Differences in the Neuromuscular Capacity and Lean Muscle Tissue in Old and Older Community-Dwelling Adults

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Background. This study investigated whether there was a worsening of the neuromuscular capacity of older adults after the seventh decade of life.

Methods. Fifteen healthy community-dwelling old (<70 years of age) and 15 older adults (≥70 years of age) were assessed for maximal isometric strength (MVC) and force production characteristics, a one-repetition maximum (1-RM) performance, electromyographic (EMG) activity, and bone-free lean tissue (BFLT) mass of the lower extremity.

Results. The isometric MVC, 1-RM, and BFLT mass values in the old group were significantly greater than in the older group. In addition, the individual BFLT mass values correlated significantly with the isometric MVC values (r = .85) and the 1-RM scores of the thigh muscle groups (r = .54–.80). The old group generated significantly greater isometric maximal rate of torque development than the older group and performed significantly better at all intervals of the absolute and relative force-time curves. The voluntary muscle activation of the knee extensors of the old group produced significantly higher integrated EMG (iEMG) activity at each epoch in the early iEMG–time curve compared with the old group.

Conclusions. The results suggest that the age-related deterioration in maximal strength measures and rapid force production characteristics in older adults could be related to a reduction in the mass and neural activation of the thigh muscles. The deterioration of the neuromuscular system of community-dwelling older adults may contribute to an increased difficulty in performing daily activities and may increase their risks of tripping and falling.

Human muscle strength and muscle mass usually attain their peak between the ages of 20 and 30 years and to some extent remain stable until the onset of the sixth decade of life. Thereafter, maximal voluntary strength and muscle tissue begin to decline (1–5). Several mechanisms underlying aging atrophy and muscle weakness have been proposed, including a decrease in the total number of muscle fibers (5), a constant atrophy of the remaining fibers and/or a preferential loss and atrophy of Type II fibers (4), and changes in hormone balance, especially with decreased androgen levels (6). Neurological changes have also been proposed and include mechanisms such as alterations in the size, number, and firing discharge rate of surviving functional motor units (5).

Even more consequential is an age-related deterioration in rapid force of development and power, whether assessed dynamically (7) or isometrically, as demonstrated by a decreased maximal rate of force production (8). Age-related decrements in maximal strength and power can significantly compromise the functional independence of old individuals in their performance of activities of daily living (ADL) (7) and can increase the risks of tripping and falling during ambulation (7,9).

Most studies, however, have focused essentially on reporting age-related neuromuscular changes comparing young and old subjects (2,4,10) and middle-aged and old individuals (11,12). However, there appears to be a further deterioration in the neuromuscular capacity of older adults after the seventh decade of life. Grimby and colleagues (13) reported an accelerated loss of muscle cross-sectional area (CSA) with a preferential reduction in fast-twitch fibers, especially Type II-b, in subjects older than 70 years of age. Danneskiold-Samsøe and colleagues (14) found that total-body cell mass and knee extensor strength were 25% and 30% lower, respectively, in a group of 78- to 81-year-old individuals compared with a group 10 years younger. Hicks and McCartney (15) showed that a group of 60- to 70-year-old subjects was significantly stronger in evoked twitch torque and in maximal voluntary contraction of the elbow flexors than 70- to 80-year-old subjects. Collectively, these findings suggest that older adults (≥70 years old) have a further reduced capacity to generate maximal strength and rapid rates of force production capacity compared with adults <70 years old. The degeneration in turn could seriously compromise their functional independence and compound the risks of falls, along with increasing health care costs and human suffering (16).

The purpose of this study was to investigate the age-related changes in maximal strength of the major muscle groups of the lower extremity, explosive force production characteris-
tics, muscle activation of the knee extensors, and lean tissue in old (<70 years old) and older (≥70 years old) community-dwelling adults.

