Differences in Muscle Endurance and Recovery Between Fallers and Nonfallers, and Between Young and Older Women

Kristen I. Schwendner,¹,³ Alan E. Mikesky,²,³ Worthé S. Holt, Jr.,⁴ Munro Peacock,¹ and David B. Burr¹,³

Background. Significant morbidity and mortality are associated with falls in older adults. We tested the hypothesis that older women with a history of falls demonstrate decreased muscle endurance and longer recovery times following fatiguing exercise.

Methods. We evaluated dynamic endurance and recoverability of the quadriceps femoris of 29 young women (YW) (M age = 21.7), 26 older women with a history of falls (FA) (M age = 73.3), and 27 older women with no history of falls (NF) (M age = 71.2) using an isokinetic dynamometer. Subjects performed repeated maximal concentric knee extensions until the force output of two consecutive repetitions fell below 50% of their maximal voluntary contraction (MVC). Recovery was defined as the time required for the return of force output > 80% MVC for 2 consecutive repetitions, within a set consisting of 3 maximal contractions. One-minute rest was allowed between sets. We collected electromyographic (EMG) data from the quadriceps during all testing to evaluate spectral shifts.

Results. ANOVA with a post-hoc Bonferroni-Dunn test revealed time to fatigue was significantly faster in FA than YW (p < .02) and in FA than NF (p < .05), but not different between YW and NF. Time to recovery was significantly slower in FA than YW (p = .01), but not different between YW and NF, or between FA and NF. EMG median frequency power shift (from the beginning to the end of the test) was significantly less in FA (p < .001) than either YW (p < .002) or NF (p < .05).

Conclusions. Older women with a history of falls demonstrate decreased muscular endurance compared to YW and NF, and increased time to recover from fatiguing exercise when compared to young women.

AGING involves changes in muscular function (1–5), which may relate to the increase in falls in elderly people (6). These falls are not random events (7) nor are they the “inevitable accompaniment of aging” (8), and many of them may be preventable. Determination of the risk factors associated with falls in the elderly will aid in formulation of prevention strategies. Understanding changes in muscle function with aging is an important aspect in the development of these prevention strategies.

There are conflicting reports about the ability of older adults to withstand muscle fatigue. Cupido et al. (5) and Klein et al. (9) reported that, despite predicted changes in neuromuscular apparatus with age, muscle endurance (when tested by electrical stimulation) was not significantly different between older and younger adults. Using isokinetic fatigue testing, Laforest et al. (10) and Aniansson et al. (11) found endurance of the knee extensors was not influenced by age. Conversely, there are reports of decreased endurance in the elderly when force at the end of a fatigue bout is compared to force at the beginning of a fatigue bout (fatigue index) (12–15). The equivocal findings regarding muscle endurance and aging warrant further investigation.

Prudham and Evans (16) reported 28% of the older adults surveyed in one community experienced one or more falls over a one-year period. Fifty percent of those who fall will do so on more than one occasion (8). With this repetitive cycle there is an increased fear of falling, decreased voluntary ambulation, and loss of mobility. These restrictions of activity lead to a decreased ability to remain autonomous, and eventual need for institutionalization. Falls and instability are mentioned as contributing factors in 40% of nursing home admissions (8).

AGING involves changes in muscular function (1–5), which may relate to the increase in falls in elderly people (6). These falls are not random events (7) nor are they the “inevitable accompaniment of aging” (8), and many of them may be preventable. Determination of the risk factors associated with falls in the elderly will aid in formulation of prevention strategies. Understanding changes in muscle function with aging is an important aspect in the development of these prevention strategies.

There are conflicting reports about the ability of older adults to withstand muscle fatigue. Cupido et al. (5) and Klein et al. (9) reported that, despite predicted changes in neuromuscular apparatus with age, muscle endurance (when tested by electrical stimulation) was not significantly different between older and younger adults. Using isokinetic fatigue testing, Laforest et al. (10) and Aniansson et al. (11) found endurance of the knee extensors was not influenced by age. Conversely, there are reports of decreased endurance in the elderly when force at the end of a fatigue bout is compared to force at the beginning of a fatigue bout (fatigue index) (12–15). The equivocal findings regarding muscle endurance and aging warrant further investigation.

Prudham and Evans (16) reported 28% of the older adults surveyed in one community experienced one or more falls over a one-year period. Fifty percent of those who fall will do so on more than one occasion (8). With this repetitive cycle there is an increased fear of falling, decreased voluntary ambulation, and loss of mobility. These restrictions of activity lead to a decreased ability to remain autonomous, and eventual need for institutionalization. Falls and instability are mentioned as contributing factors in 40% of nursing home admissions (8).

