A 12-Year Follow-up Study of Ankle Muscle Function in Older Adults

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The purpose of this study was to examine changes in strength over time in a cohort of healthy elderly people who underwent assessments of ankle muscle function 12 years earlier. The isometric strength and contractile characteristics of the dorsiflexors and plantarflexors were studied in 11 male and 11 female subjects, ranging from 73–97 yrs (mean age 84 ± 7.1 yrs). The same footplate apparatus was used as during the original testing. From 1982 to 1994, plantarflexor strength decreased 2.1% per year in females, and 2.5% per year in males (p < .01). The loss was relatively less in the dorsiflexor muscles; strength decreased 0.3% per year in females, and 0.8% per year in males (p > .05). There were no significant changes in evoked twitch torque in either muscle group, which may be due to the fact that passive tension of the connective tissue increased (p < .01) over the 12-year period. We conclude from this longitudinal assessment of ankle muscle function that the rate of loss of voluntary strength can vary considerably between antagonistic muscle groups. Factors influencing this variable loss warrant further investigation.

Based on cross-sectional studies, it has been well established that voluntary strength declines with aging (see review by Porter et al., 1995). For example, Vandervoort and McComas (1986) reported in their study of ankle muscle function in males and females aged 20 to 100 years, that subjects in the 9th and 10th decades had, on average, 50% less strength than the youngest group. They also established that ankle strength did not begin to decline until the 6th decade of life, at a rate of approximately 1.3% per year.

Other cross-sectional studies have noted age differences in strength to a more or lesser extent (Doherty et al., 1993a), depending on the muscle group under study (proximal or distal), and the type of muscle testing done (isometric, concentric, or eccentric). However, based on their cross-sectional design, these studies are limited to describing changes at the population level, and cannot explain how a specific individual’s muscle strength changes with age. As well, they are not suited for determining whether these age-related strength declines are due to confounding secular or cohort effects.

The primary mechanism to explain the decreased strength of older vs young adults appears to be a reduced muscle mass, stemming from a loss of functioning motor units (Doherty et al., 1993b). Lexell et al. (1988) reported that while the total numbers of Type I (slow-twitch) and Type II (fast-twitch) muscle fibers are lower in older adults compared to young adults, atrophy of Type II muscle fibers is also characteristic of aging muscle. Related to this atrophy, studies by Hicks et al. (1991, 1992) have described the slowed speed of contraction of the ankle dorsiflexor muscles in older adults, and the altered response to trains of tetanic stimulation. Furthermore, long-term resistance training studies such as that by McCartney et al. (1995) have shown that strength training programs can alter muscle structure and function in older adults, thereby reversing some of the aging effects (see also Porter et al., 1995).

Longitudinal studies have examined the loss of muscle strength with aging in only the quadriceps and handgrip muscle groups. Aninson et al. (1986) reported that quadriceps strength declined 3.2% per year in their 7-year follow-up study of quadriceps strength in 23 men (73–86 yrs), while Greig et al. (1993) found that quadriceps strength was well preserved after 8 years, with only a 0.3% per year decrease, in their sample of 14 men and women with a mean age of 81.5 years. Kallman et al. (1990) reported a decline in handgrip strength of 4.1% per year in their 9-year follow-up of 80–90-year-olds from the Baltimore Longitudinal Study of Aging, while Bassey and Harris (1993) found that handgrip strength decreased 3% per year in males and 5% per year in females after 4 years, in their sample of 420 subjects over 65 years of age.

To our knowledge, there have been no similar studies reported on ankle muscle function, despite the important role these muscle groups have in standing, balance, and gait (Winter et al., 1990). Therefore, the aim of this study was to examine changes in strength over time in a cohort of healthy older adults who previously underwent ankle muscle function assessments in 1982, for the purpose of determining the longitudinal strength decline over the past 12 years.

METHODS

Subjects

Based on the list of 69 subjects (60–100 yrs) tested in the original 1982 investigation (Vandervoort and McComas, 1986), an attempt was made to locate and recruit the surviving subjects for retesting. Twenty-two subjects (11 males, 11 females, 73–97 yrs) participated in the present study; mean physical characteristics values in 1982 and 1994 are shown in Table 1. This sample was consistent with the average size and strength values obtained in 1982. The investigation carried the approval of the Ethics Committee at...
McMaster University, and each subject gave written informed consent to participate.