METHODS

Subjects
Fifteen old (63.3 ± 2.6 years) and 15 older (75.7 ± 3.9 years) subjects participated in the study. There were equal numbers of men (n = 5) and women (n = 10) in each group. The mean height and weight of the old subjects were 167.4 ± 6.9 cm and 82.3 ± 12.2 kg and the mean height and weight of the older subjects was 165.0 ± 6.5 cm and 68.1 ± 10.8 kg. The subjects were recruited from the local community and were free from any known musculoskeletal and neuromuscular conditions that limited their participation in the study. They all lived independently in the community and were screened by a physician for medical conditions indicative of the testing procedures prior to the start of the study. Approval from the Deakin University Ethics Committee was obtained, and all subjects provided written consent prior to participation in the study.

Measurements

Isometric strength testing.—Maximal voluntary isometric contraction (MVC) of the knee extensor muscles of the dominant leg was assessed using a Cybex II (New York, NY) isokinetic dynamometer. Following a warm-up consisting of three sub-maximal isometric contractions, each subject performed up to five maximal contractions with a 2-minute rest period between trials. The output from the Cybex was interfaced with an Amlab Electronics System (Associate Measurement, Sydney, Australia), which allowed the force output to be analog-to-digitally sampled at a rate of 1000 Hz.

Dynamic strength testing.—Dynamic isotonic strength testing of the major lower body muscle groups shown in Table 1 was assessed using the one-repetition maximum (1-RM) method. The 1-RM method is the maximal weight an individual can lift one time through a specified range of motion without the use of momentum or change in body position (17). Successive attempts were undertaken with a 3-minute rest between attempts until the subject could not successfully complete the lift. A maximum of three to five trials was needed to determine the 1-RM for each exercise as found in similar studies (17).

Electromyographic recording.—Surface electromyographic (EMG) activity was recorded to assess the ramp of muscle activation of the knee extensors during the early force production phase. Each subject had bipolar surface electrode modules attached over the rectus femoris (RF), vastus lateralis (VL), and vastus medialis (VM) muscles of the dominant leg. Surface electrode placement was determined according to the procedure of Delagi and Perrotto (18). Before electrode application, each site was shaved, cleansed with alcohol, and gently abraded. Skin impedance was tested to ensure it was ≤5 kΩ prior to data collection.

The EMG signal was amplified with a gain of 1000, analog-to-digital converted at a sampling rate of 1000 Hz, and full-wave rectified using an on-line Amlab data collection system.

Lower-body tissue assessment.—Bone-free lean tissue mass (g) was assessed by dual energy x-ray absorptiometry (DEXA) (DPX-L Lunar Mode, Madison, WI). A whole-body scan was performed on the basis of the anthropometric individual data input prior to scanning.

Data analysis.—From the isometric strength data, MVC and several measures of rate of torque development were calculated. MVC (Nm) was defined as the highest torque recorded during isometric leg extension. Isometric torque–time curves were computed to assess the explosive force characteristics of the neuromuscular system of elderly individuals.

<table>
<thead>
<tr>
<th>Exercises</th>
<th>Muscle Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hip extension</td>
<td>Gluteus maximus</td>
</tr>
<tr>
<td>Hip flexion</td>
<td>Iliosposas</td>
</tr>
<tr>
<td>Hip adduction</td>
<td>Adductor magnus</td>
</tr>
<tr>
<td>Hip abduction</td>
<td>Gluteus medius</td>
</tr>
<tr>
<td>Knee extension</td>
<td>Quadriceps group</td>
</tr>
<tr>
<td>Knee flexion</td>
<td>Hamstrings group</td>
</tr>
<tr>
<td>Calf raise</td>
<td>Gastrocnemius</td>
</tr>
</tbody>
</table>

The maximal isometric rate of torque development (MaxRTD) was calculated to assess the explosive force characteristics of the neuromuscular system of elderly individuals. MaxRTD (Nm/s) was defined as the steepest gradient of the torque–time curve over a given 50-millisecond time period.

