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Muscle Strength and Postural Stability in Healthy, Older Women: Implications for Fall Prevention

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Background: Effect of muscle strength and balance on falls has not been well researched in healthy older women. The purpose of this study was to compare lower extremity strength and balance in older healthy women during each decade of life and to investigate which factors are different in women with a history of falling. *Methods:* We retrospectively studied 240 women age 50-89 y. Measures of muscle strength, postural stability, and incidence of falls over the past year were obtained from client charts at Texas Woman's University's Health Promotion & Research Center from 1996 to 2002. *Results:* Strength declined significantly with age in all muscle groups except knee extensors. Age, hip flexor and abductor strength, and postural stability were significantly different in women who had fallen. *Conclusions:* Strength decline was not consistent across muscle groups. Women who were older, had less hip flexor or abductor strength, or less balance were more likely to have fallen.

Key Words: aging, balance, physical activity

Impairments in muscle strength have been associated with falls, reduced function, and disability.[1, 2] About one-third of community dwelling people who are age 65 and older fall resulting in approximately 400,000 fall-related fractures annually.[3, 4] Furthermore, a fall often has a deleterious effect on the individual's independence and quality of life leading to inactivity and further decline.[5] Several studies have identified lower extremity muscle strength as a risk factor for falling,[6, 7, 8, 9, 10] but most studies included both frail and healthy older adults. Because the frail fall more frequently, they tend to influence the identification of risk factors more heavily,[8] making the effect of reduced muscle strength on incidence of falls in healthier older people less well understood. In a recent epidemiological study of high functioning 70-79 y old men and women, investigators found that fallers were more likely to be white females who reported more chronic diseases, used more medications, and

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had poorer balance and lower extremity strength.[11] Muscle strength and balance are known to decrease with aging[12, 13] but more importantly, both have been found to be modifiable with physical activity in both frail and healthy older adults.[14-19] Consequently, as people live longer, maintaining muscle strength and balance should be considered a major goal in preserving quality of life.

Beginning approximately at age 30, muscle strength declines in men and women at a rate of 10% to 15% per decade.[20] Studies also show that the rate of loss may be accelerated beyond 50 y of age.[20, 21] This accelerated loss, especially after age 55, appears to be more pronounced in women.[22] What is not well known is whether strength decline is consistent in various muscles. In a longitudinal study of muscle strength changes in older adults, Hughes, et al.[23] found that elbow and knee flexors and extensors all declined in strength with time but that women had a smaller decline ($P < 0.05$) in elbow flexor and extensor strength than men. In addition, women's knee extensor strength declined less than their knee flexors ($P < 0.01$) and more than their elbow flexors ($P < 0.0001$). That is, over a 10 y period, women's knee extensor strength declined 11.8% ± 15.5% compared to knee flexor strength which declined 17.4% ± 16.1%. Elbow flexor strength increased 2.0% ± 33.8% while elbow extensor strength declined 2.4% ± 32.9%. These findings suggest that strength may decline differently for men and women and for different muscle groups in normal aging adults. If certain muscle groups decline more rapidly with aging, then this should be considered in designing physical activity programs for maintaining muscle strength in older, well adults. That is, the muscle groups that decline most in aging women could be targeted in physical activity programs designed for older, well women.

Although several studies have shown muscle strength in the quadriceps and ankle plantar flexors to be an important factor in falls, the strength of hip musculature and its potential effect on falls has not been investigated. In a systematic review of muscle strength and falls in older adults from 1986 to 2002, Moreland et al.[24] did not identify any studies that investigated muscle strength at the hip as a risk factor for falls.

The purpose of this study was to compare muscle strength of different lower extremity muscle groups and postural stability in apparently well women during each decade of life beginning at age 50. A second purpose was to determine whether the declines in muscle strength were consistent across muscle groups. A third purpose was to determine whether age, muscle strength, or postural stability were different in women who had fallen over the past year compared to women who had not fallen.

