachii, respectively, were measured. A Universal Shear Beam Load Cell-LCC 500 (Omega, Stamford, CT) was used to measure force for both strength tests. Subjects were provided with immediate force measurement feedback by a digital transducer (Omega) and were verbally encouraged to obtain the highest force possible.

During elbow flexion, each subject stood with a metal harness to limit shoulder movement. The harness was suspended from a strap behind the subject's neck. It crossed the subject's chest and lay behind her triceps. Both arms remained fixed at the sides, with the right elbow bent to a flexion of 1.92 rad (radians) and a strap positioned over the styloid process and attached to the force transducer.

Isometric knee extension strength was measured with the subject sitting in a chair with the right knee extended to 1.92 and again at 2.44 rad. Hip movement was limited by securing the subject to the chair at the thighs and torso. Force production was measured 1 in. (2.54 cm) above the malleolus, where a strap was positioned and attached to the force transducer. IEMG was recorded during each contraction at the knee extension angles of 1.92 and 2.44 rad to normalize data during the stand–sit task. Subjects were given three practice trials, followed by three MVICs at each test angle. The average of the two highest values for each angle was used for statistical analysis.

Electrode and Goniometer Placement

As a way to measure IEMG, bipolar silver–silver chloride (Ag–Ag/Cl) 2mm in diameter, electromyography surface electrodes (Rochester Electro-Medical, Inc., Tampa, FL) were placed one electrode width apart in a longitudinal line with the quadriceps, and over the biceps muscle according to standard procedures (15). The right ear lobe was used for placement of the ground wire. All leads had an impedance of less than 10 k Ω. The knee joint angle was measured by using an electronic goniometer (ELGON). The goniometer was secured to the lateral aspect of the right leg with the axis of rotation at the knee joint and with the goniometer arms extending an equal distance above and below the knee, and aligned to the lateral malleolus and greater trochanter. A manual goniometer was used to measure and maintain elbow joint position at 1.92 rad during all elbow flexion tests.

Electromyography–ELGON and Computer Interface

At each collection point, the raw electromyography (EMG) signal was recorded over a 6-second time period, sampled at a rate of 100 Hz, and processed through a Grass Polygraph D.C. Amplifier (Quincy, MA), integrated with a time constant of 100 ms. The IEMG, along with the ELGON analog data, was stored in a Gateway 2000 4DX-66 Computer System LabVIEW program (Windows 3.1, National Instruments, Austin, TX).

Standing Test

With arms folded across the chest, each subject stood from and sat into a standardized chair with a seat height of 44 cm and a firm seating surface (50 cm wide). The chair was centered side to side on a platform so that foot placement was flat, 11 cm apart, and 2 cm from the front edge of the platform. The procedure began and ended with subject knee angle positioned at 1.4 rad to horizontal. Women unable to maintain a 1.4 rad knee flexion and foot contact with the force platform had an appropriate number of boards placed under their feet to raise them to the proper height. Subjects were instructed when to stand and sit. Velocity was controlled by viewing the angular joint position of the knee as recorded on a computer monitor. Angle change upon standing and sitting resulted in the vertical displacement of a screen cursor, allowing the subjects to match a preset rate of ascent and descent. IEMG data were collected over 6 seconds during standing (1.92 and 2.44 rad) and sitting (2.44 and 1.92 rad). Several practice trials were administered before testing. Three tests were conducted, with the test most closely matching the predetermined velocity used for analysis. Test–retest reliability in our lab for the two trials most closely matching the predetermined velocity was $R = .87$. IEMG at 1.92 and 2.44 rad during standing and sitting was normalized by dividing by the IEMG recorded during MVICs at knee extension angles of 1.92 and 2.44 rad, respectively.