EMG activity at peak torque was determined by integrating the full-wave rectified EMG signal (integrated EMG [iEMG]) over a 100-millisecond time period consisting of 50 milliseconds proceeding and 50 milliseconds following the time of peak torque (19). This variable was defined as peak iEMG activity. In addition, the iEMG data of the RF, VL, and VM were calculated separately over 100 milliseconds (μV/s) bins. An iEMG-time curve was then computed for 100-millisecond consecutive periods from the start of the contraction up to 500 milliseconds to assess the early rise in muscle activation during isometric MVC. The iEMG of each 100-millisecond interval was expressed as a percentage of each subject’s peak iEMG activity.

From the whole-body DEXA scan, a regional analysis of the thigh muscles was made from a horizontal line placed inferior of the ischium to the joint line of the femur and tibia to exclude the contribution of the hip-bone soft tissue (20). This procedure provided a better measurement of the bone-free lean tissue (BFLT) mass of the thigh muscle groups.
Percent body fat of the thigh muscles was also obtained from the same regional scan.

Statistical analysis. — Standard statistical methods were used for the computation of means, standard deviation (SD), standard error of the mean (SE), and Pearson product coefficients using the SPSS statistical software package (Version 8.00; Chicago, IL). Differences between the groups were analyzed using one-way analyses of variance. A probability level of $p < .05$ was used as the criterion for significant differences unless otherwise stated.

RESULTS

The MVC of the old group (544 ± 136 Nm) was significantly greater ($p < .01$) than that of the older group (366 ± 86 Nm). The differences between the two groups were still statistically significant ($p < .05$) when MVC was normalized to either body mass or BFLT mass. Analyses of the 1-RM measures showed that the old group was also significantly stronger ($p < .01$) in all 1-RM measures compared with the older group (Table 2). The sum of the 1-RM scores of the seven exercises revealed that the older group was 51% weaker than the old group.

The mean BFLT mass value of the thigh muscles was significantly greater ($p < .05$) in the old group (8666 ± 1956 g) compared with the older group (7348 ± 1040 g). The individual values of BFLT mass correlated significantly with the corresponding individual values of MVC of the knee extensors ($r = .851$, $p < .001$). In addition, with the exception of the seated calf raise, the individual 1-RM strength test scores correlated significantly ($p < .01$) with individual values of BFLT mass (Table 3). There were no significant differences between the two groups in the mean percentage body fat value ($44 ± 12\%$ and $40 ± 11\%$ for the old and older groups, respectively).

The old group was able to generate significantly greater isometric MaxRTD than the older group (3501 ± 1755 Nm/s and 1861.26 ± 1005 Nm/s, respectively; $p < .01$). The shape of the average torque-time curve in the absolute values differed between the two groups such that the older group took significantly longer at each interval ($p < .05$) to move between a torque of 50 Nm to 100, 150, 200, and 250 Nm (Figure 1). The older group took longer to move from 10% of MVC to 20, 30, 40, and 50% on the relative torque-time curve. However, the differences were not statistically significant between the two groups.

The analysis of the muscle activation patterns from the VL, RF, and VM showed the early iEMG–time curve was

Table 2. 1-RM Scores and Percentage Differences Between the Old (63.3 ± 2.6 years) and Older (75.7 ± 3.9 years) Groups

<table>
<thead>
<tr>
<th>Exercise</th>
<th>Old Group ($n = 15$)</th>
<th>Older Group ($n = 15$)</th>
<th>% Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leg extension, kg</td>
<td>22.83 ± 11.64</td>
<td>12.33 ± 4.57</td>
<td>46.0*</td>
</tr>
<tr>
<td>Leg curl, kg</td>
<td>13.03 ± 4.79</td>
<td>7.5 ± 2.83</td>
<td>42.1*</td>
</tr>
<tr>
<td>Hip extension, kg</td>
<td>48.66 ± 31.22</td>
<td>24 ± 9.81</td>
<td>51.68*</td>
</tr>
<tr>
<td>Hip flexion, kg</td>
<td>20.75 ± 14.95</td>
<td>12.0 ± 3.18</td>
<td>42.1*</td>
</tr>
<tr>
<td>Hip adduction, kg</td>
<td>30.17 ± 20.5</td>
<td>13.4 ± 5.75</td>
<td>55.56*</td>
</tr>
<tr>
<td>Calf raise, kg</td>
<td>16.6 ± 12.54</td>
<td>6.83 ± 3.33</td>
<td>58.86*</td>
</tr>
<tr>
<td>Calf raise, kg</td>
<td>20.2 ± 14.95</td>
<td>7.01 ± 3.18</td>
<td>65.27*</td>
</tr>
</tbody>
</table>

Note: Values are mean ± SD. 1-RM = one-repetition maximum.