Methods

A retrospective, cross-sectional study of 240 apparently healthy women ranging in age from 50 to 89 y was conducted. Measures of lower extremity muscle strength, postural stability, and number of falls were obtained from charts of clients seen at the Texas Woman's University Health Promotion & Research Center (HPRC) from 1996 to 2002. Women seen at the HPRC were primarily seen to institute a wellness exercise program that addresses their specific needs such as muscle strength, balance, postural faults or flexibility. However, all information collected at the HPRC was placed in a research database. Therefore, all measures were carefully taken using standardized measurement procedures established for all data collected at the HPRC. Informed consent was not required as the study qualified for exempt status as determined by the Texas Woman's University Institutional Review Board. All subjects did, however, sign a form allowing information from their charts to be used for research purposes.

Participants

Exclusion criteria included neurological, musculoskeletal, or cardiopulmonary complications that would prevent clients from participating in a simple exercise program at the HPRC. Women diagnosed with osteoporosis, defined as having bone density equal to or greater than 2.5 standard deviations below the young adult mean at any of the lumbar or femoral sites, were also excluded. The women who qualified for this descriptive study were subdivided into four age groups: 50 to 59 (n = 91), 60 to 69 (n = 76), 70 to 79 (n = 57), and 80 to 89 (n = 16).

Instrumentation

Lower extremity muscle strength and postural stability were measured using the Human Performance Measurement (HPM) system (Human Performance Measurements, Arlington, TX). The HPM is a computer-automated system that integrates a battery of tests used to evaluate a broad range of sensorimotor functions called basic elements of performance (BEP).[25] The BEP IIIa and BEP IV are components of the HPM system that were used in this study to measure muscle strength and postural stability, respectively. The BEP for Windows software was used to operate the BEP modules, record, and store data.

The BEP-IIIa is a hand-held dynamometer used to measure maximal isometric muscle force. The device is factory calibrated with respect to gain and has a gain accuracy of 1% of full scale. An offset calibration check is automatically performed each time the system is powered. Muscle torque in Newton-meters is calculated by the BEP for Windows software using estimated segment lengths based on each subject's height. The standard error associated with estimated segment lengths that are based on stature has previously been shown to be approximately 1.0 cm when compared to measured segment lengths.[26] The criterion validity of hand-held dynamometers as a measure of muscle strength has been previously determined.[27, 28] The intrarater reliability of the BEP-IIIa for measurement of lower extremity muscle strength in older adults (mean age 59.5 y) has previously been determined to be excellent ($ICC_{3,2}$ = 0.94).[29]

The BEP-IV postural stability measurement system is a lightweight, portable force platform that measures medial-lateral stability, anterior-posterior stability, and total stability by tracking changes in the center of pressure (COP) over time as the subject stands erect over one or both feet. For this study, only total stability was used for data analysis. Total stability is a measure of how well the subject is able to keep the COP centered over the base of support. Intrarater reliability for measures of postural stability obtained using the BEP-IV and the same measurement protocol used in this study was found to be excellent ($ICC_{3,2}$ = 0.95) in a previous study.[29] To measure postural stability in single stance, the BEP-IV samples COP movement at a rate of 60 samples per second over a 10 s time period. The resulting samples are then averaged over time and normalized for base of support by calculating the ratio of average movement of the COP to the size and placement of the stance foot. The resulting normalized score represents a “percent instability” score. This score is then subtracted from 100% to provide the score of percent stability used for data analysis.

Measurement Procedures

This was a retrospective study performed on existing chart data. Information available through the charts consisted of a detailed client history including documentation of fall history. For this study, number of falls experienced over the past year was the only piece of information extracted from the medical history. Next, measures of muscle strength and postural stability were extracted from the charts. Although four different physical therapists contributed to the clinical database, all therapists were trained to use the same standardized measurement procedures.

A written manual of standardized procedures developed by the primary investigator of this study was used in all participant testing at the HPRC. The following is a description of the standardized measurement procedures used to obtain all muscle strength and postural stability measurements.