Weight-Loaded Walking Test

Subjects walked on a treadmill for 4 minutes at 2 miles/h while carrying a simulated box of groceries with the right arm. The box was filled with sand equivalent to a weight that was 30% of the subject's elbow flexion MVIC. A metal harness was suspended from behind the neck to prevent shoulder movement and to maintain position of the right arm. Elbow flexion was maintained at 1.92 rad with the use of a manual goniometer. IEMG data at the biceps brachii were recorded for a 6-second time period at 00:10, 2:00, and at 3:45 from the beginning of the test. IEMG was normalized by dividing the results of the carry test by the IEMG obtained during elbow flexion MVIC.

Lower arm mass had to be accounted for as it contributed to the load being carried at 1.92 rad elbow flexion. Because the younger women possessed significantly greater lower arm mass than the older women, lower arm mass was included as a covariate during the carry task.

Analysis of Data

The means and standard deviations for all quantitative data were calculated for both groups (young and old). Independent *t* tests were used to compare mean observations between groups. Relationships among limb LTM, strength, and age were analyzed by using Pearson product moment correlations and first-order partial correlations. Differences between groups for the stand–sit task were analyzed with a two-way analysis of variance (ANOVA) with repeated measures and a two-way analysis of covariance (ANCOVA) with repeated measures, with limb LTM and knee extensor strength as covariates. Young–old was the fixed factor and joint position was the repeated measure. Differences between groups for the carry task were also analyzed with repeated measures two-way ANOVA and two-way ANCOVA, with lower arm mass, limb LTM, and carried weight as covariates. Young–old was the fixed factor and time was the repeated measure. The general linear models procedure of SPSS (SPSS, Inc., Chicago, IL) was used with the statistical significance determined at $p \leq .05$.

Results

Characteristics of the study population are shown in Table 1. Weight, height, BMI, and percentage of body fat were not significantly different between the younger and older women; however, overall LTM was significantly higher in the younger women (38.5 vs 35.5 kg, $p = .028$). Table 1 also provides regional body composition measurements of upper leg (knee extensors), total arm and upper arm (primary location of elbow flexors), and strength measures for the right side of the body. The older women had 15% and 14% less LTM in the legs and arms, respectively, and 23% and 10% less strength for the knee extensors and elbow flexors compared with the younger women ($p < .05$).

Significant inverse correlations (Table 2) were observed between age and MVIC for knee extension ($r = -.524$, $p < .01$) and elbow flexion ($r = -.354$, $p < .05$). Upper leg LTM was significantly related to maximum knee extension ($r = .464$, $p < .01$), whereas upper and total arm LTM were significantly related to MVIC for elbow flexion ($r = .514$, $p < .01$; $r = .561$, $p < .01$). After upper leg LTM was adjusted for, a significant inverse correlation remained between age and maximum knee extension (partial, $R = -.338$, $p < .05$). After upper arm or total arm LTM was ad-

Table 1. Subject Characteristics

Parameter	Young ($n = 20$)	Old ($n = 21$)	*p* Value
Demographics			
Weight (kg)	65.3 ± 8.7	62.3 ± 9.0	.279
Height (cm)	163.9 ± 7.7	163.6 ± 5.4	.894
Body mass index (kg/m^2)	24.2 ± 2.0	23.5 ± 3.0	.343
% Fat mass (% total weight)	34.2 ± 5.1	35.8 ± 7.1	.413
Fat free, bone free, lean tissue (kg)	38.5 ± 4.6	35.5 ± 3.4	.028
Regional body composition measures			
Upper arm lean mass (kg)	1.64 ± 0.23	1.47 ± 0.26	.006
Total arm lean mass (kg)	2.35 ± 0.36	2.02 ± 0.37	<.001
Lower arm mass (kg)	4.73 ± 0.48	4.02 ± 0.42	<.001
Upper leg lean (kg)	1.09 ± 0.33	0.91 ± 0.15	.023
Strength measures			
Elbow Flexion 1.92 radian (N)	178 ± 26.5	160 ± 47.0	.026
Knee Extension 1.92 radian (N)	433 ± 118.0	330 ± 65.0	.001

Note: Subject characteristics are mean ± standard deviation.

