

Age and gender comparisons of muscle strength in 654 women and men aged 20–93 yr

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Lindle, R. S., E. J. Metter, N. A. Lynch, J. L. Fleg, J. L. Fozard, J. Tobin, T. A. Roy, and B. F. Hurley. Age and gender comparisons of muscle strength in 654 women and men aged 20–93 yr. *J. Appl. Physiol.* 83(5): 1581–1587, 1997.—To assess age and gender differences in muscle strength, isometric, concentric (Con), and eccentric (Ecc) peak torque was measured in the knee extensors at a slow (0.52 rad/s) and fast (3.14 rad/s) velocity in 654 subjects (346 men and 308 women, aged 20–93 yr) from the Baltimore Longitudinal Study of Aging. Regression analysis revealed significant ($P < 0.001$) age-related reductions in Con and Ecc peak torque for men and women at both velocities, but no differences were observed between the gender groups or velocities. Age explained losses in Con better than Ecc peak torque, accounting for 30% (Con) vs. 19% (Ecc) of the variance in men and 28% (Con) vs. 11% (Ecc) in women. To assess age and gender differences in the ability to store and utilize elastic energy, the stretch-shortening cycle was determined in a subset of subjects ($n = 47$). The older women (mean age = 70 yr) showed a significantly greater enhancement in the stretch-shortening cycle, compared with men of similar age ($P < 0.01$) and compared with younger men and women (each $P < 0.05$). Both men and women showed significant declines in muscle quality for Con peak torque ($P < 0.01$), but no gender differences were observed. Only the men showed a significant decline in muscle quality ($P < 0.001$) for Ecc peak torque. Thus both men and women experience age-related losses in isometric, Con, and Ecc knee extensor peak torque; however, age accounted for less of the variance in Ecc peak torque in women, and women tend to better preserve muscle quality with age for Ecc peak torque. In addition, older women have an enhanced capacity to store and utilize elastic energy compared with similarly aged men as well as with younger women and men.

eccentric strength; gender differences

IT HAS BEEN WELL DOCUMENTED that both muscle mass and strength decline with age (17, 20). This decline is associated with an increased risk of falls (6), hip fractures (4), and adverse physiological changes, such as glucose intolerance (5) and a loss of bone mineral density (29). Consequently, these changes may predispose elderly individuals to osteoporosis, atherosclerosis, and diabetes as well as to functional limitations in activities of daily living (16).

Although many previous studies have assessed age-related declines in absolute strength by using measurements of isometric (Iso) and/or concentric (Con) force production (9, 12, 17), few studies have examined changes in eccentric (Ecc) strength with age. Information regarding the relationship between Ecc strength and age may have important functional implications

for the elderly, because Ecc muscle actions play a vital role in normal ambulatory activities by providing stabilization and deceleration forces (14, 30). The studies available suggest that Ecc strength in humans may be less affected by age than is Con strength (15, 27, 27a, 28, 32), particularly at higher velocities (15, 28). Additionally, in a preliminary study (22), we observed a gender difference in the age-associated change in Ecc strength. However, the results of gender difference with age are conflicting (15, 27, 27a, 28, 32), and these studies have used relatively small sample sizes and limited age ranges (15, 27, 27a, 28, 32). Furthermore, no data were presented in any of these studies that would provide evidence explaining gender differences in Ecc strength. Thus there is a need to further examine this issue by using a larger sample size of men and women representing a wide age range.

Age-associated changes in the mechanical and elastic properties of the passive component (connective tissue) have been postulated as one factor that could preserve Ecc strength (14). These changes could increase the resistance to stretch during an Ecc action without affecting the Con or Iso force production (15). Indeed, age-related increases in connective tissue (21) and collagen cross-linking (1) have been reported that might enhance the elastic potential and increase Ecc force production. One method of assessing the mechanical and elastic properties of the muscle *in vivo* is to measure the stretch-shortening cycle (SSC). The SSC reflects the ability of the muscle to store and recover elastic energy from an Ecc action. Gender differences in the SSC have been reported in young subjects (18), suggesting that men and women may differ in their ability to store elastic energy. Whether such gender differences persist into later life is unknown.

Muscle quality (strength per unit of muscle) is an important indicator of muscle performance and is thought to decline with age in men (9, 17, 26, 34) but not in women (33). However, gender differences have not been assessed in the same study throughout a wide age range. Furthermore, only one study has addressed the effects of age on muscle quality when using Ecc peak torque (15).