First, standardized test procedures were used to obtain height measurements using a stadiometer. Height was recorded in centimeters. Next, body weight in kilograms was obtained using a platform scale with beam and moveable weights.

All muscle force measurements were taken in a gravity-lessened position, using a “make” test. To perform a make test, the examiner held the dynamometer steady with one hand while manually stabilizing the client with the other hand. Instructions to the clients were to gradually start pushing against the dynamometer, and then to increase their force until they were pushing as hard as they could. Muscle tests were performed on the following muscle groups: hip flexors, hip extensors, hip abductors, and knee extensors. The specific muscle testing position and force transducer placement used for testing each muscle group are published elsewhere.[30] Clients practiced once prior to performance of two maximum effort test trials. The mean of the two trials was then adjusted for body weight by dividing the mean strength value for each muscle group by the client’s body weight and multiplying by 100.

Plantar flexor strength was measured using the unilateral heel raise test. To perform this test, the client stood facing a treatment table, with each index finger resting on the table for balance. The examiner instructed the client to stand straight with the opposite knee bent to 90° and to rise up onto her toes using her calf muscle. She was instructed to perform this motion repeatedly without leaning forward and without pushing down on the table with her index fingers. As the client performed this motion repetitively, the therapist watched carefully that the motion was performed with no breaks in form such as leaning forward, pushing up with the index finger(s), bending the knee, or not completing the available ankle range of motion when rising up onto the toes. The number of repetitions (up to 20) the client was able to perform with good form was adjusted for body weight as described above and used for data analysis.

Postural stability in single leg stance with eyes open was measured as clients attempted to stand steadily on one barefoot extremity. The examiner first instructed each client to step onto the force platform, stand on both feet, and look straight ahead. Upon hearing an audible beep from the HPM system, the client flexed one knee to 90° and removed her hands from the table in front of her. The client then maintained this single stance posture as steadily as possible until a second beep sounded, signifying the end of the 10-s trial. The trial was terminated by the examiner before the end of the 10-s interval if clients lost their balance, and had to touch down with a hand or foot. Three trials of postural stability were measured and the BEP for Windows software calculated mean percent stability using the two trials with the most similar values. When the timed trial had to be terminated early (less than 10 s), percent stability for that trial was based on a shorter period of time. Each client was allowed one practice trial prior to the three test trials, and a 5-s rest was taken between trials.

Data Analysis

Means, standard deviations, and percent decline across each decade of life for each muscle strength variable (hip flexors, extensors, abductors, knee extensors, and plantar flexors) and for postural stability were calculated for each of the four age groups. Strength and postural stability across four decades of life were analyzed using multivariate analysis of variance (MANOVA). Univariate trend analyses were conducted across age groups for the strength and postural variables. Age, muscle strength, and postural stability were compared between women who had fallen over the past year and women had had not fallen using a second MANOVA. A significant MANOVA was followed with univariate ANOVAs and a post hoc discriminant function analysis. An alpha level of 0.05 was used for all statistical analyses.

Results

Table 1 presents means and standard deviations for subject demographics and measures of muscle strength prior to weight adjustment for each age group. Table 2 presents means and standard deviations for muscle strength adjusted for body weight and postural stability for each of the four different age groups. Adjusted strength values were used for all data analysis. Muscle strength declines were observed across each decade of life in all muscle groups with the largest decline occurring between the eighth and ninth decade. The calculated total percent decline from the sixth to the ninth decade of life for each muscle group was as follows: hip flexors (39.0%), hip extensors (29.4%), hip abductors (44.6%), knee extensors (16.0%), and plantar flexors (63.7%) (see Table 3). This decrease in strength with age across the four decades of life was statistically significant in all muscle groups ($P < 0.05$) with the exception of the knee extensors. Linear trends were significant ($P < 0.001$) for each strength measure; the postural stability trend was quadratic ($P < 0.0001$).