Table 2. Correlations of Strength, Age, and LTM of the Upper Leg and Arm

	Max. Knee Extension		Max. Elbow Flexion		
	Unadjusted	Adj. for Upper Leg LT	Unadjusted	Adj. for Upper Arm LT	Adj. for Total Arm LT
Age	−0.524*	−0.338**	−0.354**	−0.231	−0.154
Upper leg LT	0.464**				
Upper arm LT			0.514*		
Total arm LT			0.561*		

Notes: LT = lean tissue; LTM = LT mass.
$^{*}p < .01$; $^{**}p < .05$.

justed for, there was no longer a significant relationship between maximum elbow flexion and age (Table 2).

A repeated measures ANOVA was used to compare nIEMG at knee joint angles of 1.92 and 2.44 rad in the younger and older women during standing and sitting. The group effect was significant at $p < .01$. Figure 1 represents the means of this repeated measures ANOVA. Older women used a higher percentage of maximum IEMG than younger women at all standing and sitting joint positions. Overall, the nIEMG changed significantly across all subject knee joint angles, but there was no joint angle by group interaction. Repeated measures ANCOVA means (covariates upper leg lean tissue and knee extensor strength) are shown in Table 3. With upper leg lean tissue as a covariate, there was no overall change in the nIEMG as a result of change in knee angle, and the nIEMG at each joint angle remained significantly different between groups. No interaction between knee joint angle and group on nIEMG was observed; however, the group effect still remained significant (p = .004). In the same ANCOVA model, a significant group effect remained (p = .014) when both the covariates of upper leg LTM and knee extensor strength were included.

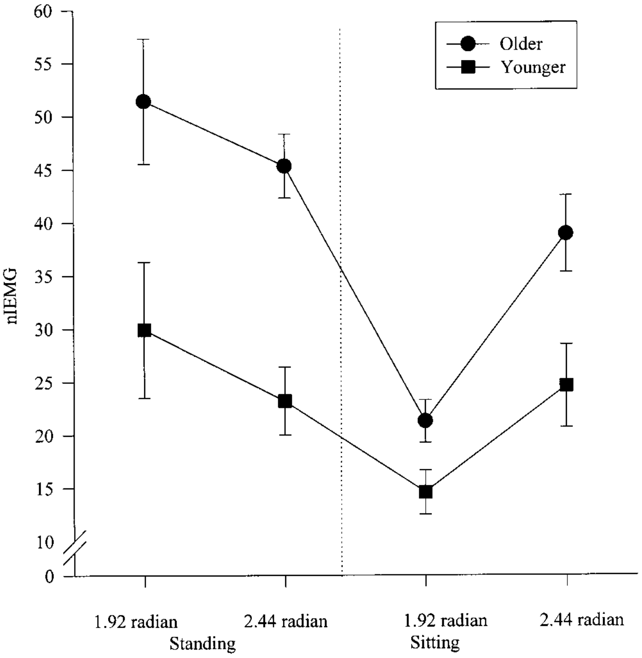

Figure 1. Two-way repeated measures analysis of variance of the percentage of maximum knee extension IEMG (nIEMG) at measured knee angles during the stand–sit task; $p < .01$ represents the overall significant difference between young and old across different knee joint angles. Data are means ± SEM.

A repeated measures ANOVA was used to evaluate differences in nIEMG of the elbow flexors between groups during the carry task (absolute means are presented in Table 3). Overall, the change in nIEMG across time was significant at p = .021. The group effect was also significant (p = .019), with the younger women averaging a higher nIEMG value. This same repeated measures model was performed again with the covariates of carried weight, lower arm mass, and total arm lean tissue. No significant differences in nIEMG were found between groups when these covariates were added to the model (Table 3).

DISCUSSION

These cross-sectional data indicate that, compared with younger women, older women have reduced strength and increased difficulty in doing daily tasks. After either leg or arm LTM was adjusted for, these differences persisted in the legs but not in the arms. These results suggest that age-related reductions in muscle mass are responsible for most of the loss of function in the arms, but additional factors appear to contribute to the loss of function in the legs.