Therefore, the main purpose of this study was to compare age and gender differences in Iso, Con, and Ecc peak torque in the knee extensors. To help explain age and gender relationships to Ecc strength levels, the ability to store and utilize elastic energy was examined by using the SSC in a representative subset of subjects. The effects of age, gender, and type of muscle action (Con vs. Ecc) on muscle quality was also examined.

METHODS

Subjects. Six hundred fifty-four subjects (346 men and 308 women, aged 20–93 yr), who were already enrolled in the Baltimore Longitudinal Study of Aging (BLSA) volunteered to participate in the study. The physical characteristics of these subjects did not deviate significantly from the rest of the BLSA population. All subjects received a complete physical examination, a bone scan, a joint pain assessment questionnaire, a physical-activity questionnaire, and a functional assessment; those with clinical cardiovascular and musculoskeletal disease were excluded, as were subjects with active neck and back pain, frequent and severe joint pain, prior joint surgery, prior bone scan below normal for their age, any recent (6 mo) major surgery, or other condition that might be aggravated by testing. All subjects were asked questions on the physical-activity questionnaire concerning their involvement in weight training exercise. The average number of minutes per week was recorded, analyzed, and compared among the various age groups. Only a very small percentage of subjects (<1%) participated in any type of regular resistive exercise, and there was no significant difference in participation by age or gender. Before the study, all subjects received a complete explanation of the purpose and procedures of the investigation and gave their written informed consent. This study was approved by the Johns Hopkins Bayview Medical Center and by the University of Maryland Institutional Review Boards for Human Subjects.

Assessment of body composition. Body mass and height were measured to the nearest 0.1 kg and 0.5 cm, respectively, by using a Detecto medical beam scale. A total body scan was performed by using dual-energy X-ray absorptiometry (DEXA) (model DPX-L Lunar Radiation, Madison, WI) to determine fat mass, fat-free mass (FFM), and bone mineral content for the total body, legs, and the thigh (24) in 245 subjects. The region below the superior border of the patella was subtracted from the total leg region to define the thigh region of interest. The scanner was not available for use during the time that the remaining subjects were tested. All scans were analyzed by one investigator using the Lunar version 1.2i DPX-L program for body-composition analyses (23). Reliability was assessed by performing two total body scans, 6 wk apart on 12 older (>65 yr) male subjects. Their values were 52.94 ± 1.23 vs. 53.03 ± 1.36 kg for FFM and 22.99 ± 1.46 vs. 22.88 ± 1.43 kg for fat mass. This accounted for <1% difference between the two scans for FFM and fat mass. The scanner was calibrated daily before testing.

Measurement of muscle strength. Before this investigation, a pilot study was conducted to determine the best protocol to use for this diverse population group and to establish instrument accuracy and reliability. To accommodate all age groups (20–93 yr), the joint arc was limited to 1.22 rad (70°) and the maximal knee extension angle to 2.97 rad (170°). It has been reported that straighter knee angles can produce discomfort and cause displacement of the knee center away from the dynamometer axis of rotation (10). The dominant leg was tested to be consistent with other BLSA testing protocols. However, for comparison, the nondominant leg was also tested concentrically at 0.52 rad/s. No significant differences were found between the dominant and nondominant leg. This is consistent with other studies that have reported no significant difference between torque generated by left and right knee extensor and knee flexor muscle groups (11).

All testing was performed by using the Kinetic Communicator (Kin-Com) (model 125E, Chattecx, Chattanooga, TN) isokinetic dynamometer. Maximal voluntary Con and Ecc torque were measured in the dominant knee extensor at

angular velocities of 0, 0.52, and 3.14 rad/s (0, 30, and 180°/s). Subjects were positioned sitting with the backrest at an angle of 1.83 rad (105°), with the hip angle between 1.40 and 1.48 rad (80 and 85°) and were stabilized by using chest, waist, and thigh straps. The rotational axis of the dynamometer was aligned with the lateral femoral epicondyle and the resistance pad positioned just proximal to the lateral malleolus of the ankle joint. The Kin-Com angle reading was calibrated to the anatomic joint angle measured by a goniometer. Gravity corrections to torque were based on leg weight at 2.97 rad (170°) (3.14 rad = leg straight) and calculated by the gravity correction program in the Kin-Com software package (version 3.2). The acceleration/deceleration rate was set at low, the activation force (i.e., force threshold required for movement of the dynamometer arm) was set at 50 N, and the minimum force for lever arm movement was set at 20 N.