The subjects in the present investigation were originally selected based on health status, not on physical activity levels. All of the elderly subjects could walk independently, without aids, and most stated that daily walking was a part of their normal activity. Health status of the subjects over the past 12 years was discussed during an initial interview. After 12 years, all subjects could still walk independently (some with the use of a cane), and were involved in other activities such as gardening and light household work. All subjects were generally in good health, and there were no incidences of any debilitating ankle injuries over the past 12 years. A few reported health problems such as hip replacement and bypass surgeries, heart attacks, high blood pressure, dizzy spells, and arthritis in hands and legs. None of the subjects were taking medications that would affect muscle contractile properties, for example, beta blockers or thyroid medication. One female subject could not have anything attached to the skin on her legs and thus could not be included in the 12-year comparison of isometric twitch properties. However, values were obtained on this subject for voluntary strength and passive range of motion.

Physical activity levels were then assessed using a questionnaire for the elderly from Voorrips et al. (1991), who adapted a previous questionnaire designed for young adults by Baecke et al. (1982). The questionnaire consisted of scores for household, sporting, and leisure activities, altogether resulting in a total physical activity score for each subject. To test the validity and reliability of their test, Vorrips and colleagues administered the questionnaire to 60 free-living, healthy adults (63–80 yrs), and found a mean physical activity score of 11.0 ± 4.6, with scores ranging from 2.5 to 21.7. In the present study of 22 subjects (73–97 yrs), the mean score was 10.8 ± 7.2, ranging from 4.7 to 24.6. This score reflects mainly moderate activities such as gardening or light housework, and seldom-vigorous activities such as jogging and regular sports participation.

Measurement of Muscle Contractile Properties

The same testing apparatus that was used in 1982 was also utilized in the present investigation. All measurements were conducted on the right ankle with the subjects seated in a vertically adjustable chair with the leg flexed 90° at the knee. Isometric torque produced about the ankle joint by the dorsiflexor and plantarflexor muscles was recorded using the leg holder and footplate first employed by Marsh et al. (1981). The inclination of the foot could be altered by rotating the footplate about an axis that corresponded to that of the ankle joint. Torque acting on the footplate was sensed by strain gauges mounted on a rigid bar underneath the plate.

Adjustments to the footplate placed the muscle group under study at its optimal length for tension development, according to earlier investigations by Marsh et al. (1981) and Sale et al. (1982). The ankle was placed in 30° of plantarflexion for measurements on the dorsiflexor muscle group, and in 10° of dorsiflexion for testing the plantarflexor muscle group. Measurements of passive tension were recorded with the ankle in 10° of dorsiflexion, and 30° of plantarflexion. This measure indicates the stiffness of the musculotendinous unit for transmission of contractile tension. Passive range of motion of the plantarflexor muscles was also measured by rotating the footplate into the dorsiflexion position, as far as possible, and recording the maximum angle in degrees.

Stimulating and Recording Apparatus

Prior to electrode placement, the skin was shaved, scraped, and cleansed with alcohol, and conducting gel was applied to the electrodes in order to minimize resistance. The stimulating electrodes consisted of a lead plate cathode (radius = 15 mm) and rubber anode (37 mm × 45 mm). For the dorsiflexor muscle group, the stimulating cathode was wrapped in gauze, dampened, and secured over the common peroneal nerve just distal to the proximal head of the fibula, while the anode was placed on the anterior aspect of the leg, approximately 50 mm distal to the patella. For the plantarflexor muscle group, the pair of stimulating electrodes were placed snugly against the skin in the popliteal fossa overlying the tibial nerve, with the cathode distal to the anode.

A high-voltage stimulator (Devices System, Model 3072, Welwyn Garden City, Hertfordshire, UK) was used to deliver single 50 usec rectangular pulses to the peroneal and tibial nerves. The stimulating voltage was gradually increased until there were no further increases in evoked twitch torque; this was the voltage that was subsequently used to evoke the maximum twitch. Data were streamed continuously to disc using a Datasq waveform scrolling board (WFS-200DC, Datasq Instruments, Akron, OH) configured in an IBM-compatible computer system.