Age, Knee Extensor Strength, and Upper Leg Lean Tissue

Several factors may contribute to the age-related decline in knee extensor strength: poor nutrition; pain; decreased flexibility and range of motion; or atrophy of type II muscle fibers (12,13,16). Because the older women in this study were healthy and free of joint pain, the most plausible explanation for these results may be a disproportionate atrophy of type II muscle fibers. Preferential decline of type II fiber cross-sectional area in leg muscle is a consistent finding in cross-sectional studies of age, strength, and muscle mass (17–20).

Type I muscle fibers are the primary fiber used for maintenance of posture and slow, low-intensity movements. Changes in muscle fiber type that occur with aging may be related to changes in the functional demands of muscle over long periods of time (21). A slowing of leg movements with age, caused by decreased activity and therefore a predominance of low-threshold tonic activation of leg muscles, may contribute to the reinnervation of type II fibers by type I motor neurons. Because several studies suggest that type II muscle fibers are characteristically capable of generating more force than type I muscle fibers of similar cross-sectional area (18,22,23), a change in the size of type II muscle fibers would decrease the strength-to-cross-sectional area ratio.

Age-related changes in fiber architecture may also interfere with the development of maximum force. Lexell and Taylor (17) have found structural abnormalities in the fiber size and shape in approximately one third of all fascicles of vastus lateralis muscle in older individuals (69–74 years of age) whereas these abnormalities were rarely seen in the

Table 3. nIEMG Values for Stand–Sit and Carry Tasks

	Unadjusted*		Adj. for LT of the Upper Leg*		Adj. for Upper Leg LT & Knee Extensor Strength**	
Parameter	Older ($n = 21$)	Younger ($n = 18$)	Older ($n = 21$)	Younger ($n = 18$)	Older ($n = 21$)	Younger ($n = 18$)
Knee Joint Angle[†]						
Stand 1.92 radian	51.4 ± 33	29.9 ± 18	52.2	29.0	51.1	30.4
Stand 2.44 radian	45.3 ± 14	23.2 ± 13	44.7	23.9	43.7	25.2
Sit 2.44 radian	21.3 ± 11	14.6 ± 06	21.8	14.1	20.8	15.2
Sit 1.92 radian	38.9 ± 17	24.6 ± 15	41.1	22.1	39.6	23.8

	Unadjusted**		Adj. for LT of the Total Arm, LAM, and Carry Weight	
Carry Time[‡]	Older ($n = 21$)	Younger ($n = 20$)	Older ($n = 21$)	Younger ($n = 20$)
10 s	44.1 ± 11	51.0 ± 23	45.7	49.2
2 min	45.8 ± 14	54.9 ± 17	47.7	53.0
4 min	47.4 ± 17	64.0 ± 19	49.0	62.0

Notes: No significant interaction occurred for any repeated measures analyses; nIEMG values are expressed as percent of maximum IEMG; repeated measures analysis of variance and analysis of covariance are means ± standard deviation. IEMG = integrated electromyography; nIEMG = normalized IEMG; LT = lean tissue; LAM = lower arm mass.

[†] The p value represents an overall significant difference between young and old across different knee joint angles.

[‡] The p value represents an overall significant difference between young and old across time.

*$p < .01$; **$p < .05$.

vastus lateralis of younger individuals (19–35 years of age). The abnormalities were suggested to be the result of negligible neural stimulation (24). Structural abnormalities that occur with age and affect force production may be more easily recognized in pennate versus fusiform muscle. Pennate muscles (e.g., knee extensors) are composed of fibers that lie at an angle to the longitudinal axis of the muscle. This fiber arrangement allows for increased force production. This is in contrast to fusiform muscle (e.g., biceps brachii), in which all muscle fibers run parallel to the longitudinal axis of the muscle. The result of age-related changes in neural stimulation possibly affecting the size and shape of muscle fibers may, therefore, have a more pronounced effect on force production by the knee extensors compared with elbow flexors.

