Lower extremity muscle performance associated with community ambulation in elderly fallers

ORIGINAL ARTICLE

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ABSTRACT

Background. Knowing lower extremity muscle groups associated with community ambulation functions is important for developing physical disability prevention/intervention programmes for older adults experiencing falls. We aimed to identify lower extremity muscle groups significantly associated with walking endurance, walking speed, and stepping performance among community-dwelling elderly fallers.

Methods. 17 male and 25 female community-dwelling older persons (mean age, 76 years) with at least one fall in the previous year were recruited. Mobility was measured by distance walked in 5 minutes (meters), fast walking speed (m/s), and time to step up and down a curb 5 times (step/s). Isometric muscle strength of bilateral hip flexors and extensors and knee extensors were measured by a handheld dynamometer and standardised by body mass index. The functional strength of bilateral ankle plantar flexors was measured by the heel-rise test.

Results. The ankle plantar flexor strength was significantly associated with walking endurance, gait speed, and stepping performance, accounting for 42% to 57% of the variance.

Conclusions. The functional strength of plantar flexors is an important determinant of ambulation capacity in community-dwelling elderly fallers. This finding has clinical implications for effective prevention or intervention for older adults experiencing falls.

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INTRODUCTION

Walking endurance, gait speed, and the ability to manage stairs or curbs are important physical requirements for independent ambulation in the community.[1-3] Once older persons experience difficulty in these tasks, they are at twice the risk of disability in instrumental and basic activities of daily living.[4] Thus the ability to ambulate independently in the community is an important marker of physical function.

The associations between reduced lower extremity strength, poor mobility, and functional dependence in frail elders are well known.[5-7] Fortunately, muscle does not lose its ability to respond to training, even in older persons.[8] Older persons' functional mobility performance and independence can be improved by enhancing lower extremity muscle function.[9,10] Therefore, identifying specific lower extremity muscle functions associated with such ambulation activities is important for developing disability prevention/intervention programmes.

Many studies have investigated strength/function relationships in community-dwelling elders. The strength of hip extensors (HE),[6,7] hip flexors (HF),[11] knee extensors (KE),[11,12] and ankle plantar flexors

(PF)[13] is related to mobility functions of older adults. However, lower extremity muscle strength in community-dwelling older adults who are healthy may differ from those with a history of falls and physical de-conditioning.

Thus, the current study was designed to identify the lower extremity muscle performance (measured by simple clinical tests) that was significantly associated with walking speed, walking endurance, and stair climbing in community-dwelling elderly fallers.

METHODS

Subjects

17 males and 25 females were recruited from a community centre. Initial telephone screening had excluded those with neuromusculoskeletal problems and other types of instability preventing muscle and functional performance tests. Inclusion criteria were: age of ≥60 years, ability to follow simple commands and perform the strength and functional tests, and living with family or alone in their homes. A fall was defined as coming to rest inadvertently on the floor, ground, or anywhere below knee level, but not as a consequence of a violent blow, loss of consciousness, sudden onset of paralysis, or epileptic seizure.[14] Fallers were defined as those who had experienced such an event in the past 12 months. The subjects had a mean age of 76 (standard deviation [SD], 7.5; range, 61-91) years, a mean height of 165 (SD, 10.8; range, 140-188) cm, and a mean weight of 76 (SD, 17.4; range, 40-114) kg. They gave informed consent prior to the collection of information related to their health and self-care activities, and the testing.

Procedures

Lower extremity muscle performance tests for hip and knee strength were measured with a Nicholas handheld dynamometer (Model 01160, Lafayette Instruments, Lafayette [IN], USA). The calf strength was too strong to be assessed against manual resistance with or without a handheld dynamometer. Therefore, it was most commonly tested with its functional strength (heel-rise ability) in clinic.[15,16]

The handheld dynamometer was factory-calibrated, and the force gauge was properly zeroed prior to each measurement. Maximal isometric strength of HE, HF, and KE was assessed using a 'make' test.[17] During the 'make' test, the subject pushed with maximum voluntary effort against the tester-stabilised handheld dynamometer. The bilateral muscle strength scores were summed for the final score, and the summed scores were normalised for body size (dividing the score by the body mass index). The testing procedure followed that was described in a prior study in community-dwelling elders, in which isometric strength measurements of lower extremity muscle groups was found to be reliable ($ICC_{2,1}$=0.97-0.99) and valid.[18]