AGING involves changes in muscular function (1–5), which may relate to the increase in falls in elderly people (6). These falls are not random events (7) nor are they the “inevitable accompaniment of aging” (8), and many of them may be preventable. Determination of the risk factors associated with falls in the elderly will aid in formulation of prevention strategies. Understanding changes in muscle function with aging is an important aspect in the development of these prevention strategies.

There are conflicting reports about the ability of older adults to withstand muscle fatigue. Cupido et al. (5) and Klein et al. (9) reported that, despite predicted changes in neuromuscular apparatus with age, muscle endurance (when tested by electrical stimulation) was not significantly different between older and younger adults. Using isokinetic fatigue testing, Laforest et al. (10) and Aniansson et al. (11) found endurance of the knee extensors was not influenced by age. Conversely, there are reports of decreased endurance in the elderly when force at the end of a fatigue bout is compared to force at the beginning of a fatigue bout (fatigue index) (12–15). The equivocal findings regarding muscle endurance and aging warrant further investigation.

Prudham and Evans (16) reported 28% of the older adults surveyed in one community experienced one or more falls over a one-year period. Fifty percent of those who fall will do so on more than one occasion (8). With this repetitive cycle there is an increased fear of falling, decreased voluntary ambulation, and loss of mobility. These restrictions of activity lead to a decreased ability to remain autonomous, and eventual need for institutionalization. Falls and instability are mentioned as contributing factors in 40% of nursing home admissions (8).

AGING involves changes in muscular function (1–5), which may relate to the increase in falls in elderly people (6). These falls are not random events (7) nor are they the “inevitable accompaniment of aging” (8), and many of them may be preventable. Determination of the risk factors associated with falls in the elderly will aid in formulation of prevention strategies. Understanding changes in muscle function with aging is an important aspect in the development of these prevention strategies.

There are conflicting reports about the ability of older adults to withstand muscle fatigue. Cupido et al. (5) and Klein et al. (9) reported that, despite predicted changes in neuromuscular apparatus with age, muscle endurance (when tested by electrical stimulation) was not significantly different between older and younger adults. Using isokinetic fatigue testing, Laforest et al. (10) and Aniansson et al. (11) found endurance of the knee extensors was not influenced by age. Conversely, there are reports of decreased endurance in the elderly when force at the end of a fatigue bout is compared to force at the beginning of a fatigue bout (fatigue index) (12–15). The equivocal findings regarding muscle endurance and aging warrant further investigation.

Prudham and Evans (16) reported 28% of the older adults surveyed in one community experienced one or more falls over a one-year period. Fifty percent of those who fall will do so on more than one occasion (8). With this repetitive cycle there is an increased fear of falling, decreased voluntary ambulation, and loss of mobility. These restrictions of activity lead to a decreased ability to remain autonomous, and eventual need for institutionalization. Falls and instability are mentioned as contributing factors in 40% of nursing home admissions (8).

AGING involves changes in muscular function (1–5), which may relate to the increase in falls in elderly people (6). These falls are not random events (7) nor are they the “inevitable accompaniment of aging” (8), and many of them may be preventable. Determination of the risk factors associated with falls in the elderly will aid in formulation of prevention strategies. Understanding changes in muscle function with aging is an important aspect in the development of these prevention strategies.

There are conflicting reports about the ability of older adults to withstand muscle fatigue. Cupido et al. (5) and Klein et al. (9) reported that, despite predicted changes in neuromuscular apparatus with age, muscle endurance (when tested by electrical stimulation) was not significantly different between older and younger adults. Using isokinetic fatigue testing, Laforest et al. (10) and Aniansson et al. (11) found endurance of the knee extensors was not influenced by age. Conversely, there are reports of decreased endurance in the elderly when force at the end of a fatigue bout is compared to force at the beginning of a fatigue bout (fatigue index) (12–15). The equivocal findings regarding muscle endurance and aging warrant further investigation.

Prudham and Evans (16) reported 28% of the older adults surveyed in one community experienced one or more falls over a one-year period. Fifty percent of those who fall will do so on more than one occasion (8). With this repetitive cycle there is an increased fear of falling, decreased voluntary ambulation, and loss of mobility. These restrictions of activity lead to a decreased ability to remain autonomous, and eventual need for institutionalization. Falls and instability are mentioned as contributing factors in 40% of nursing home admissions (8).
muscle endurance and recoverability of muscle to risk for falling. We hypothesize that women who have experienced one or more falls have lower endurance and need a longer recovery time than either younger women or older women who have not fallen.