Age, Elbow Flexor Strength, and Arm Lean Tissue

Age was significantly related to elbow flexor strength before but not after an adjustment for total arm LTM. This finding suggests that the age-related decline in elbow flexor strength was primarily a function of reduced LTM of the arm. The extent of muscle and strength decline with age is probably influenced by use of the muscle. Because both sedentary younger and older women perform relatively modest work with the arms, it is possible that the majority of the age-related decline in physical activity of this group occurs in the legs. Thus, as an individual ages, relative arm activity may be maintained to a greater extent than leg activity, leading to greater inactivity-induced type II muscle fiber atrophy in the leg versus arm muscles.

Physical Tasks of Daily Living

The knee extensors were the primary leg muscles used in the performance of the standardized stand–sit task. Younger and older women in this study were of similar height and weight, so all women were moving a similar mass during this task. Though total mass was similar, the older women did have significantly less total LTM ($p < .05$) than younger women. As expected, older women experienced greater difficulty (increased nIEMG) during standing and sitting. These data suggest that the initial phase of rising from a chair requires the greatest effort from both young and old women, but with the older group using a significantly greater percentage of maximum muscular activity (51.4 vs 29.9). These results suggest a diminished reserve capacity of strength in the older women and are in agreement with previous nIEMG values obtained from similar research (2). Alexander and colleagues (25) did not record muscle electrical activity but did find that older subjects spent a greater percentage of time in the first phase of rising from a chair than did a younger group. Although the healthy older women in this current study successfully completed the task, the results from nIEMG suggest that they were stressing their knee extensors to a greater extent than the younger women.

The age-related decline in the ability to carry objects with the arms seemed to be primarily a function of muscle size and strength. Interestingly, similar results with the triceps brachii muscle were seen in nIEMG data collected by Wheeler and colleagues (2). When younger and older persons spontaneously used their arms to assist their standing from a seated position, peak nIEMG activity as well as average nIEMG activity were not statistically different between the two groups.

The data recorded in this current study suggest that other factors may influence the ability of older women to stand from and sit into a chair (Table 3). Balance, flexibility, and muscular endurance may contribute to the ability of older adults to perform these daily tasks (26,27). These data suggest that one or more of these factors may contribute to difficulty in standing from and sitting into a chair but not in carrying objects with the arm.

Conclusions

The older women in this study were not as strong as the younger women, and they experienced greater difficulty standing from and sitting into a chair than did the younger group. The relative strength difference between younger and older women was greater in the leg than in the arm despite an almost identical difference in arm and leg lean tissue. The difference in arm strength between groups appeared to be largely due to the difference in arm LTM, whereas the difference in upper leg strength between groups was only partly accounted for by upper leg LTM. Though the tasks used in this study did not test similar capacities of leg and arm function, these results indicate that muscle strength and perhaps function is reduced more in the legs than in the arms of older women. Interventions designed to reduce the age-related decline in muscle function should include whole body strengthening exercises with particular emphasis on the legs.