Maximum Voluntary Strength

For analysis of maximal voluntary strength (MVC), subjects were given several attempts to achieve as large a torque as possible during either a dorsiflexion or plantarflexion movement. During the MVC, the same stimulus as that used to evoke the peak twitch was given to the appropriate motor nerve, to assess the extent of motor unit activation in the muscle group under study. Attempts at MVC were continued until either no interpolated twitch was present, or in the case of incomplete activation, the torque output became constant over several trials. Post-activation potentiation was examined by eliciting a twitch 3 seconds after a 5-second maximal voluntary contraction, at the same stimulus as above, similar to the method in Vandervoort and McComas (1986).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Gender</th>
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<th>1994</th>
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<td>Age (yrs)</td>
<td>M</td>
<td>73.5 ± 7.5*</td>
<td>85.5 ± 7.5</td>
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<td>F</td>
<td>69.5 ± 6.4</td>
<td>81.5 ± 6.4</td>
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<td>Height (cm)</td>
<td>M</td>
<td>174.0 ± 7.5</td>
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<td></td>
<td>F</td>
<td>158.6 ± 5.5</td>
<td>153.9 ± 1.8*</td>
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<tr>
<td>Weight (kg)</td>
<td>M</td>
<td>70.8 ± 7.7</td>
<td>66.9 ± 9.6*</td>
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<tr>
<td></td>
<td>F</td>
<td>56.3 ± 9.1</td>
<td>54.4 ± 12.0*</td>
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</tbody>
</table>

*Values are means ± SD.

**Significant time effects indicated by asterisks.
Data and Statistical Analysis

Custom-designed Advanced CODAS software (Dataq Instruments) was used for analysis of maximum voluntary strength, as well as evoked and potentiated recordings of peak twitch torque (TT). All measurements taken in this study were compared to the 1982 values corresponding to the same subjects. The data were analyzed using a 3-factor (Gender × Leg Muscle Group × Measurement Time) mixed analysis of variance (ANOVA). Tukey A post-hoc tests were conducted whenever significant main effects and interactions were found. Level of significance was set at $p < .05$. Throughout the text, the data are presented as means ± the standard deviation (SD).

The reliability of each measurement technique was assessed by comparing values for 10 subjects on two different days. The mean reliability coefficient of 20 measurements was .905 ± .05, using the Intraclass Correlation Coefficient method, and the variation ranged from 0.2–12%.

RESULTS

Height and weight declined significantly from 1982 to 1994 for both genders (Table 1); height losses amounted to 2.5% for males and 3.0% for females, and weight decreased by 5.5% for males and 3.4% for females.

Ankle muscle stiffness. — Passive tension increased significantly for both genders, in the dorsiflexor and plantarflexor testing positions (Figure 1). Dorsiflexor values increased from a mean value of 1.83 newton meters (Nm) to 3.13 Nm ($p < .01$) from 1982 to 1994, and plantarflexor values increased from 2.49 Nm to 3.95 Nm ($p < .01$). As well, there was a decline in passive range of motion in the dorsiflexor direction of 19.4% for males ($p < .01$) and 7.0% for females ($p > .05$) (Table 2).

Isometric twitch torque. — Resting twitch torques were significantly larger for the plantarflexors than for the dorsiflexors in both testing years. There were no significant changes in twitch torque from 1982 to 1994 for either muscle group, and the trend was similar for both genders (Figure 2).

Maximal voluntary strength. — In both muscle groups, males were significantly stronger than females. There was an overall decline in voluntary strength over the past 12 years, for both genders and muscle groups (Figure 3). Plantarflexor strength decreased from 122.3 ± 39.6 Nm to 85.3 ± 25.5 Nm (30.3%) in males, and from 89.1 ± 23.0 Nm to 67.0 ± 21.8 Nm (24.8%) in females ($p < .01$). The loss was relatively less for the dorsiflexors; strength decreased from 29.5 ± 5.5 Nm to 26.7 ± 9.3 Nm (9.5%) in males, and from 21.4 ± 2.8 Nm to 20.7 ± 3.2 Nm (3.3%) in females ($p > .05$).

Voluntary strength, expressed as a ratio of body weight, decreased significantly ($p < .01$) in the plantarflexors (26.6% decline for males, and 20.8% decline for females), while the dorsiflexor strength/mass ratios remained stable (5% decline for males, and 2.6% increase for women) over the past 12 years.