METHODS

Power analysis prior to the beginning of the study revealed that it was necessary to have 21 subjects per group in order to have 90% power to determine a 10% difference in time to fatigue. This analysis used muscle endurance data from young adults (21). Twenty-nine active young women (21.6 yrs), and 53 older women (>65 yrs) volunteered to perform fatigue and recovery tests on an isokinetic dynamometer (KINCOM 500H, Chattanooga, Chattanooga, TN). The older women were selected from a group of older adults participating in an osteoporosis study. Participation was solicited via phone survey, excluding women with conditions that precluded their involvement in strenuous physical activity (had been advised by their physicians to avoid exercise), and those with prosthetic knees or hips. The group of older women consisted of 26 women with a history of falls (M age = 73.2 yrs) and 27 without a history of falls (M age = 71.1 yrs). Fallers were defined as those who had experienced a fall (unexplained contact with the ground) during the previous 18 months based on data reported from a monthly calendar each woman maintained as part of the osteoporosis study. Young women were recruited from the university campus through the use of posted notices. Older women fallers and nonfallers were matched by height. All demographic data are reported in Table 1, and number of falls for older women in Table 2. The study was approved by the Indiana University Institutional Review Board, and was in accordance with American College of Sports Medicine guidelines regarding use of human subjects. All subjects signed an informed consent.

Isokinetic testing. — The young subjects underwent an isokinetic familiarization session at least 48 hours prior to testing. The older women were involved in a study using the KINCOM, and thus were familiar with isokinetic testing. At the beginning of the testing session, subjects were seated on the KINCOM, and the thorax, pelvis, thigh, and ankles were stabilized using padded straps. The peak force of a 5-repetition strength test was used as each subject’s maximum voluntary contraction (MVC). A computer screen displayed continuous feedback of force output during the test. Markers were set at 80% and 50% of the subject’s MVC. The 80% marker was used to help motivate subjects, as they were instructed to maintain a contraction force greater than this level for as long as possible. The 50% marker was used by the investigator for termination of the test.

The muscle endurance test involved repeated concentric contractions of the quadriceps until the force output fell below 50% MVC for 2 consecutive repetitions. During the recovery phase, subjects performed 3 maximal contractions beginning 30 seconds after completion of the endurance test. This was repeated every 60 seconds thereafter until the subject recovered to 80% MVC, or performed a maximum of 15 sets. Recovery was defined by force output of 2 consecutive repetitions ≥ 80% of the MVC.

Electromyography. — We measured EMG activity of the quadriceps during all fatigue and recovery testing. The skin was shaved and scrubbed with isopropyl alcohol, and silver electrodes (Grass Instrument Co., Quincy, MA) were applied to the mid-thigh over the distal one-third of the rectus femoris. Electrodes were placed 25 mm apart, aligned parallel to the long axis of the muscle. Electrode leads were grounded and shielded to help eliminate external noise. Data were collected at 1000 Hz. We amplified all signals × 1000, with a band-pass filter between 10 Hz (to reduce movement artifact) and 1000 Hz. Following A to D conversion, signals were recorded, viewed, and analyzed on a Samsung 386 computer using software from RunTechnologies (Laguna Hills, CA).

Spectral analysis. — Data were filtered using a 60 Hz notch filter prior to spectral analysis, to eliminate bias of external noise. Each contractile burst consisted of approximately 1500 points, and we used 1028 points for analysis beginning at 100 ms from the onset. Bursts 2, 3, 4, and the final 3 bursts from the fatigue test were converted to the frequency domain using Fast Fourier Transforms (RunTechnologies). The respective power spectra were averaged, and median frequencies (MDF) were used for statistical comparison.

Data analysis. — Data were analyzed using StatView software (Abacus Concepts, Berkeley, CA). Comparisons among groups were made using analysis of variance with post-hoc Bonferroni-Dunn multiple comparison tests to describe interactions. Prediction measures were established using simple regression analysis. Values given are mean ± SEM.

RESULTS

Twelve subjects (11 older adults and 1 young adult) recorded unsuccessful tests (5 failed to produce consistent decline in force output during the fatigue test; 5 recorded EMG data which we were unable to analyze due to external noise; and 2 were unable or unwilling to complete the test).
These data were classified as "unsuccessful" prior to analyses and were not analyzed with the other three groups. Values from these subjects were not included in statistical analyses, nor are these women included in reported numbers of subjects tested. Thus there were 29 young women, 26 older women fallers, and 27 older women nonfallers successfully tested and reported.

Muscle strength. — Muscle strength was evaluated using the MVC of five maximal knee extensions (Figure 1). MVC was significantly different \((p < .0001)\) between the young group and each older group, but not between FA and NF. Verbal encouragement was given to all subjects in a uniform manner.