All subjects performed a 5-min warm-up on a stationary cycle ergometer, followed by mild stretching of the hamstring and quadriceps muscle groups. A consistent test order was applied to all subjects by measuring knee extensor Con peak torque at 0.52 and 3.14 rad/s, followed by Ecc peak torque at 0.52 and 3.14 rad/s and then isometric (Iso) peak torque. Three graded submaximal practice repetitions preceded each specific test. For each test, subjects performed three maximal efforts, separated by 30-s rest intervals. All tests were separated by a 2-min rest period. The best of the three maximal efforts was used as peak torque. The Con/Con and Ecc/Ecc test modes were utilized to avoid any possible influence in torque values due to the SSC (Con preceded by Ecc). Isometric peak torque values were obtained for the knee extensors at angles of 2.09 and 2.44 rad (120 and 140°) of knee flexion.

Peak torque was assessed by using the Kin-Com computer software (version 3.2). The force measurement was calibrated by positioning and stabilizing the lever arm level to the floor (3.14 rad) and hanging known weights of 2.27 and 4.54 kg directly on the load cell. The resulting force reported by the Kin-Com was compared with that of the actual weights. Force outputs were checked daily. A spirit angle and protractor were used to compare the Kin-Com reported angle with the measured angle. Adjustments were never needed.

Reliability of strength testing when using the Kin-Com dynamometer has been reported elsewhere (14). Nevertheless, we performed a test-retest reliability study using 10 older men to determine reliability of our specific test machine and protocol. Subjects were tested twice, separated by a 1-wk interval. For all test conditions, i.e., Iso, Con, and Ecc, torques at both test velocities in the knee flexor and knee extensor muscle groups, intraclass correlation coefficients ranged between 0.96 and 0.99. Coefficients of variation ranged between 1.5 and 7.5%, with a mean coefficient of variation value for all tests of 5%.

Table 1. Subject characteristics for stretch-shortening cycle participants

	20–35 yr	60–80 yr
Men	<i>n</i> = 14	<i>n</i> = 16
Age, yr	29.5 ± 4.4	70.4 ± 6.2
Height, cm	178.3 ± 5.5	174.5 ± 6.0
Body mass, kg	81.1 ± 13.3	83.6 ± 11.3
Women	<i>n</i> = 9	<i>n</i> = 7
Age, yr	27.3 ± 4.8	67.0 ± 8.1
Height, cm	169.1 ± 10.4	164.0 ± 3.0
Body mass, kg	70.3 ± 22.3	67.9 ± 18.8

Values are means ± SD; *n*, no. of subjects.

Table 2. Subject characteristics

	20–34 yr	35–49 yr	50–64 yr	65–93 yr
Men	<i>n</i> = 35	<i>n</i> = 86	<i>n</i> = 103	<i>n</i> = 122
Age, yr	28.5 ± 3.6	43.6 ± 4.5	57.4 ± 5.0	75.2 ± 7.0
Height, cm	179.7 ± 6.5	179.0 ± 7.9	177.7 ± 5.9	174.5 ± 6.6*
Body mass, kg	83.1 ± 17.5	86.8 ± 18.0	88.0 ± 14.1	80.8 ± 12.5
Women	<i>n</i> = 50	<i>n</i> = 120	<i>n</i> = 88	<i>n</i> = 50
Age, yr	29.1 ± 3.3	44.7 ± 3.9	55.2 ± 4.6	74.7 ± 7.7
Height, cm	166.7 ± 6.8	165.5 ± 5.7	164.0 ± 6.4	160.1 ± 7.0*
Body mass, kg	65.8 ± 11.8	69.1 ± 13.2	68.5 ± 12.8	65.7 ± 11.0

Values are means ± SD; *n*, no. of subjects. *Significantly different from all other groups ($P < 0.05$).

SSC. To examine a possible mechanism for gender differences in Ecc peak torque with age, a subgroup of subjects ($n = 47$) underwent additional testing to assess the SSC. The physical characteristics of this subpopulation are presented in Table 1.

The continuous Ecc/Con mode on the Kin-Com was used for this test. The test began with a maximal Ecc action of the knee extensors, followed immediately by a maximal Con contraction, both at an angular velocity of 0.52 rad/s. In analyzing age group and gender differences in the SSC the following equation was used: $(Con_{SSC} - Con)/Ecc_{SSC}$. The numerator yields the absolute enhancement of Con peak torque via SSC, and the denominator relates this enhancement to the Ecc force output, i.e., percentage of Ecc peak torque recovered and utilized in the subsequent Con action.