Table 4 shows mean age, muscle strength, and postural stability in women who had reported a fall in the past year compared to women who had not reported a fall. Forty three women reported having fallen at least once over the past year while 197

Table 1 Means (standard deviations) for Subject Height, Weight, and Non-Normalized Strength Measures Across Age Group (years)

Variables	50-59 (*n* = 91)	60-69 (*n* = 76)	70-79 (*n* = 57)	80-89 (*n* = 16)
Body weight (kg)	63.0 (15.8)	62.2 (10.8)	59.0 (10.3)	60.1 (8.2)
Height (cm)	163.8 (6.5)	162.3 (6.0)	160.2 (6.3)	157.0 (7.0)
Hip flexors (Nm)	41.7 (10.1)	36.5 (9.8)	30.1 (9.9)	24.6 (7.5)
Hip extensors (Nm)	40.7 (11.2)	40.3 (11.2)	34.7 (12.9)	28.0 (5.7)
Hip abductors (Nm)	49.7 (32.9)	41.9 (11.5)	34.6 (11.9)	26.5 (7.7)
Knee extensors (Nm)	51.0 (18.5)	50.1 (16.0)	46.6 (13.6)	41.2 (12.3)
Plantar flexors (reps)	15.5 (13.3)	13.0 (6.2)	10.2 (7.3)	5.4 (5.3)

Table 2 Means (standard deviations) for Body Weight Adjusted Muscle Strength (% body weight) and Postural Stability (%) Across Age Groups (years)

Variables	50-59 (*n* = 91)	60-69 (*n* = 76)	70-79 (*n* = 57)	80-89 (*n* = 16)
Hip flexors (%BW)	68.4 (19.6)	59.8 (16.4)	53.6 (18.5)	41.7 (13.4)
Hip extensors (%BW)	63.8 (20.7)	61.7 (19.4)	57.5 (23.7)	45.0 (15.1)
Hip abductors (%BW)	80.5 (49.4)	69.1 (21.3)	60.1 (23.2)	44.6 (13.5)
Knee extensors (%BW)	83.0 (30.1)	82.9 (28.0)	81.2 (27.2)	69.7 (21.4)
Ankle plantar flexors (%BW)	26.4 (22.9)	22.1 (11.4)	18.7 (14.4)	9.6 (10.6)
Postural stability (%)	91.7 (12.9)	85.4 (17.9)	69.8 (32.0)	18.2 (24.8)

Table 3 Percent Decline in Muscle Strength Across Each Decade of Life from the Sixth to Ninth Decade

Muscle group	6th to 7th	7th to 8th	8th to 9th	Total
Hip flexors	12.6	10.4	28.5	39.0*
Hip extensors	3.2	6.9	21.7	29.4*
Hip abductors	14.2	13.0	25.8	44.6*
Knee extensors	0.2	2.0	14.1	16.0
Ankle plantar flexors	16.0	15.5	48.8	63.7*

Note. Decline between any two decades was calculated by taking the difference between mean body weight-adjusted strength in the two decades of comparison and dividing by the mean body weight-adjusted strength of the younger decade. This value was then multiplied by 100 to yield percent decline.

Table 4 Results of ANOVA and Post Hoc Discriminant Function Analysis Comparing Age (years), Muscle Strength (percent body weight), and Postural Stability (percent) Measures Between Women Who Did Fall and Women Who Did Not Fall Over the Past Year

	Fallers (n = 43)	Non-fallers (n = 172)			
Measures	Mean (SD)	Mean (SD)	P	Effect size	Structure coefficient*
Age	66.4 (10.0)	63.2 (8.9)	0.041	–0.36	–0.49
Hip flexors	55.0 (13.7)	63.5 (20.2)	0.010	0.45	0.63
Hip extensors	58.6 (17.4)	62.4 (21.5)	0.276	0.14	0.26
Hip abductors	61.9 (18.6)	71.5 (24.1)	0.016	0.42	0.58
Knee extensors	86.3 (22.2)	83.6 (28.5)	0.571	–0.07	–0.14
Plantar flexors	19.2 (11.9)	22.8 (17.0)	0.197	0.24	0.31
Postural stability	72.8 (34.3)	83.43 (23.7)	0.018	0.45	0.57

Note. Percent body weight was calculated as (mean strength value/body weight) × 100.

