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


1Department of Kinesiology, College of Health and Human Performance, University of Maryland, College Park 20742; and 2Gerontology Research Center, National Institute on Aging, National Institutes of Health, Baltimore, Maryland 21224

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 differences 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. 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, 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 directly on the load cell. The resulting force reported by the 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 1-wk intervals. 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 for all tests of 5%.

Table 1. Subject characteristics for stretch-shortening cycle participants

<table>
<thead>
<tr>
<th>Age Group</th>
<th>Men</th>
<th>Women</th>
</tr>
</thead>
<tbody>
<tr>
<td>20–35 yr</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age, yr</td>
<td>29.5 ± 4.4</td>
<td>27.3 ± 4.8</td>
</tr>
<tr>
<td>Height, cm</td>
<td>178.3 ± 5.5</td>
<td>169.1 ± 10.4</td>
</tr>
<tr>
<td>Body mass, kg</td>
<td>81.1 ± 13.3</td>
<td>70.3 ± 22.3</td>
</tr>
<tr>
<td>60–80 yr</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age, yr</td>
<td>70.4 ± 6.2</td>
<td>67.0 ± 8.1</td>
</tr>
<tr>
<td>Height, cm</td>
<td>174.5 ± 6.0</td>
<td>164.0 ± 3.0</td>
</tr>
<tr>
<td>Body mass, kg</td>
<td>83.6 ± 11.3</td>
<td>67.9 ± 18.8</td>
</tr>
</tbody>
</table>

Values are means ± SD; n, no. of subjects.
Table 2. Subject characteristics

<table>
<thead>
<tr>
<th>Age Group</th>
<th>Men</th>
<th>n</th>
<th>20–24 yr</th>
<th>25–49 yr</th>
<th>50–64 yr</th>
<th>65–93 yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, yr</td>
<td>28.5±3.6</td>
<td>n=35</td>
<td>28.2±3.5</td>
<td>n=86</td>
<td>27.8±3.6</td>
<td>n=103</td>
</tr>
<tr>
<td>Height, cm</td>
<td>179.7±6.5</td>
<td>179.0±7.9</td>
<td>177.7±5.9</td>
<td>174.5±6.6*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Body mass, kg</td>
<td>83.1±17.5</td>
<td>86.8±18.0</td>
<td>80.8±14.1</td>
<td>80.8±12.5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

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

<table>
<thead>
<tr>
<th>Age Group</th>
<th>Men</th>
<th>n</th>
<th>20–24 yr</th>
<th>25–49 yr</th>
<th>50–64 yr</th>
<th>65–93 yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>BMI, kg/m²</td>
<td>25.9±4.8</td>
<td>26.8±4.4</td>
<td>28.1±4.8</td>
<td>26.2±3.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>%Body fat</td>
<td>22.3±3.3</td>
<td>25.9±6.9</td>
<td>29.6±6.9*</td>
<td>28.4±6.5*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TB-FFM, kg</td>
<td>61.4±4.9</td>
<td>58.6±6.1</td>
<td>56.1±5.7*</td>
<td>53.8±5.2*</td>
<td></td>
<td></td>
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<tr>
<td>T-FFM, kg</td>
<td>7.0±0.9</td>
<td>6.7±0.9</td>
<td>6.4±0.9</td>
<td>6.1±0.8*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T-Fat, kg</td>
<td>2.1±0.7</td>
<td>2.4±0.7</td>
<td>2.7±1.1</td>
<td>2.4±0.9</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Values are means ± SD; n, no. of subjects. BMI, body mass index; TB-FFM, total body nonosseous mass; T-FFM, thigh nonosseous 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).

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 heavier (P < 0.05) than women. The oldest men (65–93 yr) were significantly shorter (P < 0.05) and 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.

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

<table>
<thead>
<tr>
<th>Muscle Group</th>
<th>B₀</th>
<th>B_age</th>
<th>B_gender</th>
<th>B_age_gender</th>
<th>df</th>
<th>F</th>
<th>P</th>
<th>R</th>
</tr>
</thead>
<tbody>
<tr>
<td>KE Iso, N</td>
<td>734.96</td>
<td>0.01</td>
<td>-284.77</td>
<td>-0.05</td>
<td>1.63</td>
<td>595</td>
<td>130.27</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>KE Con 0.52, Nm</td>
<td>202.34</td>
<td>1.34</td>
<td>-105.84</td>
<td>-0.03</td>
<td>0.60</td>
<td>605</td>
<td>170.51</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>KE Ecc 0.52, Nm</td>
<td>254.86</td>
<td>1.45</td>
<td>-137.08</td>
<td>-0.03</td>
<td>0.87</td>
<td>594</td>
<td>118.14</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>KE Con 3.14, Nm</td>
<td>150.88</td>
<td>0.50</td>
<td>-79.91</td>
<td>-0.02</td>
<td>0.48</td>
<td>596</td>
<td>205.54</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>KE Ecc 3.14, Nm</td>
<td>234.52</td>
<td>2.52</td>
<td>-120.06</td>
<td>-0.04</td>
<td>0.49</td>
<td>511</td>
<td>112.43</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

KE, knee extensor; Iso, isometric; Con, concentric; Ecc, eccentric; B, intercept; df, degree of freedom. Regression equation = B₀ + B_age + B_gender + B_age_gender. Gender: men = 0, women = 1. Regression equation for men: B₀ + B_age + B_age_gender for women: B₀ + B_gender + B_age + B_age_gender. 

Strength, Age, and Gender
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 \( B_{age \times gender} \) 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 40s 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 \( \sim 30\% \) 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 suggests 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
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 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 \(\sim 50\) yr of age in men and then declines at a rate of \(\sim 12\text{--}15\%\) 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 \(I_{so}\) and Con strength starting in the fourth decade at a rate of \(\sim 8\text{--}10\%\) 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 Vandervoorst 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 \(\sim 34\%\)) 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 \((3.14\text{ rad/s})\). 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 \((22\%)\) losses 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 ~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 ~31% in men and ~22% in women. Hortobagyi et al. (15) reported a gender difference in the SSC of young men and older men, 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 using Con strength, whereas losses have been reported for men (9, 17, 26, 34).

In conclusion, the results of this study indicate that Con peak torque 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.

This study was supported in part by an NIADDK grant to R. Lindle and was conducted as part of the Baltimore Longitudinal Study of Aging, a component of the National Institute on Aging intramural research program. The authors thank Bernice Swann for analysis of DEXA body composition scans and J. Ryan Lindle for technical assistance. Special thanks to the research volunteers in the Baltimore Longitudinal Study of Aging, who participated in this study.

Address for reprint requests: B. Hurley, Dept. of Kinesiology, Univ. of Maryland, College Park, MD 20742.

Received 12 December 1996; accepted in final form 11 July 1997.

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