Statistical analyses. For the purpose of comparing specific age groups with regard to physical characteristics and body composition, subjects were divided into four distinct age categories (Table 2). Analysis of variance was used to compare age group and gender differences in physical characteristics (height and body mass), body composition [body mass index (BMI) %body fat (%Fat) total body and thigh nonosseous FFM, and thigh fat], and SSC. When a difference was found, a Scheffé's post hoc test was used to determine the specific comparisons that were significant. Regression analysis was used to assess age- and gender-related differences in Con, Ecc, and Iso peak torque. Significance level was set at $P < 0.05$ for analyses of physical characteristics, body composition, and SSC. However, the significance level was set at $P < 0.01$ for analysis of peak torque values to compensate for the effects of an inflated alpha level due to multiple comparisons [Bonferroni correction for multiple comparisons ($\alpha 0.5/5$)]. All analyses were performed with the SPSS for Windows (version 6.1) statistical package.

RESULTS

Physical characteristics. Physical characteristics of the subjects by age group and gender are presented in Table 2. Men were significantly taller ($P < 0.05$) and

Table 3. Total body and thigh composition in each age group

	20–34 yr	35–49 yr	50–64 yr	65–80 yr
Men	<i>n</i> = 14	<i>n</i> = 30	<i>n</i> = 35	<i>n</i> = 32
BMI, kg/m ²	25.9 ± 4.8	26.8 ± 4.4	28.1 ± 4.8	26.2 ± 3.2
%Body fat	22.3 ± 3.3	25.9 ± 6.9	29.6 ± 6.9*	28.4 ± 6.5*
TB-FFM, kg	61.4 ± 5.9	58.6 ± 6.1	56.1 ± 5.7*	53.8 ± 5.2†
T-FFM, kg	7.0 ± 1.0	6.7 ± 0.9	6.4 ± 0.9	6.1 ± 0.8*
T-Fat, kg	2.1 ± 1.1	2.4 ± 0.8	2.7 ± 1.1	2.4 ± 0.9
Women	<i>n</i> = 18	<i>n</i> = 57	<i>n</i> = 37	<i>n</i> = 11
BMI, kg/m ²	23.6 ± 4.5	24.9 ± 4.6	25.4 ± 5.2	25.3 ± 4.1
%Body fat	32.4 ± 8.3	36.2 ± 9.2	36.2 ± 9.3	38.7 ± 8.6
TB-FFM, kg	42.4 ± 4.0	39.8 ± 3.7	38.9 ± 4.6	39.1 ± 3.8
T-FFM, kg	5.1 ± 0.7	4.5 ± 0.6	4.4 ± 0.7*	1.9 ± 0.3*
T-Fat, kg	4.0 ± 1.4	4.2 ± 1.6	3.9 ± 1.8	4.2 ± 1.4

Values are means ± SD; *n*, no. of subjects. BMI, body mass index; TB-FFM, total body nonosseous fat-free mass; T-FFM, thigh nonosseous fat-free mass; T-Fat, thigh fat. *Significantly different from the 20- to 34-yr-old group ($P < 0.01$); †significantly different from the 20- to 34- and the 35- to 49-yr-old groups ($P < 0.01$).

heavier ($P < 0.05$) than women. The oldest men (65–93 yr) were significantly shorter ($P < 0.05$) than the other male age groups. There was no significant difference in body mass among the male groups. The oldest women were significantly shorter than the other three female age groups ($P < 0.05$).

Total body and thigh composition. Body composition data, including BMI, %Fat, total body FFM, thigh nonosseous FFM, and thigh fat by age group and gender are reported in Table 3. Percent body fat ranged from “fair” to “poor” for each age category, according to American College of Sports guidelines (2). Men had significantly higher BMI ($P < 0.001$), total body FFM ($P < 0.001$), and thigh FFM ($P < 0.001$) and lower %Fat ($P < 0.001$) and thigh fat ($P < 0.001$) than the women. BMI did not differ significantly by age group in either men or women (Table 3). These values are comparable to national norms (19). In men, total body FFM was significantly lower in the two older groups (50–64 and 65–93 yr old) compared with the youngest group (20–34 yr old), whereas in women there was no significant difference in total body FFM between age groups. Men and women in the 65- to 93-yr-old age group had significantly less thigh FFM compared with the 20- to 34-yr-old group.