*Derived from discriminant function analysis.

women reported no falls. However, because 25 participants (all non-fallers) had missing data on at least one of the strength or postural stability variables, the total sample size was reduced to 215 (43 fallers, 172 non-fallers). A MANOVA analyzing the differences between these two groups of women revealed that the differences were significant ($P < 0.05$). Post hoc univariate ANOVAs revealed significant differences ($P < 0.05$) for age, hip flexor strength , hip abductor strength, and postural stability. That is, women who were older, had lower values of hip flexor and abductor strength, or lower values of postural stability reported more falls. The structure coefficients (correlations between the dependent variables and the faller/non-faller difference) of a post hoc discriminant function analysis are provided in Table 4. The coefficients demonstrate that the non-fallers are younger and have better hip flexor strength, hip abductor strength, and postural stability than fallers.

Discussion

The results of this study indicate that strength consistently declines with each decade of life but that the amount of decline varies for each muscle group. Our results show that the largest strength decline occurred in the plantar flexors followed by the hip abductors and flexors, respectively. The smallest decline was found in the knee extensors. Our results also indicate that women who had fallen in the last year had lower values of postural stability and lower values of hip flexor and abductor strength than women who had not fallen. The groups however, were similar in measures of quadriceps and plantar flexor strength.

Our results are consistent with other studies showing muscle strength declines with age in healthy women.[22] Our study showed steady decline with each decade of life but the largest decline occurred between the eighth and ninth decade in all muscle groups tested. The decline between these two decades ranged from 14.1% for the knee extensors to 48.8% for the plantar flexors.

Although we did expect to see differences in muscle strength decline across the muscle groups tested, it was somewhat unexpected to find only a 16% decline in strength of the knee extensors from the sixth to ninth decade of life. Samson et al.[22] showed a 46% decline in isometric knee extensor strength in women between the ages of 20 and 80 y. The decline in muscle strength reported by Samson et al. was based on a cross-sectional study such as ours but with a total of only 74 women (mean age 49.0 y). Samson et al. also did not adjust the knee extensor strength data for body weight and concluded that 11% of the decline in strength was associated with height and weight differences between the young and the old. Another reason why our decline in the knee extensors may have been less than that detected by Samson et al. is that our ability to measure quadriceps strength may have been limited by tester strength. Though Samson et al. used a strain gauge to measure isometric strength in the same test position that we used in our study, they affixed the device to the lower leg with a strap, thereby removing tester strength as a variable. In our study, the physical therapist manually resisted the clients' knee extensors. Using manual resistance to measure strength of very large muscle groups has the limitation of being less sensitive to changes in muscle strength due to difficulty in stabilizing the hand-held dynamometer.[31]

It is interesting to note that in a recent study of trunk angular displacement during stand to sit transfers, older adults (mean age 75.9 y) inclined the trunk an average of 10° less than younger adults (mean age 26.8 y).[32] That is, older adults leaned forward significantly less ($P < 0.05$) when sitting down from a standing position. Although it is impossible to know why older adults may modify their stand to sit movement strategy, the investigators who conducted the study speculated that it could be a coping mechanism to address the decreased postural control experienced with aging. Regardless of the reason for the altered movement strategy, the effect of the decreased trunk angle during stand to sit is to decrease the muscle forces needed at the hip while increasing the forces that the knee extensors must generate. Habitual performance of the stand to sit transfer while maintaining a more upright trunk would tend to preserve knee extensor muscle strength while facilitating disuse of hip musculature and would support the findings in our study.

