Age-Related Changes in Hip Abductor and Adductor Joint Torques

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ABSTRACT. Johnson ME, Mille M-L, Martinez KM, Crombie G, Rogers MW. Age-related changes in hip abductor and adductor joint torques. Arch Phys Med Rehabil 2004;85: 593-7.

Objective: To test the hypothesis that older age significantly affects hip abduction and adduction joint torque-time generating capability in women.

Design: Cross-sectional study, wherein subjects were tested in a supported standing position.

Setting: University human performance laboratory.

Participants: Seventy-six healthy, adult women (38 young; 38 old).

Interventions: Not applicable.

Main Outcome Measures: The dependent variables were peak isometric torque and its corresponding torque rate and average peak isokinetic torque. Age group differences were assessed by analysis of variance.

Results: Isometric peak torques were significantly lower in older women ($P \leq .001$) for hip abduction (34%) and adduction (24%). Decreases with age were also significant for isometric rates of torque for both muscle groups ($P \leq .001$). Average isokinetic peak torque of hip abduction and adduction showed even greater declines in older women versus the young ($P \leq .001$) with losses of 44% and 56%, respectively.

Conclusions: The hip abductor and adductor torques showed relatively marked age-related changes. To enhance balance assessment and treatment, and to reduce the risk of falls and related injuries in older women, greater focus should be placed on understanding the role of joint torque-time changes on frontal plane balance control.

Key Words: Accidental falls; Aging; Balance; Hip; Muscles; Rehabilitation.

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A REDUCTION IN MUSCLE strength is a common accompaniment of human aging that tends to escalate in the seventh and eighth decades.[1] Lower-extremity strength losses have been well documented in longitudinal and cross-sectional studies for the ankle dorsiflexors and plantarflexors[2-5] and knee flexors and extensors.[6-10] In healthy community-dwelling older adults 65 years of age or older, age-associated reductions in the range of 20% to 40% characterize isometric tests of ankle and knee muscle groups, with losses tending to be greater for concentric contractions and less for eccentric contractions.[1] The associations between strength losses in these muscle groups and functional limitations are moderate to high for tasks such as sit to stand[11-14] and stair ascent and descent,[13-15] but they are lower for balance-demanding tasks such as obstacle course performance.[12]

In contrast to knee and ankle muscle strength, relatively few studies have documented aging-related changes in hip muscle strength, especially for hip abductor and adductor muscle performance. This is surprising considering the functional importance of these muscles for frontal plane balance control and, potentially, for their relevance in fall prevention. For example, falls that lead to hip fractures commonly occur in the lateral direction with an approximately 3-fold increased incidence in women compared with men.[16-19] Older persons at greater risk for falls also have increased lateral postural sway,[20-22] increased sideways motion of the body during forward protective stepping for balance recovery,[23] and an increased step width accompanying gait. Such aging changes in lateral postural balance during stepping and walking may partly result from an inability to rapidly stabilize the head, arms, and trunk (HAT) in the frontal plane during single-limb support. During the transition from double- to single-limb stance, the base of support is significantly reduced such that the center of mass rapidly falls downward and laterally toward the unsupported swing side unless the body is repositioned and stabilized over the support limb. Moreover, hip abduction, adduction, and spinal moments of force are dominant in countering the large mediolateral (ML) imbalance of HAT to prevent lateral destabilization and to control ML foot placement.[24,25] Thus, hip abduction-adduction joint torque reductions and torque rate declines with aging are potentially important contributors to lateral instability and falls among older people.

Cahalan et al[26] and Murray and Sepic[27] found significant age-related hip abduction and adduction isometric and isokinetic strength declines in their cohort of subjects, but the age ranges of their older women subgroups were, respectively, 40 to 64 years and 40 to 55 years. Bohannon has reported isometric strength reference values for hip abduction by using isometric handheld dynamometry in a supine position for adults ages 20 to 79 and reported a −.227 correlation of dominant hip abduction strength to age,[28] which is less than previously reported.[26]

Besides the limited information on age-related changes in maximum strength of the hip abductor and adductor muscles, no other study to date has reported on aging changes in the rate of force or torque production of these muscle groups. Previous studies[2,4,29] of the knee and ankle have shown significant age differences in isometric force and torque-time production. The rate of torque development may be a more critical performance measure than maximum torque capacity for understanding the mechanisms underlying functional performance problems in challenging balance tasks.[30,31] For example, although older adults might have the capacity to generate functionally ade-

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quate hip muscular forces and joint torque magnitudes for frontal plane balance control when their balance is challenged during standing or walking, they may be compromised in situations requiring rapid torque production within a critical time period during balance recovery through stepping.[23] The purpose of the present study was to test the hypothesis that age significantly affects women's ability to generate hip abduction and adduction joint torque.