Iso, Con, and Ecc peak torque. Results from regression analysis of absolute peak torque values for men and women are reported in Table 4. Quadratic models were used to analyze all peak torque values. As evi-

Table 4. Regression analysis of knee extensor peak torque by age, gender, and the age-by-gender interaction

Muscle Group, rad/s	B_0	B_{age}	B_{gender}	$B_{age*age}$	$B_{age*gender}$	df	<i>F</i>	<i>P</i>	<i>R</i>
KE Iso, N	734.96	0.01	-284.77	-0.05	1.63	595	130.27	<0.001	0.68
KE Con 0.52, Nm	202.34	1.34	-105.84	-0.03	0.60	605	170.51	<0.001	0.73
KE Ecc 0.52, Nm	254.86	1.45	-137.08	-0.03	0.87	594	118.14	<0.001	0.67
KE Con 3.14, Nm	150.88	0.50	-79.91	-0.02	0.48	596	205.54	<0.001	0.76
KE Ecc 3.14, Nm	234.52	2.52	-120.06	-0.04	0.49	511	112.43	<0.001	0.68

KE, knee extensor; Iso, isometric; Con, concentric; Ecc, eccentric; *B*, intercept; df, degree of freedom. Regression equation = $B_0 + B_{age} + B_{gender} + B_{age*age} + B_{age*gender}$. Gender: men = 0, women = 1. Regression equation for men: $B_0 + B_{age} + B_{age*age}$; for women: $B_0 + B_{gender} + B_{age} + B_{age*age} + B_{age*gender}$.

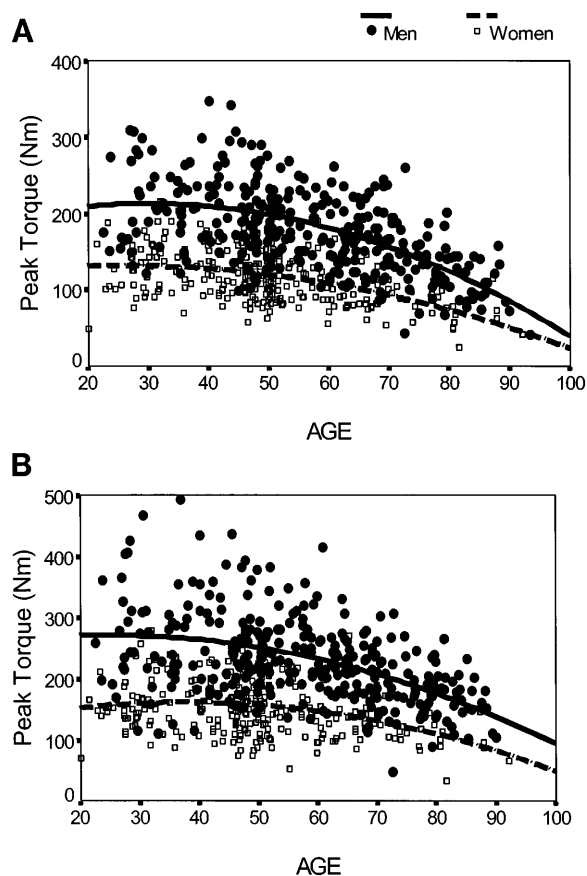


Fig. 1. Regression analysis of age- and gender-related differences in concentric (Con; A) and eccentric (Ecc; B) peak torque of knee extensors at slow (0.52 rad/s) velocity. Both Con and Ecc peak torque declined significantly (all $P < 0.001$) for men ($r^2 = 0.30$ for Con and 0.19 for Ecc) and women ($r^2 = 0.28$ for Con and 0.11 for Ecc).

denced by the beta values in the B_{gender} column of Table 4, peak torque values for men were significantly ($P < 0.001$) higher than those of women across all ages, velocities (0, 0.52, and 3.14 rad/s), and types of muscle action (Iso, Con, and Ecc). Values in the $B_{\text{age} \times \text{gender}}$ column of Table 4 show that there was a significant ($P < 0.01$) age-by-gender interaction for all muscle actions and velocities, indicating that men and women showed different patterns of change in peak torque with age. Results of univariate analyses found that both men and women experienced significant ($P < 0.001$) age-related declines in all of the variables tested. Figure 1A shows that these age-associated Con strength losses begin in the 40 s in both genders, whereas Ecc strength losses appear to occur somewhat later in women. Contrary to our hypothesis, Ecc peak torque of the knee extensors decreased with age in both women and men (Fig. 1B). However, age accounted for only 11% of the variance in Ecc peak torque for women compared with 19% for men.

Age-associated losses in Con and Ecc peak torque expressed as a percentage of the mean of the youngest group are shown in Fig. 2, A and B. In contrast to absolute peak torque values (Fig. 1, A and B), the percent decline was similar for both men and women for Con and Ecc peak torque at the slow velocity. Age

accounted for ~30% of the variance for Con and 19% for Ecc peak torque.