Fatigue and recovery. — The time to fatigue and time to recovery are shown in Figures 2 and 3, respectively. FA exhibited the least muscular endurance, and YA the greatest. Time to fatigue was significantly less in FA than YA \((p < .02)\) and in FA than NF \((p < .05)\), but was not different between YA and NF. Time to recovery of force output to \(> 80\% \) MVC (Figure 3) was significantly slower in FA than YA \((p = .01)\), but not different between YA and NF, or between FA and NF.

Following simple regression, age was found to be a very weak predictor of time to fatigue \((r^2 = .06)\) \((p < .05)\), but height, weight, and muscle strength (MVC) were not. Age \((r^2 = .07)\) \((p < .02)\) and time to fatigue (inversely related) \((r^2 = .085)\) \((p < .01)\) were weak predictors of time to recovery.
EMG. — Median frequencies of the EMG power spectra (MDF) were compared as a measure of spectral activity and to evaluate spectral compression (shift of the power spectrum to lower frequencies) with fatigue (Figure 4). MDF values are reported relative to nonfatigued values (1-MDF end of test/MDF beginning of test).

The frequency shift was not different between YA and NF, but was significantly less in FA than in either YA (p < .002) or NF (p < .05). At recovery to 80% MVC, MDF relative to nonfatigued values was at 93% ± 3% for YA, 86% ± 4% for NF, and 98% ± 7% for FA. These values were not significantly different among groups.

DISCUSSION

A decline in maximal force output with age is well documented (1–3). Isometric and dynamic strength increases to age 20–29 years, plateaus between 40–49 years, and decreases with age beyond 50 years (1). Our data strongly support this age-related loss of quadriceps muscle strength. There are several possible reasons for the age-related decrease in strength. There is a smaller percentage of type 2 fibers in the elderly, and a decreased type 2 to type 1 ratio (22). Davies and White (12) described a progressive decrease in alpha motoneurons and decreased conduction velocity with aging, which may be partially responsible for
selective atrophy of type 2 fibers. Inactivity in the elderly population may also be a contributing factor (1,23). Other factors related to decreased strength may include altered endocrine function (4), decreased intramuscular bloodflow, changes in the neuromuscular system (5), and decreased contractile proteins and protein metabolism (1).

Studenski et al. (24) proposed that the decline in muscle strength with age may be greater in older adult fallers than nonfallers, but we did not find differences in strength between fallers and nonfallers. All of our subjects were ambulatory older adults, many of them still active. There may be no difference in strength between our FA and NF because of their maintained activity levels. Also, testing was done at a slow contractile speed of 60° per second. This may have decreased differences in strength between older adult fallers and nonfallers.

Time to fatigue is a measure of muscular endurance. Previous studies of muscle endurance are equivocal as to the changes in muscular endurance with aging (10,23,25). Increased, decreased, and unchanged endurance are reported for older adults. Discrepancies among studies may have resulted from differences in testing protocols, subject motivation, and demographic variability. Two basic protocols have been used in previous studies to evaluate muscular endurance. In the first protocol, Thorstensson and Karlsson (26) used a 50-repetition test and studied the force output of the last three to the first three muscular contractions (fatigue index) to quantify voluntary, dynamic muscle endurance. Testing was performed with isokinetic dynamometers at 180° sec⁻¹. This index has been frequently used in evaluating muscle endurance, although the reliability of the test has been challenged (27). When utilizing electromyography (EMG) to evaluate effort during a dynamic muscle endurance test of older adults, Laforest et al. (10) found that subjects were not working maximally at the beginning of the fatigue protocol. This lack of effort will significantly confound the results of a muscle endurance test. The unchanged or enhanced endurance in elderly subjects (compared to young subjects) performing voluntary dynamic contractions may be due to lack of subject motivation which cannot be controlled well with this protocol (5). The analysis in these studies also involved a measure of muscle endurance that cannot be determined until after completion of the test. To study the progression of muscle fatigue it is necessary to use a protocol that gives simultaneous feedback about the developing state of muscle fatigue.

The second protocol uses the number of repetitions to 50% MVC as an indicator of muscle endurance. This measure of endurance allows for termination of a test at a time specific to development of fatigue for each subject. This protocol is a valid test of muscle fatigue (28) as well as a more reliable measure than the fatigue index (27). A contraction speed of 90° sec⁻¹ is often used with this protocol, and this slower contraction speed may better accommodate the decreasing strength at high speeds in the elderly (10). We used a contraction speed of 60° sec⁻¹ because it could be easily performed by older adults based on observations made during previous isokinetic testing in our lab. Visual feedback of performance, provided by markers set on a computer screen which displayed force output during the test, may have helped motivate subjects to perform at a maximal effort level during the fatigue test used in this study.