Motor unit activation. — Interpolated stimulation during voluntary contractions indicated that all subjects were able to fully activate their dorsiflexor motor units, since there was no evidence of extra torque when a twitch was superimposed on the voluntary contractions. With respect to plantarflexor muscles, 9 out of 21 subjects (3 males, 6 females) could not achieve full activation. Their interpolated twitches were

![Figure 1. Passive tension values for dorsiflexor (DF) (above) and plantarflexor (PF) (below) muscles, for 11 male (left) and 10 female (right) subjects, for 1982 (open bars) and 1994 (filled bars). A main effect for time was found for both genders and muscle groups, indicated by asterisks. Values are means ± SD.](https://academic.oup.com/biomedgerontology/article-abstract/51A/3/B202/568725/2342567)

![Table 2. Passive Range of Motion (ROM) and Twitch Torque (TT) in 21 Subjects (11 Males, 10 Females)](https://academic.oup.com/biomedgerontology/article-abstract/51A/3/B202/568725/2342567)
Figure 2. Peak twitch torque values for dorsiflexor (DF) (above) and plantarflexor (PF) (below) muscles, for 11 male (left) and 10 female (right) subjects, for 1982 (open bars) and 1994 (filled bars). Values are means ± SD.

Figure 3. Maximum voluntary strength (MVC) values for dorsiflexor (DF) (above) and plantarflexor (PF) (below) muscles, for 11 male (left) and 11 female (right) subjects, for 1982 (open bars) and 1994 (filled bars). Time effect was significant for plantarflexor muscles only, for both genders, indicated by asterisks. Values are means ± SD.

relatively small, and the mean calculated motor unit activation (MUA) (based on the comparison with the resting twitch) was 83.4 ± 5.4%, ranging from 75.5% to 91.0% (method cited in Belanger and McComas, 1981). For these 9 subjects the mean loss in plantarflexor MVC was 30%, compared to 28% for the whole group.

Post-activation potentiation. — Table 2 shows the mean values for resting and potentiated twitch torques in 1982 and 1994. Dorsiflexor torque potentiated 28.6% for males and 38.1% for females in 1982, and 30.2% for males and 38.2% for females in 1994; plantarflexor values were 29.3% for males and 3.1% for females in 1982, and 41.3% for males and 33.3% for females in 1994. Overall, no significant effects for time were found in the percentage change from resting to potentiated twitch torque for either muscle group.

DISCUSSION

This is the first report of a longitudinal assessment of ankle muscle function in very old adults (mean age 83.5 yrs). Since this study examined muscle changes over a 12-year period of aging, care should be taken when comparing these results with cross-sectional studies of aging, which tend to report differences between young and old subjects.

The loss of voluntary strength from 1982 to 1994 was significantly less for the dorsiflexors than the plantarflexors (7% and 28%, respectively). Christ et al. (1992), in their study of women aged 25–74 years, also reported dorsiflexor strength was maintained to a greater degree than that of the plantarflexors. They credited the selective decline in the strength of the plantarflexors to the difference in the size of the motor nerves innervating the two antagonistic ankle muscle groups. Type II fibers, which are more numerous in plantarflexor muscles (e.g., gastrocnemius), are innervated by larger motor neurons that tend to be affected before smaller ones during aging (Kanda et al., 1986). Based on human autopsy studies, the tibialis anterior and the soleus muscles have been found to consist of mostly Type I fibers (around 73% and 87%, respectively), whereas the gastrocnemius, the larger plantarflexor muscle, is made up of approximately equal proportions of Type I and Type II fibers (Johnson et al., 1973).

Changes in postural activity of leg muscles could also contribute to greater Type II fiber atrophy. Primarily Type I motor units are recruited at moderate force levels. Because slower-moving older adults rarely reach high force levels or produce rapid movements, it is likely that Type IIb motor units are rarely recruited (McDonagh et al., 1984). Winter et al. (1990) studied walking patterns of the healthy elderly compared with young adults, and found the former adopt a safer, more stable gait pattern. For example, elderly subjects used a shorter step length, an increased support stance period, decreased push-off power, and a more flat-footed
landed that required less power from their plantarflexors and dorsiflexors.

Several mechanisms have been proposed to explain the age-related decline in muscle strength: loss of excitable muscle mass; changes in muscle morphology; changes in the nervous system and motor units; and decreased physical activity levels. Lexell et al. (1988) concluded that the loss of muscle cross-sectional area begins as early as 25 years, with approximately 10% decreased by the age of 50, and then almost 50% lost by the age of 80 years. In the present study, there was a significant decrease in body mass over the 12 years, which could be reflecting in part a loss in muscle mass, and in turn the loss in muscle strength.