METHODS

Participants

A total of 76 healthy, community-dwelling, adult women, 38 young (age range, 21–27y; mean, 23±1.3y) and 38 older women (age range, 62–91y; mean, 74±6.8y) participated in the study. The younger adults were recruited from a university community. The older adults were recruited through an Aging Research Registry and Geriatric Evaluation Service. A physical therapist screened all subjects, and a physician geriatrician examined the older adults. Volunteers were excluded from participation if they had a significant history of cardiovascular, pulmonary, neurologic, musculoskeletal, or other major systemic problems. All subjects signed an informed consent form approved by the institutional review board before their participation.

Experimental Methods and Procedures

We used a calibrated Biodex System 3 PRO dynamometer[a] to measure isometric and isokinetic (concentric mode) joint torques of hip abduction and adduction. Only the dominant side was tested. This decision was made to minimize subjects fatigue and because previous reports indicated no significant differences in hip abduction-adduction joint torques between dominant and nondominant limbs,[27,32] with the exception of testing the abductor muscles isometrically in an elongated position (0° or −10° of abduction).[32] The isometric tests were performed in a midrange position. The preferred leg was defined as the limb that the subject would select to kick a ball.

We conducted an initial pilot study with 12 subjects to determine which protocol would be optimal with this diverse age-group in terms of joint angles and speeds and to assess the effect of the order of testing. Our methods were based on those of Cahalan et al.[26] Subjects in the pilot study performed isokinetic abduction and adduction repetitions at angular velocities of 30°, 60°, and 90°/s. Because both older and younger subjects complained of muscle soreness at a velocity of 30°/s and older adults were unable to consistently generate torque at 90°/s, we used a speed of 60°/s in the final protocol. The pilot study also established that randomizing the order of testing did not change the torque output. In the present study, we kept the testing positions constant (isokinetic abduction and adduction, isometric abduction, isometric adduction) to minimize testing time and limit fatigue. The reliability of the testing method has been previously reported.[26]

Adapting the method described by Cahalan,[26] subjects were positioned in standing by using a customized body stabilization frame that was height and width adjustable. The frame facilitated the subjects' control of upright alignment. The standing, weight-bearing posture was chosen because of its functional relevance. The test limb was strapped to the Biodex input arm, with the thigh pad just proximal to the knee. A marker was placed to approximate the location of the hip center of rotation.[24,33] The subjects were instructed to align the marker with the axis of motion of the dynamometer. Each subject was asked to "push" (abduction) or "pull" (adduction) "as hard and fast as you can" in response to an acoustic reaction stimulus. A physical therapist stood beside each subject throughout the experiment to encourage maximal efforts and to monitor alignment, breathing, and correct movement execution.

Isokinetic concentric testing was performed at 60°/s through a range-of-motion arc of 0° to 30°. The subject's initial starting position was as follows: (1) the anterior superior iliac spines level right to left, (2) hips and knees extended to 0°, (3) tibial tuberosities facing forward with minimal rotation, and (4) the feet shoulder width apart. A reference line on the base of the stabilization frame directed the subjects to return to the standardized foot position at the beginning of each block of trials. Subjects performed 2 blocks of 5 consecutive repetitions of abduction and adduction exertions. Participants were given a rest period of 5 minutes between blocks of isokinetic trials and between modes.

Maximal isometric tests were performed at a hip angle of 15° of abduction. Subjects were allowed 1 to 2 submaximal practice trials for each direction. Each subject performed a minimum of 3 consecutive trials for abduction and adduction conditions with each trial lasting 5 seconds. Rest periods of 10 seconds between trials and 5 minutes between abduction and adduction conditions were given.

Data and Statistical Analysis

Torque, velocity, position analog voltage signals from the Biodex and a voltage step marking the acoustic start signal were simultaneously recorded at a sampling frequency of 1000Hz on a computer by using Labview data acquisition software.[b] The data were further processed and analyzed by a customized MATLAB software program.[c] Torque, velocity, and position signals were digitally low-pass filtered by using a seventh-order Butterworth filter with a 10-Hz cutoff frequency.

For the isometric mode, we selected the performance trial with the best peak torque and used this trial for the subsequent statistical analysis. The torque onset time (T_i) in milliseconds was defined as the first point in time when the rate of torque change (ie, first derivative) was greater than the zero baseline value; the torque end time (T_f) in milliseconds was defined as the first point in time when the torque rate change returned to zero after its maximum. The peak isometric torque in Newton meters was defined as the value of torque recorded at T_f. We used this definition because it is a reliable, quantitative means of measurement. This method avoided the problem of fluctuating multiple peaks by taking the first peak reached by the subject. The average rate in Nm/s of isometric torque development (RTD) was calculated by peak torque/time to peak (T_f–T_i).