The older adults in our study were living independently and many were active. All were participating in a bone density and muscle strength study, and as such had been taking part in regular isokinetic testing, familiarizing them with the nature of isokinetic exercise. Subjects (young and older) were well motivated during muscle fatigue and recovery tests. We saw no difference between YA and NF in time to fatigue, consistent with the findings of Larsson and Karlsson (23), Aniansson et al. (11), and Laforest et al. (10). However, there was a difference (p < .02) in time to fatigue between YA and FA, and between NF and FA (p < .05). It may be that within this subpopulation of older adults at increased risk for falling there is an increased deterioration of muscle endurance.

We measured muscle endurance relative to an individual’s maximum strength. While there may be no change in the relative muscle endurance of many older women (as with the NF group), there is a decline in muscle strength. Thus, absolute endurance of older adults will be less than that of their younger counterparts. As strength decreases, absolute endurance decreases, and it will be much more fatiguing for older adults to perform such activities of daily living as climbing stairs or carrying groceries.

Time to recovery indicates muscular ability to return to maximal force-generating capacity after fatiguing exercise. This parameter may be important in relation to the risk of falling, as it describes a time period following muscle fatigue (e.g., after climbing a flight of stairs) during which older adults may be more vulnerable to falls due to their inability to produce adequate force with the weight-bearing musculature. Although time to recovery was not different between YA and NF in our study, there was an increased time to recovery (p < .02) between YA and FA. Women at risk for falling may benefit by taking extra time to relax following mildly strenuous activities. During recovery, there were no differences in MDF among the groups once quadriceps femoris function had returned to 80% of the resting levels. Therefore, although it took the FA longer to recover muscle strength following fatigue, there was no compromise to muscle electrical activity once recovered.

The power density spectrum represents the power (measured in volts) as a function of the frequency (measured in Hertz) of the EMG signal. The MDF has often been used to describe the average power of the power spectrum (e.g., 29–31). With muscle fatigue, there is a spectral compression, as the EMG frequency shifts to the lower end of the spectrum. It is generally accepted that this shift is due to changes in conduction velocity, motor unit recruitment, motor unit synchronization, and motor unit firing frequency.

With aging, there is a decrease in the type 2 (fast twitch) to type 1 (slow twitch) fiber ratio (1) in the quadriceps. As type 2 fiber area declines, we would expect to see a shift from strength to endurance in functional muscle properties, because of the properties of these individual fiber types (32). With a higher percentage of slow twitch fibers, there would be a shift in the power spectrum (resting) toward slower frequencies. The older adults in our study displayed a resting MDF that was lower than the YA. Relative shifts in MDF...
(1-MDF post-fatigue/MDF pre-fatigue) were not different between YA and NF, but were different between YA and FA (p = .001), with YA exhibiting a greater shift than FA. This suggests a difference between muscle activity of YA and the FA. Hakkinen and Komi (33) described increased lactate accumulation and greater decline in EMG MPF (mean power frequency, a second measure of “average” spectral values) in subjects with a higher percentage of type 2 fibers. This is in accordance with our findings, if in fact our YA had a greater type 2/type 1 ratio than the FA. Continued study into the specific mechanisms affecting decreased muscle function of older women fallers is necessary to fully understand these changes and to begin developing preventative strategies. Exercise programs designed to increase muscle strength (34,35) and endurance in older adults may be an important factor in fall prevention programs.

In conclusion, older women with a history of falling demonstrated decreased muscular endurance and increased time to recovery from fatiguing exercise when compared to young women and older women nonfallers. It may be that a significant decline in muscle endurance and ability to recover following fatiguing activity predisposes these women to falling.

ACKNOWLEDGMENTS

This project was funded by a Foundation Research Grant from the American College of Sports Medicine, and by GCRC PHS MO1 RR 06429. This is in accordance with our findings, if in fact our YA had a greater type 2/type 1 ratio than the FA. Continued study into the specific mechanisms affecting decreased muscle function of older women fallers is necessary to fully understand these changes and to begin developing preventative strategies. Exercise programs designed to increase muscle strength (34,35) and endurance in older adults may be an important factor in fall prevention programs.

In conclusion, older women with a history of falling demonstrated decreased muscular endurance and increased time to recovery from fatiguing exercise when compared to young women and older women nonfallers. It may be that a significant decline in muscle endurance and ability to recover following fatiguing activity predisposes these women to falling.

REFERENCES


Received July 22, 1996
Accepted December 3, 1996