Muscle quality. Regression analysis of Con and Ecc peak torque (0.52 rad/s) of the knee extensors relative to thigh nonosseous FFM (muscle quality) as a function of age for men and women is presented in Fig. 3. The gender difference diminished from 37 to 9% when Con peak torque was expressed relative to muscle quality for all groups combined. However, age-related differences in muscle quality remained highly significant ($P < 0.001$) for both men and women. When Ecc peak torque was related to muscle quality, men showed a significant age-related decline ($P < 0.001$), whereas women showed no significant decline with age.

SSC. The SSC results from the subgroup are presented in Fig. 4. The SSC significantly ($P < 0.01$) enhanced Con peak torque of the knee extensors in all subject groups tested. Similar enhancement of Con peak torque via the SSC was found in young men (20%), young women (20%), and older men (15%). However, the older women showed a significantly greater ($P < 0.01$) enhancement than the other three groups. These results suggest that the older women had a greater ability to store and utilize elastic energy via the SSC.

Velocity. To assess the age- and gender-related differences in slow vs. fast Con and Ecc peak torque in the

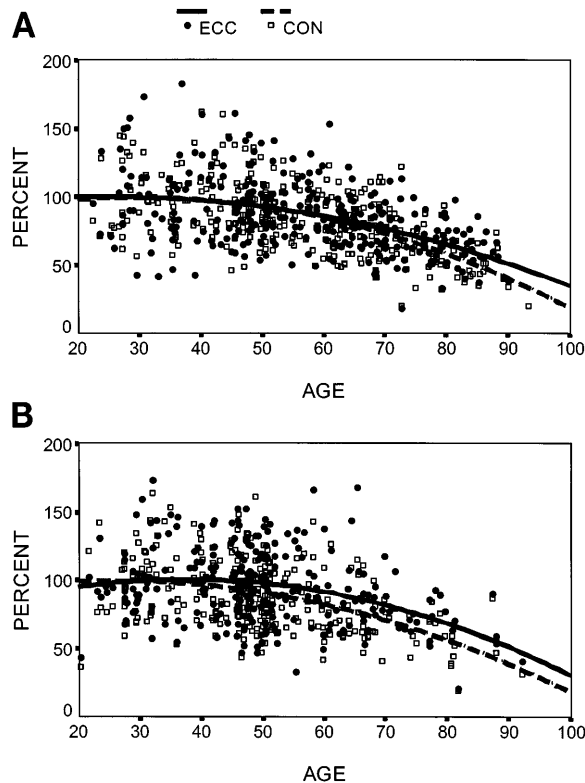


Fig. 2. Regression analysis of age- and gender-related differences in Con and Ecc peak torque of knee extensors at slow (0.52 rad/s) velocity, represented as a percentage of mean of the youngest group. Both Con and Ecc peak torque declined significantly with age ($r^2 = 0.30$ for Con and 0.19 for Ecc) for men (A) and women (B) (all $P < 0.001$), but there was no significant gender difference or age-by-gender interaction.

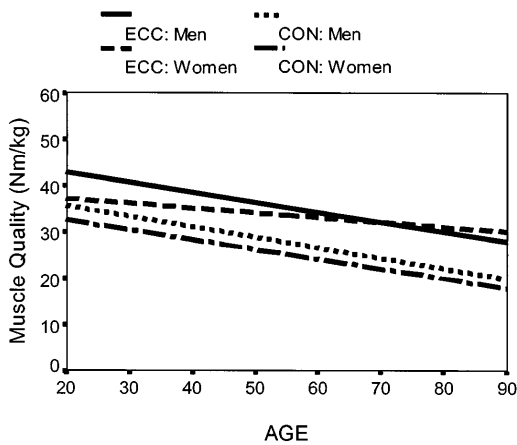


Fig. 3. Regression analysis of age- and gender-related differences in Con and Ecc peak torque (Nm) of knee extensors at slow (0.52 rad/s) velocity relative to thigh fat-free mass (FFM; kg) (muscle quality). There was a significant age ($P < 0.001$) and gender ($P < 0.001$) effect in Con muscle quality, but there was no significant interaction. Conversely, there was a significant ($P < 0.05$) age-by-gender interaction in Ecc muscle quality, but univariate analysis revealed that only men showed a significant decline ($P < 0.001$, $r^2 = 0.15$) in Ecc muscle quality.

knee extensors, regression analysis was performed on the slow (0.52 rad/s) divided by the fast (3.14 rad/s) peak torque values (Fig. 5). There was no significant age effect or age-by-gender interaction in either Con or Ecc ratios and no significant gender effect in the Ecc ratio. However, there was a significant ($P < 0.001$) gender difference in Con slow-to-fast ratio, but the difference was quite small.