*Indicates significant differences between the groups ($p < .01$).

Table 3. Pearson Correlation Coefficients Between Individual Values of Lean Tissue and Corresponding Individual Values of 1-RM Score for the Whole Sample ($n = 30$)

<table>
<thead>
<tr>
<th>1-RM Exercises</th>
<th>Free Lean Tissue Mass (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leg extension</td>
<td>0.805*</td>
</tr>
<tr>
<td>Leg curl</td>
<td>0.677*</td>
</tr>
<tr>
<td>Calf raise</td>
<td>0.263</td>
</tr>
<tr>
<td>Hip flexion</td>
<td>0.730*</td>
</tr>
<tr>
<td>Hip extension</td>
<td>0.541*</td>
</tr>
<tr>
<td>Hip adduction</td>
<td>0.792*</td>
</tr>
<tr>
<td>Hip adduction</td>
<td>0.720*</td>
</tr>
</tbody>
</table>

Note: 1-RM = one-repetition maximum.

*Indicates significant correlation values ($p < .01$).

Figure 1. Absolute torque-time curves of the knee extensor muscles during maximal isometric strength of the knee extensors showing the time taken to move from 50 Nm to 100, 150, 200, and 250 Nm in the old (<70 years) and older (>70 years) groups. *Indicates a significant difference between the two groups at $p < .05$.

Figure 2. Relative integrated electromyographic activity (iEMG)–time curves (expressed as a percentage of peak iEMG) showing the iEMG activity at 100-millisecond consecutive epochs from the start of muscle activation up to 500 milliseconds in the old (<70 years) and older (>70 years) groups. *Indicates a significant difference between the two groups at $p < .01$. 

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different between the two groups: The old group produced significantly higher iEMG \((p < .01)\) at each 100-millisecond epoch from the start of muscle activation up to 500 milliseconds compared with the older group (Figure 2).

**DISCUSSION**

The major findings of the present study of old and older community-dwelling adults showed that further declines take place in the maximal strength capacity and rapid rates of torque development in the seventh decade of life. This is the first study to show that these physiological degenerations were primarily related to a reduction of the lean tissue mass of the thigh musculature and also to a worsening in the ability to rapidly increase neural activation. The age-related degeneration in strength and explosive force characteristics of the neuromuscular system provides further evidence that community-dwelling older adults are more likely to experience difficulties in ADL and are more vulnerable to tripping and falling \((7,12)\).

**Muscle Strength**

The findings of the present study confirm the phenomenon of an accelerated age-related decline in muscle strength after the seventh decade of life. We found a 33% decline in MVC after the seventh decade of life, similar to a 30% decrease found in a group of 78- to 81-year-old individuals compared with a group 10 years younger \((14)\).

Reduction in dynamic strength after 70 years of age was also evident from the 1-RM values of several key muscle groups of the lower limb. The differences in 1-RM ranged from 42% for hip flexion to 65% for plantar flexion (Table 2). These results have several implications. First, they indicate that the isometric MVC of the knee extensors, although being a reliable and general measure of leg strength, may mask individual muscle groups that are perhaps undergoing varying rates of age-related muscle weakness. Second, functional independence for community-dwelling elderly people involves dynamic activities such as chair rising, stair climbing, and carrying groceries, and a 1-RM method is perhaps a more functionally specific strength test for older adults. Our 1-RM results, however, show that dynamic strength is severely compromised beyond the seventh decade of life, which potentially could threaten the functional capacity of older community-dwelling adults. Third, mobility is an imperative requirement for independent living, and the contribution of the hip abductors, hip extensors, knee extensors, and plantar flexor muscle groups is critical to the smooth forward translation of the center of mass during locomotion. Interestingly, these four muscle groups displayed the highest magnitudes of difference in strength between the groups, suggesting that mobility may be severely compromised in community-dwelling older adults.