Unilateral ankle PF performance was assessed with the heel-rise test.[19] Subjects performed heel rises in a one-legged standing posture with the other knee flexed and with their fingers lightly touching the back of a chair for balance. The number of repetitions of heel rises the subject could perform at a frequency of 1 Hz was recorded. During the test, one tester stood by the subjects to ensure safety and pay attention to fingers/hand placement on the back of the chair. The second tester was responsible for counting the number of heel rises and stopping the test when one of the following was noted on subjects: (1) performance of task ceased, (2) inability to raise the heel high enough to reveal a space between the heel and the floor, (3) grasping the chair or leaning forward on their hands to help raise the heel off the floor. The number of repetitions of heel rises at the 1 Hz frequency was recorded. In older adults (aged ≥60 years), the retest reliability was reported as excellent (ICC=0.94-0.98) for both legs.[19] We tested the 1-week test-retest reliability in a separate group of 10 female and 10 male community-dwelling older adults (aged 74.6±6.8 years) and found it to be acceptable for right (ICC=0.92) and left (ICC=0.77) legs.

The timed 5-step-up test was used to measure ability to step up and down a curb.[14] Subjects stood facing an 8.8 cm high step, and at the command 'ready, go', they were asked to step up onto the step and then backward down from the step 5 times as fast as possible. The time required to complete 5 steps was recorded to the nearest 0.1 second. The rate of stepping (steps/s) was calculated and used for data analysis; higher values indicated better performance. The reliability of this test in older adults is high ($r=0.97$, $p<0.001$).[14]

Table 1
Mobility ambulation measures (n=42)

Mobility tests	Mean±SD (range)	25th %	50th %	75th %
Walking endurance (m)	220.7±99.5 (24.4-396.6)	139	234	287
Fast walking speed (m/s)	0.81±0.4 (0.2-1.5)	0.56	0.81	1.1
Step test (step/s)	0.27±0.16 (0.0-0.64)	0.15	0.22	0.40

Table 2
The strength of lower extremity muscle groups (n=42)

Lower extremity muscle group	Mean (SD) muscle performance value*	Mean (SD) body mass index standardised value†
Hip flexor strength (kg)	18.8±5.8	0.7±0.3
Hip extensor strength (kg)	16.1±6.4	0.6±0.3
Knee extensor strength (kg)	23.1±9.7	0.9±0.4
Plantar flexor endurance (no. of repetitions)	17.7±16.4	-

* The performance values of each muscle group were the sum of the value from both sides
† Summed bilateral muscle strength (kg) divided by body mass index

A timed, 5-minute walk test was used to measure walking endurance.[20] This test has been found to be moderately associated with peak oxygen consumption in elderly women,[21] and have excellent test-retest reliability (r=0.92)[22] and responsiveness.[23,24] Subjects were asked to walk for 5 minutes in a rectangular hallway at the fastest speed they could maintain safely. A tester held a surveyor's wheel to measure the distance while walking with the subjects for their safety, giving standard periodic encouragement and noting the elapsed time. The distance walked was recorded in meters. The 5-minute walk test correlates moderately with peak oxygen consumption in elderly women[20] and has excellent test-retest reliability (r=0.92).[22]

A timed 50-foot walk was used to assess the fastest gait speed. Subjects were timed while they walked as fast as possible for 25 feet, turned 180°, and walked rapidly back to the starting point. The gait speed was recorded as m/s. This test is also one component of the Physical Performance Test (PPT), and its inter-rater reliability was reported to be r=0.93.[25] The test-retest reliability of this particular measure was high in our setting (ICC=0.98, p<0.0001).[14]

Data analysis

Descriptive statistics were reported for the performance values of the 4 muscle groups and the 3 community ambulation performance values.