DISCUSSION

The results of this study do not support the hypothesis that Ecc strength is more preserved with age than Con strength in men or women. However, age does appear to explain losses in Con strength better than losses in Ecc strength. Both men and women experience age-related losses in muscle quality when using

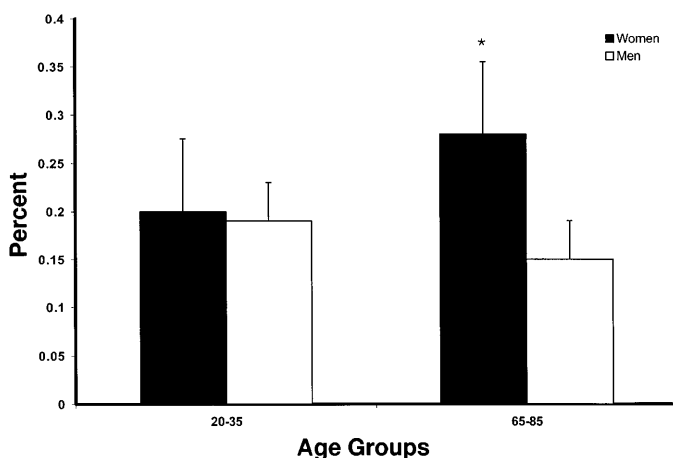


Fig. 4. Percentage of Ecc peak torque that was recovered and utilized in subsequent Con action via stretch-shortening cycle (SSC) [(SSC - Con)/Ecc] in young (20–35 yr) compared with older (65–80 yr) men and women. *Significantly different from young men ($P < 0.05$), young women ($P < 0.05$), and the older men ($P < 0.01$).

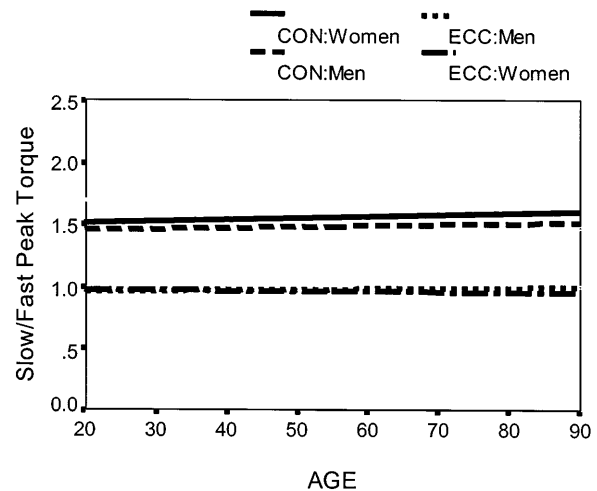


Fig. 5. Regression analysis of age- and gender-related differences in slow (0.52 rad/s) divided by fast (3.14 rad/s) velocity Con and Ecc peak torque ratios of knee extensors. There was no age or age-by-gender interaction in either Con or Ecc ratios. However, women had a significantly ($P < 0.001$) higher Con slow-to-fast velocity ratio than men.

Con strength, but only men experience these losses when using Ecc strength. Based on our SSC results from a small representative subgroup, older women have a greater capacity to store and utilize elastic energy compared with similarly aged men and younger women and men.

Investigators have concluded in previous studies that Con strength tends to peak in the 20s and 30s, then plateaus until ~50 yr of age in men and then declines at a rate of ~12–15% per decade (9, 17, 20, 34). The results of the present study show that both men and women exhibit age-related declines in knee extensor Iso and Con strength starting in the fourth decade at a rate of ~8–10% per decade in both men and women. The age-related decline for Ecc strength is about the same for men and women, but women appear to start their decline at least a decade later.

Our results differ from those of Vandervoort et al. (32), who concluded that in women Ecc strength was less affected by age than was Con. The researchers reported a difference of 53% for Con and 34% for Ecc in knee extensor peak torque between the young and the old women. Their 53% difference in Con peak torque of the knee extensors between the ages of 23 and 72 yr is considerably greater than the results of the present study (Con ~34%) and some studies previously reported (20, 25, 29). The results of the present study also slightly differ from those of Poulin et al. (28), who reported a 32% Con vs. 19% Ecc difference in peak torque of the knee extensors between young and old age groups of men at 1.57 rad/s (90°/s) and a 31% Con vs. 2% Ecc age-related difference at the faster velocity (3.14 rad/s). The men in the present study showed almost identical declines in Con (33%) compared with Ecc (31%) strength, whereas women showed more of a difference between Con (35%) and Ecc losses (22%) with age, but this difference was not significant.