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REFERENCES

1. Klitgaard H, Mantoni M, Schiaffino S, et al. Function, morphology and protein expression of ageing skeletal muscle: a cross-sectional study of elderly men with different training backgrounds. *Acta Physiol Scand.* 1990;140:41–54.
2. Wheeler J, Woodward C, Ucovich RL, Perry J, Walker JM. Rising from a chair: influence of age and chair design. *Phys Ther.* 1985;65:22–26.
3. Schultz A. Muscle function and mobility biomechanics in the elderly: an overview of some recent research. *J Gerontol Biol Sci Med Sci.* 1995;50A(special issue):60–63.
4. Schulz R, Curnow C. Peak performance and age among superathletes: track and field, swimming, baseball, tennis, and golf. *J Gerontol.* 1988;43:P113–P120.
5. Overend T, Cunningham D, Kramer J, Lefcoe M, Paterson D. Knee extensor and knee flexor strength: cross-sectional area ratios in young and elderly men. *J Gerontol Med Sci.* 1992;47:M204–M210.
6. Young A, Stokes M, Crowe M. Size and strength of the quadriceps muscle of old and young women. *Eur J Clin Invest.* 1984;14:282–287.
7. Larsson L, Grimby G, Karlsson J. Muscle strength and speed of movement in relation to age and muscle morphology. *J Appl Physiol.* 1979;46:451–456.
8. McDonagh MJN, White MJ, Davies CTM. Different effects of ageing on the mechanical properties of human arm and leg muscles. *Gerontology.* 1984;30:49–54.
9. Young A, Stokes M, Crowe M. The size and strength of the quadriceps muscles of old and young men. *Clin Physiol.* 1985;5:145–154.
10. Frontera WR, Hughes VA, Lutz KJ, Evans WJ. A cross-sectional study of muscle strength and mass in 45- to 78-yr-old men and women. *J Appl Physiol.* 1991;71:644–650.
11. Jubrias S, Odderson I, Esselman P, Conley K. Decline in isokinetic force with age: muscle cross-sectional area and specific force. *Pflugers Arch.* 1997;434:246–253.
12. Fiatrone MA, Marks EC, Ryan ND, Meredith CN, Lipsitz LA, Evans WJ. High-Intensity strength training in nonagenarians: effects on skeletal muscle. *JAMA.* 1990;263:3029–3034.
13. Lexell J. Human aging, muscle mass, and fiber type composition. *J Gerontol Biol Sci Med Sci.* 1995;50A(special issue):11–16.
14. Hunter GR, Treuth MS, Weinsier RL, et al. The effects of strength conditioning on older women's ability to perform daily tasks. *J Am Geriatr Soc.* 1995;43:756–760.
15. Delagi E, Perotto A. *Anatomic Guide for the Electromyographer—The Limbs.* 2nd ed. Springfield, IL: Thomas; 1980;66–67:180–181.
16. Brown M, Sinacore DK, Host HH. The relationship of strength to function in the older adult. *J Gerontol Biol Sci Med Sci.* 1995;50A(special issue):55–59.
17. Lexell J, Taylor C. Variability in muscle fibre areas in whole human quadriceps muscle: effects of increasing age. *J Anat.* 1991;174:239–249.
18. Grimby G, Danneskiold-Samsoe B, Hvid K, Saltin B. Morphology and enzymatic capacity in arm and leg muscles in 78–81 year-old men and women. *Acta Physiol Scand.* 1982;115:125–134.
19. Stalberg E, Borges O, Ericsson M, et al. The quadriceps femoris muscle in 20–70 year-old subjects: relationship between knee extension torque, electrophysiological parameters, and muscle fiber characteristics. *Muscle Nerve.* 1989;12:382–389.
20. Lexell J, Taylor C, Sjostrom M. What is the cause of the ageing atrophy? Total number, size and proportion of different fiber types studied in whole vastus lateralis muscle from 15- to 83-year-old men. *J Neurol Sci.* 1988;84:275–294.
21. Larsson L. Morphological and functional characteristics of the ageing skeletal muscle in man. *Acta Physiol Scand.* 1978;S457:4–28.
22. Tesch P, Karlsson J. Isometric strength performance and muscle fibre type distribution in man. *Acta Physiol Scand.* 1978;103:47–51.
23. Rivero JL, Talmadge RJ, Edgerton VR. Fibre size and metabolic properties of myosin heavy chain-based fibre types in rat skeletal muscle. *J Muscle Res Cell Motil.* 1998;19:733–742.
24. Lexell J. Evidence for nervous system degeneration with advancing age. *J Nutr.* 1997;127:1011S–1013S.
25. Alexander NB, Schultz AB, Warwick DN. Rising from a chair: effects of age and functional ability on performance biomechanics. *J Gerontol Med Sci.* 1991;46:M91–M98.
26. Cress ME, Buchner DM, Questad KA, Esselman PC, de Lateur BJ, Schwartz RS. Continuous-scale physical functional performance in healthy older adults: a validation study. *Arch Phys Med Rehabil.* 1996;77:1243–1250.
27. Tanaka K, Kim HS, Yang JH, Shimamoto H, Kokudo S, Nishijima T. Index of assessing functional status in elderly Japanese men. *Appl Human Sci.* 1995;14:65–71.

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