Univariate regression analysis was performed separately for each muscle group. Muscle groups that showed significance, with p values of <0.05, in the univariate regression analysis were subsequently included in the standard multiple regression analysis, while controlling for age and gender. A standard multiple regression analysis was performed using each of the 3 mobility-related test results (walking endurance, gait speed, stepping ability) as dependent variables and the 4 lower extremity muscle performance test results (HE, HF, KE, PF) as independent variables, adjusted for age and gender.

RESULTS

The descriptive statistics for the 3 community ambulation performance values and the 4 muscle performance values are reported in **Tables 1** and **2**.

The results of univariate regression indicated that all 4 muscle groups were significantly associated with walking endurance, gait speed, and stepping after adjustment for age and gender. Therefore, the 4 muscle groups were entered into the standard multiple regression analysis.

Tables 3 to **5** display the correlations between the variables, the unstandardised regression coefficients (B) and intercepts, the standardised regression coefficients (β), the semipartial correlations (sr_i^2) and unadjusted and adjusted R^2 values. R for regression

Table 3
Standard multiple regression of 3 lower extremity muscle performances on walking endurance*

Parameter	Walking endurance	Age	Gender	HE/BMI	HF/BMI	KE/BMI	B	β	Sr_i^2
Age	-0.35†						-3.61‡	-0.28	-0.27
Gender	-0.08	0.16					-28.78	-0.14	-0.11
HE/BMI	0.39‡	-0.07	0.48‡				59.39	0.15	0.08
HF/BMI	0.38‡	0.05	0.46‡	0.71‡			36.82	0.10	0.06
KE/BMI	0.30†	0.01	0.34†	0.75‡	0.65‡		-6.50	-0.03	-0.02
PF	0.63‡	-0.09	0.01	0.49‡	0.55‡	0.40‡	2.37‡	0.49	0.37

* HE denotes hip extensors, BMI body mass index, HF hip flexors, KE knee extensors, and PF plantar flexors; intercept=399.95, R^2=0.51, adjusted R^2=0.42, R=0.71
† p<0.05
‡ p<0.01

Table 4
Standard multiple regression of 3 lower extremity muscle performances on gait speed*

Parameter	Gait speed	Age	Gender	HE/BMI	HF/BMI	KE/BMI	B	β	Sr_i^2
Age	-0.40‡						-0.02‡	-0.36	-0.34
Gender	0.08	0.16					0.08	0.11	0.08
HE/BMI	0.47‡	-0.07	0.48‡				0.13	0.09	0.05
HF/BMI	0.41‡	0.05	0.46‡	0.71‡			-0.13	-0.10	-0.06
KE/BMI	0.38‡	0.01	0.34†	0.75‡	0.65‡		0.08	0.09	0.06
PF	0.70‡	-0.09	0.01	0.49‡	0.55‡	0.40‡	0.02‡	0.64	0.48

* HE denotes hip extensors, BMI body mass index, HF hip flexors, KE knee extensors, and PF plantar flexors; intercept=1.73, R^2=0.63, adjusted R^2=0.57, R=0.80
† p<0.05
‡ p<0.01

Table 5
Standard multiple regression of 3 lower extremity muscle performances on stepping*

Parameter	Stepping	Age	Gender	HE/BMI	HF/BMI	KE/BMI	B	β	Sr_i^2
Age	-0.26						-0.00	-0.19	-0.18
Gender	-0.06	0.16					-0.02	-0.05	-0.04
HE/BMI	0.42‡	-0.07	0.48‡				0.02	0.03	0.02
HF/BMI	0.44‡	0.05	0.46‡	0.71‡			0.06	0.10	0.06
KE/BMI	0.33†	0.01	0.34†	0.75‡	0.65‡		-0.01	-0.01	-0.01
PF	0.74‡	-0.09	0.01	0.49‡	0.55‡	0.40‡	0.01†	0.64	0.48

* HE denotes hip extensors, BMI body mass index, HF hip flexors, KE knee extensors, and PF plantar flexors; intercept=0.43, R^2=0.57, adjusted R^2=0.49, R=0.75
† p<0.05
‡ p<0.01

differed significantly from zero. The results of standard multiple regression analysis indicated that only calf muscle performance was significantly associated with fast walking speed (adjusted R^2=0.57, $F(6,33)$=9.49, $p<0.0005$), walking endurance (adjusted R^2=0.42, $F(6,33)$=5.62, $p<0.0005$) and the stepping (adjusted R^2=0.49, $F(6,33)$=7.21, $p<0.0005$).