**Force Production Characteristics**

Several studies have shown that aging is characterized by a worsening of the rapid force generation capacity of the neuromuscular system \((4,7,12,16)\). The 47% decline in MaxRTD reported in this study shows that a further deterioration in the rapid torque development takes place after the seventh decade of life. The decrease in the explosive capacity of the older adults was further evident for the absolute torque–time curve where they took significantly more time (almost twice) at each interval to move from a torque of 50 Nm to 100, 150, 200, and 250 Nm (Figure 1). The relative torque–time curve shows that the older adults also took longer to reach a percentage of their peak torque, although the times were not significantly different, probably due to the large variances found in the groups.

**Electromyographic Activity**

Maximal voluntary neural activation may decrease with age especially with regards to the rapid activation of the knee extensors during an isometric MVC \((8)\). As shown in Figure 2, the older group showed significantly less \((p < .001)\) iEMG activity at every 100-millisecond epoch of the iEMG–time curve. Differences in iEMG between the two groups ranged from 219% for the first interval (start of contraction to 100 milliseconds) to 379% for the last interval (401 to 500 milliseconds). A similar pattern has been reported between middle-aged and older subjects \((12)\), suggesting that the ability for rapid recruitment of motor units may decline further with aging. It could be conjectured that a worsening in the rapid rate of torque development, perhaps due to a reduced capacity to activate the muscles quickly, might expose community-dwelling older adults to a greater risk of tripping and falling. This hypothesis appears to have some support: It has been shown that the time available to make initial responses to postural disturbances is short—usually within 300 milliseconds of the disturbance \((21)\). Furthermore, simulations of tripping responses have shown that the available rates of torque development rather than maximal strength production are often critical to a successful restoration of balance in such circumstances \((9)\).

**Muscle Mass**

Muscle mass usually starts to decrease at 25 years of age, and by the fifth decade of life approximately 10% of the muscle CSA is lost. Thereafter, the atrophy accelerates, and at age 80 a decline of up to 50% of the muscle area has been reported \((4,5)\). Our study reported a reduction of 15% in BFLT mass of the thigh in the older group compared with the younger sample, confirming that aging is accompanied by muscle atrophy. Our result is comparable to a 25% decrease in total-body cell mass (calculated from total body potassium), which has been reported between similar groups \((14)\). In addition, in the present study significant correlations found between BFLT mass and isometric MVC and the summed 1-RM values of the six thigh muscle groups were relatively strong \((r = .851 \text{ and } r = .811, \text{ respectively}; p < .001)\). This finding supports the concept that age-related muscle weakness is paralleled by a reduction in muscle tissue.

However, the correlation coefficient between BFLT mass and the summed 1-RM values was lower and nonsignificant for the older group \((r = .468, p > .05)\) compared with the old group \((r = .828, p < .001)\). This finding suggests the possibility of mechanisms other than muscle atrophy underpinning age-related muscle weakness for the older group. Several qualitative factors have been proposed and include a reduction in specific muscle tension \((3)\), a degeneration of
nerve–muscle interactions (22), alterations in the size and number of functional motor units (5,23), a reduction in excitable muscle mass (24), and a slower conduction velocity (24).

Conclusion
In summary, the findings of the present study show a worsening of the neuromuscular capacity of older adults compared with old adults. Maximal strength measures deteriorate with aging with an accelerated loss of dynamic strength evident in some muscle groups. Declines in strength appear to be related to a reduction in lean tissue mass, although it cannot be excluded that older adults may have a reduced capacity to activate the muscles compared with old adults. The explosive capacity of the older adults decreases with age, suggesting that the atrophying effects of aging may have a considerable impact on fast-twitch muscle fibers. The overall deterioration of the neuromuscular system suggests that community-dwelling older adults may experience considerable decline in their functional capacity and may be further at risk of tripping and falling.

Acknowledgment
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