Our results showed that the largest strength decline occurred in the plantar flexors. It should be noted, however, that our use of the heel rise test to measure plantar flexor strength is perhaps a better indicator of plantar flexor muscle endurance. This test was chosen because it is the most practical and feasible way of assessing muscle performance of the plantar flexors. The heel rise test is the only accepted method of assessing plantar flexor strength in a weight-bearing position and thus is considered a better measure of a person's potential for function.[33] Lunsford and Perry advocate that a person be able to perform 25 standing heel raises whereas Hislop and Montgomery advocate 20 heel raises.[33, 34] Our study used 20 standing heel raises as the criterion for normality as advocated by Hislop and Montgomery because our subjects were older than those used in the study by Lunsford and Perry. Therefore, to measure plantar flexor muscle performance, we counted the number of heel raises that each client could perform with no breaks in form. If the subject was able to reach 20 repetitions, she was stopped. We recognize that this test is not a measure of absolute strength but we also recognize that as muscle strength of the plantar flexors decreases with age, the task of heel rising represents a greater proportion of maximal strength. As such, we feel that the heel rise test is a fair representation of plantar flexor strength.

Our study showed that women who had fallen in the last year had significantly lower values of hip flexor and abductor muscle strength but not significantly lower values of knee extensor and plantar flexor strength than women who had not fallen. This was somewhat unexpected for plantar flexors because of the high percentage of decline observed with increased age. Our findings that fallers and non-fallers had similar values of plantar flexor strength is difficult to compare to other studies because investigations of muscle strength and falls often compare different muscles or combinations of lower extremity muscles. Gehlsen and Whaley,[35] for example, compared the combined force produced by hip extensors, knee extensors, and plantar flexors in a group of non-fallers to that produced by a group of fallers and found the difference between the two groups to be statistically significant ($P < 0.01$). Graafmans et al.[36] studied various risk factors for falls and concluded that impairment of balance, knee extensor strength, and gait were strongly associated with falls but the study did not distinguish between the three factors. That is, impairment of balance, knee extensor strength, and gait were grouped under one risk factor of "mobility impairment." The association with falls was found to be strong for the mobility impairment but did not provide information about the association of knee extensor strength by itself. In a systematic review and meta-analysis of muscle weakness and falls in older adults, Moreland et al.[24] concluded that lower extremity weakness is a statistically significant and clinically important risk factor for falls. They also concluded that because most studies in the systematic review combined muscle tests to give an index of strength, it was not possible to conclude anything about the relative contribution of different muscle groups. Our study found hip flexor and abductor muscle strength to be significantly lower in women who had fallen than women who had not fallen in the last year. Moreland et al.'s systematic review of studies of muscle strength and falls from 1986 to 2002 did not identify any studies that investigated hip flexor and abductor strength as a risk factor for falls.[24]

There are limitations associated with retrospective, cross-sectional studies such as this. It should be noted, however, that Hughes et al.[23] conducted a longitudinal study of muscle strength changes in older adults and found that differences in muscle strength decline compared to cross-sectional estimates were dependent on gender and muscle group. Specifically, Hughes et al. found that longitudinally measured strength declines in knee flexors and extensors in men were 60% greater than those measured in cross-sectional studies. No differences were found, however, between longitudinal and cross-sectional measures of strength decline in knee flexors and extensors in women.

An additional limitation is the potential for cohort effects. That is, there is the possibility that the decreases in strength with age found in our study were in fact not due to the effects of ageing but to an extraneous sampling variable. Although no cause and effect can be inferred from cross-sectional studies, our study infers a trend for decreased strength with aging, particularly in certain lower extremity muscles that should be further investigated using a longitudinal or experimental design.

Muscle strength and postural stability appear to decrease steadily with age from the sixth to the ninth decade of life and the decrease appears to be accelerated in those age 80 to 89 y. Of the muscle groups tested, the plantar flexors and hip abductors declined most rapidly from the sixth to ninth decade. Women who were older, had lower values of hip flexor or abductor strength, or lower values of postural stability, were more likely to have experienced a fall over the past year. Current fall prevention programs emphasize strengthening of the knee extensors and plantar flexors. The results of the present study indicate that fall prevention programs and programs promoting physical activity in older, healthy women should include activities for strengthening hip flexors and abductors in addition to the more traditional knee extensor and plantar flexor strengthening exercises. Strengthening activities in the standing position should be encouraged in order to challenge and improve postural stability.

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