The regression equations for the 3 community ambulation tasks were reported as follows. Stepping speed (step/s)=0.43+0.01 (PF, number of heel rises). Walking endurance (m)=399.9–3.6(age)+4.7 (PF, number of heel rises). Fast walking speed (m/s)=1.77–0.016(age)+0.02 (PF, number of heel rises).

DISCUSSION

Our results support the premise that at least one of the lower extremity muscle performance indices is an important determinant of ambulation activity in community-dwelling older adults with a history of falls. Among the 4 lower extremity muscle groups tested, the PF was significantly associated with the 3 mobility-related tasks, explaining 42% to 57% of the variance.

Our results are consistent with previous work that examined the relationship of specific individual muscle groups and mobility tasks indicating that the contribution of HE, HF, and KE individually were significant predictors of ambulation functions in older adults in the community.[6,7,11] Inadequate HE and PF strength leads to short stride lengths and slow gait velocities.[26] The ankle PF provides stability for the weight-bearing limb and allows for advancement of the swinging limb in both walking and stair climbing tasks.[27,28] However, when all 4 muscle groups were considered together, only the PF muscle performance (repeated heel-rise ability) showed a significant association with all 3 mobility tasks. The importance of PF muscle performance in lower extremity ambulation activities has been emphasised.[13,27,29] The PF is also a significant predictor of postural control[13] and balance[29] in community-dwelling older persons.

The variance in walking speed explained by PF (heel-rise performance) in our study (42%) was much higher than the 13%[30] reported using isometric calf strength. This disparity might be due to the fact that our measure of ankle muscle performance might provide a better estimate of the real capability of this muscle in performing the functional tasks than isometric strength measurements. It is also possible that apart from the functional strength of the PF, the heel-rise performance reflects the strength/endurance of ipsilateral HE and KE, the endurance of the contralateral hip and knee flexors, the individual's balance, or a combination of all of these.

Our participants differed from those in previous studies, in which they were community residents[31] with or without self-reported difficulty in mobility/exercise tolerance, upper extremity abilities, basic self-care and higher functioning tasks of independent living.[11] All of our subjects were community-dwelling elderly who had a history of fall in the year before joining the study. Important physical requirements for independent community ambulation are: ablility to walk continuously for 320 m, to walk at a speed of 1.2 m/s, and to manage stairs/curbs.[1-3] Our data showed that less than 25% of our subjects were able to walk 320 m continuously or to walk at a speed of 1.2 m/s (**Table 1**). The mean number of repetitions for heel rises in a single leg (10-11 repetitions) was slightly lower than that found in older adults (>60 years) with chronic heart failure (median: 16-17 repetitions)[19] and much lower than that found in young healthy subjects (27-29 repetitions).[32]

Our study population was a specific convenience sample of community-dwelling older adults. Thus, applicability of these results is limited to subjects with similar characteristics and not appropriate for generalisation to relatively healthy community-dwelling or institutionalised older adults. In addition, the fastest gait speed was assessed by a 50-foot walk test, which includes both walking and turning components, thus reflecting both abilities rather than walking speed alone.

Our results have important clinical implications for developing effective interventions to prevent such older adults experiencing further falls and de-conditioning. Simple exercises to improve heel-rise performance may be more effective in maintaining independent walking (endurance and speed) and step up and down capabilities than other strengthening exercises focused on the isometric strength of the HE, HF, or KE. Possibly, heel-rise ability represents the functional strength of the PF as well as the strength of other antigravity muscle groups such as HE and KE. Apart from improving the functional strength of the PF, heel-rise exercises might also improve the strength of other antigravity muscle groups. Future studies are needed to determine the effectiveness of interventions that focus on heel-rise ability for maintaining independent walking and climbing ability, and to establish the threshold values of PF performance for independent walking and stair-climbing in older adults who have experienced falls and physical de-conditioning.

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