For the isokinetic mode, we computed average isokinetic peak torque for the 3 middle repetitions of the second block of 5 trials to use in the statistical analysis. All subjects were able to reach the nominal velocity (60°/s) as determined by inspection of the angular velocity signals. To permit intersubject comparisons, the torque values were normalized by body weight by body height ($Nm \cdot kg^{-1} \cdot m^{-1}$).

Means and standard deviations were computed for each outcome variable by age group. Age group differences were assessed by a 1-way analysis of variance (ANOVA). A significance level of *P* equal to .05 or less was used for all comparisons.

RESULTS

Demographic and anthropometric data for the participants are summarized in table 1. All isometric peak torque variables showed significant age group effects for both the absolute (abduction: $F_{1,74}=42.14$, $P \leq .001$; adduction: $F_{1,74}=25.53$,

Table 1: Subject Characteristics

	Young (n=38)	Old (n=38)
Age (y)	23±1.3	74±6.8
Height (m)*	1.66±.08	1.58±.10
Mass (kg)	62.7±7.8	64.8±10.2
BMI (kg/m²)	22.8±2.7	26.1±5.3

NOTE. Values are mean ± standard deviation (SD).
Abbreviation: BMI, body mass index.
*Significant (*t* test, $P<.05$) difference between the young and old groups.

$P \leq .001$) and normalized (abduction: $F_{1,74}=50.11$, $P \leq .001$; adduction: $F_{1,74}=21.63$, $P \leq .001$) magnitudes (fig 1, table 2). The older women had 34% less absolute hip torque in abduction and 24% less in adduction than the younger women. Older women also showed significantly lower isometric rates of torque development for both muscle groups (abduction: $F_{1,74}=24.03$, $P \leq .001$; adduction: $F_{1,74}=113.14$, $P \leq .001$) (see table 2). The reduction in RTD was 43% in abduction and 36% in adduction. Adduction rates were slower than abduction for both groups.

The older women developed significantly less average isokinetic peak torque in abduction and adduction for absolute (abduction: $F_{1,74}=113.14$, $P \leq .001$; adduction: $F_{1,74}=106.68$, $P \leq .001$) and normalized (abduction: $F_{1,74}=125.75$, $P \leq .001$; adduction: $F_{1,74}=25.53$, $P \leq .001$) magnitudes (fig 2, table 2). The older group had 44% less absolute hip torque in abduction and 56% less in adduction than the young. Thus, the percentage declines were more marked for the isokinetic-concentric mode than for the isometric mode.

DISCUSSION

The present study showed distinct differences in hip abduction and adduction joint torque production related to age in healthy-community dwelling women when measured in a standing position. We found a significant age-related reduction in absolute and normalized *isometric* peak hip abduction-adduction joint torque, which is consistent with other reports[2-4,8] of lower-extremity strength declines in the range of 20% to 40% in cross-sectional studies of knee and ankle musculature. Further, the percentage declines of 34% reported isometrically in abduction and 24% in adduction for the old compared with the young were approximately 15% to 20% lower in abduction and 5% to 10% lower in adduction than reported in the Cahalan et al[26] and Murray and Sepic[27] studies at similar joint angles in which their older women subgroups were more middle aged.

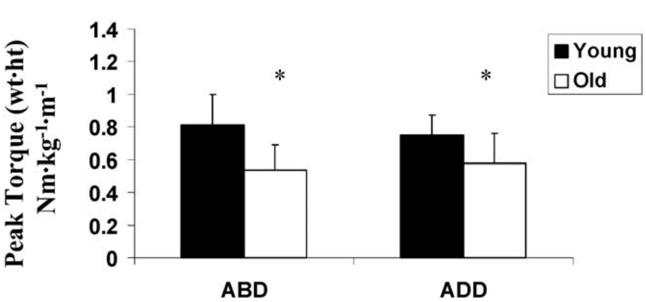

Fig 1. Hip isometric muscle strength. Hip abduction (ABD) and adduction (ADD) isometric torque at a hip joint angle of 15° of abduction, by group. NOTE: Values are mean ±1 SD. *Significant difference ($P \leq .001$) between young and older groups.