With respect to the central nervous system, a progressive loss of motor neurons in the spinal cord (Lexell and Downham, 1991) leads to cycles of denervation and reinnervation within the motor unit population. As well, the number of motor units has been found to decrease beyond the age of 60 years (Campbell et al., 1973; de Koning et al., 1988; Doherty et al., 1993b), whereas the size of the remaining motor units increases with age. Vandervoort and McComas (1986) also credited the reduction in strength in part to muscle denervation, since estimates of functioning soleus motor units in five of the oldest subjects were reduced by 70%, likely well past the point where reinnervation could maintain the normal strength (de Koning et al., 1988).

The ability to voluntarily activate the entire motor unit population is another important issue when measuring muscle strength. In the present study, the retested subjects were all able to maximally activate their dorsiflexor muscles, which is in agreement with the study by van Schaik et al. (1992) that reported 96% motor unit activation. With respect to plantarflexor muscles, full motor unit activation is not as easily achieved (Belanger and McComas, 1981; Belanger and Quinlan, 1982). Forty-three percent (9 out of 21) of our subjects could not reach full activation, compared to 22% (14 out of 63) subjects (60–100 yrs) in Vandervoort and McComas’s study (1986). Thus, central activation of the plantarflexor muscles appears to be affected to a greater extent than the dorsiflexors in older adults and may play a small role in the differential strength loss.

Two factors contributing to movement about the ankle joint are passive tension and range of motion. Passive resistive force of the dorsiflexors and plantarflexors increased from 1982 to 1994, while range of motion decreased. These findings have been confirmed in other studies of aging ankle muscles (Vandervoort et al., 1992). The increased muscle stiffness is thought to be due to the accumulation of connective tissue within the muscle (Lexell et al., 1988; Rice et al., 1989; Overend et al., 1992). Cross-sectional areas taken of the plantarflexors have shown that although elderly limbs were of similar overall shape and exterior girth to young adults, the actual muscle size was smaller and there were greater amounts of noncontractile tissue located within its boundaries (Rice et al., 1989). Thus, the weaker dorsiflexor muscles of older adults have greater passive stiffness to overcome when attempting to lengthen the antagonist group and dorsiflex the ankle.

Resting isometric twitch torque values were similar when compared to 1982 values for both muscle groups. The lack of any decline in twitch torque was not unexpected, as other investigations from our laboratory have also reported similar twitch torques between young and old adults (Hicks et al., 1991; van Schaik et al., 1994). Vandervoort and McComas (1986) reported reduced twitch torque values in elderly (60–100 yrs) compared to young adults (20–29 yrs); however, the greatest decline occurred in the 60–69-year-old group, with smaller changes thereafter. The mean age of the subjects who were retested for the present investigation was 71.5 years in 1982, somewhat past the age when the greatest change occurred.

Following a maximal voluntary contraction, increased twitch torque was observed, as has been previously reported for these and other muscle groups (Belanger and Quinlan, 1982; Belanger et al., 1983; Vandervoort et al., 1983; Alway et al., 1987). Post-activation potentiation is thought to increase the state of readiness of muscle for movement. One proposed mechanism underlying twitch potentiation is that fast myosin light chains become phosphorylated, which increases the sensitivity of the contractile element to activation by calcium (Houston et al., 1985). Previously, the capacity for twitch potentiation had been thought to decrease with aging (Vandervoort and McComas, 1986; Petrella et al., 1989; Hicks et al., 1991); however, no significant differences were found in the percent of twitch potentiation from 1982 to 1994, for either muscle group.

In summary, the rate of decline in voluntary strength in this longitudinal study of ankle muscle function in older adults was greater for the plantarflexors than for the dorsiflexors; and in the former case, it was consistent with the 1982 cross-sectional data (Vandervoort and McComas, 1986). In the future, it would be of interest to examine this issue prospectively with more subjects, including detailed analysis of the factors responsible for the apparent maintenance of twitch torque. It would also be useful to conduct a longitudinal study of structural changes in muscle and connective tissue using a technique such as magnetic resonance imaging; this would provide insight regarding the apparent differences in rate and extent of age-related losses in antagonistic skeletal muscles.

The loss of muscle strength with aging, and its reversibility with resistance training programs, has received increased attention in recent years due to important links between muscle impairment and disability in the elderly age group (Frontera et al., 1988; Brown et al., 1990; Fiatarone et al., 1990, 1994; McCartney et al., 1995). Given the importance of plantarflexor muscles to standing, balance and gait, continued research in this area is needed to enhance our ability to promote independent living, and increase the quality of life of our expanding elderly population.

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