Hortobagyi et al. (15) reported a gender difference in the relationship of Ecc strength and age. However, they reported nonsignificant declines in Ecc knee extensor strength with age in both men and women. The older men (70 ± 1.5 yr) generated 20% less Ecc strength than the young men (29.5 ± 1.5 yr), whereas the older women (69 ± 1.8 yr) actually exceeded the young women (29.3 ± 1.8 yr) by $\sim 10\%$ in Ecc strength. This is in contrast to the results in the present study, which found an age-related decline in Ecc knee extensor strength of $\sim 31\%$ in men and $\sim 22\%$ in women. Hortobagyi et al. (15) reported angle-specific (2.36 rad) peak force, whereas in the present study peak force was corrected for the length of the lever arm and reported as peak torque. More recently, Porter et al. (27a) reported Ecc torques of the plantar flexors and dorsiflexors in 16 older women to be 97 and 100%, respectively, of the values obtained from 16 younger women. Thus, these conflicting results may be due to differences in sample sizes, methodological differences, or other factors.

It has been postulated that changes in neural, muscular, and mechanical and/or elastic properties of muscle might contribute to a maintenance of Ecc strength with age (7, 8, 15, 28, 32). We studied the mechanical and elastic properties in the present investigation because these factors have been previously connected to a possible gender difference in Ecc strength decline with age (18), which was indicated from our preliminary findings (22). It is well established in young populations that Con peak torque is enhanced when preceded by an Ecc exertion, i.e., the SSC (10, 13, 18, 30). Prior studies have reported SSC-induced increases in Con peak torque ranging from 5 to 100%, depending on the muscle group, velocity of testing, and methodology (13, 18, 30). Additionally, gender differences in the SSC capacity of young subjects have been reported, but these differences were relatively small (18, 31). In the present study, the older women showed a significantly greater SSC enhancement than the older men, the younger men, and younger women. These results differ from those of Svantesson and Grimby (31), who did not find any age or gender-related differences in the SSC of the plantar flexors. The discrepancy between the studies may be due to differences in the populations and/or to muscle groups tested. The increased ability of the older women to store and utilize elastic energy observed in the present study suggests differences in the mechanical and elastic properties of the muscle and would appear to support our original hypothesis of a greater preservation of Ecc strength with age in women. However, Ecc strength declined similarly with age in both sexes in our overall sample.

The results of this study suggest a decline in muscle quality (strength per kilogram of regional FFM) with age in both men and women when Con strength values are used but only in men when Ecc strength is used. This finding has not been reported elsewhere. Young et al. (33) found no difference in muscle quality when comparing women in their eighth decade with those in their third decade using Con strength, whereas losses have been reported for men (9, 17, 26, 34). More

recently, Hortobagyi et al. (15) found no age-related alterations in muscle quality in either men or women when using Ecc strength values. One factor that may explain the discrepancies in the various investigations is that almost every study has used a different technique to estimate muscle mass or FFM. Creatinine excretion, hydrodensitometry, anthropometry, and bioelectrical impedance have all been used in previous studies. To the best of our knowledge, the present study is the first to examine age-related changes in muscle quality by using DEXA to assess regional nonosseous FFM.

Because of the preferential loss of type II fibers associated with aging (20), it has been postulated that older individuals might exhibit a greater loss of maximal Con peak torque at fast compared with slow velocities. However, relatively few studies have examined this relationship in a young compared to an older population, and the results are conflicting (3, 11). Additionally, some studies have reported a greater maintenance of Ecc force with age at the faster velocities (15, 28). We did not observe any differences in losses of strength with age between slow and fast velocities; however, there was a small velocity-related difference between men and women when assessing Con peak torque. Women had a greater age-related decrease in fast velocity peak torque than men.

In conclusion, the results of this study indicate that Con strength levels begin to decline in the fourth rather than in the fifth decade, as was previously reported. Contrary to previous reports, there is no preservation of Ecc compared with Con strength in men or women with advancing age. Nevertheless, the decline in Ecc strength with age appears to start later in women than in men and later than Con strength did in both sexes. In a small subgroup of subjects, there appears to be a greater ability to store and utilize elastic energy in older women. This finding needs to be confirmed by using a larger sample size. Muscle quality declines with age in both men and women when Con peak torque is used, but declines only in men when Ecc peak torque is used.

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