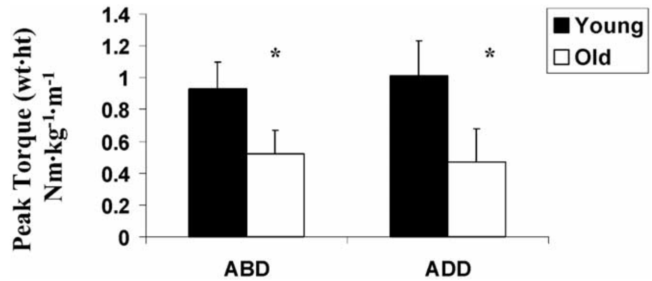

Fig 2. Hip isokinetic muscle strength. Hip abduction and adduction isokinetic torque at a velocity of 60°/s, by group. NOTE. Values are mean ± 1 SD. *Significant difference ($P \leq .001$) between young and older groups.

Isometric Findings

Because we tested at 1 joint angle of 15° abduction, the maximal isometric torque—especially for adduction in the young group—may be underestimated. Previous studies have shown that the adductors have greater strength in a more abducted position of 25° to 30°,[26,27] although this joint position is not commonly assumed in upright functional activities. However, it may explain why the younger adults were able to generate greater adduction torque in the isokinetic mode than in the isometric in the present study, which is contrary to common principles of muscle mechanics. Compared with the older subjects, the younger subjects may more frequently use their adductors in more elongated positions, especially in the context of sporting and recreational tasks—as was allowed during the 0° to 30° arc of motion in the isokinetic testing. Further studies in other than a midrange hip joint position are needed to look at these considerations. It is expected from previous studies[27,32,33] that the abductors may be stronger in −10° or 0° of abduction and the adductors in 25° to 30° of abduction. In the more elongated postures, it is expected the isometric values for the young would likely then surpass the isokinetic values. Also, we chose to use a conservative method for determining the peak isometric torque (the value at the first point in time when the rate in change of the torque returned to zero after its maximum). This decision may have impacted isometric to isokinetic comparisons. This initial isometric peak may be more functionally relevant to when torque must be rapidly developed in daily functional tasks.

Isokinetic Findings

The isokinetic-concentric peak torques at 60°/s were also significantly lower for the old than for the young: the capability to generate torque declined more than 40% for both hip abduction and adduction. One would expect that the age-related deficits would become even more marked at higher velocities; the older adults tested in our pilot studies were not able to consistently generate torque at a velocity of 90°/s. Overall, our findings suggest that, compared with other anteroposterior-oriented, lower-extremity muscle groups, such as the quadriceps, tested at 60°/s, similar, to slightly proportionately higher, age-related strength losses occur in maximum isokinetic hip abduction and adduction.[8,29] The quadriceps muscle group has been commonly used as a marker of lower-limb strength. It is a predictor variable for lateral sway stability,[22] gait performance,[12,13,34] and falls in older persons.[22] However, considering the joint torque declines documented in the present study and other researchers' task analysis of frontal versus sagittal plane balance control,[24,25] greater attention should be given to

Table 2: Mean (±1 SD) Absolute and Normalized Torque Measurements

		Peak Torque				Isometric Average Rates Torque Development		
		Isometric		Isokinetic				
		ABD	ADD	ABD	ADD		ABD	ADD
Young	Nm*	84.3±20.4	77.4±14.7	96.4±18.8	105.6±26.8	Nm/s*	268.2±126.8	159.4±73.9
	Nm·kg^{-1}·m^{-1}*	0.81±0.19	0.75±0.12	0.93±0.17	1.01±0.22			
Older	Nm*	55.5±18.2	58.8±17.2	53.6±16.2	46.9±22.6	Nm/s*	153.5±68.9	101.6±53.7
	Nm·kg^{-1}·m^{-1}*	0.54±0.15	0.58±0.18	0.52±0.15	0.47±0.21			

*Significant (1-way ANOVA, $P<.001$) difference between groups.

how the force/torque-time losses in the hip abductor-adductor muscle groups may specifically contribute to lateral instability and falls.

From a functional standpoint, not only the magnitude but also the rate of hip abduction-adduction torque development has potentially vital importance for balance challenging tasks—tasks in which rapid changes in muscle force may be required to regain stability.[35] It is difficult to directly compare our findings with previous lower-extremity strength studies because of the many ways that rate measurements have been reported.[2,4,29,31,35] However, a torque rate decline in the range of 40% in abduction and adduction among healthy-community older women suggests that this impairment in the time to reach maximal muscle force would likely influence performance when fast lower-limb movements are required to recover and maintain balance. For example, during stepping induced by external perturbation, the initiation liftoff time for a protective step normally occurs within 300 to 450ms and the first-step duration is commonly 300ms.[23] In younger adults, for both volitional and induced stepping, the onset timing of step liftoff and the peak magnitude of the electromyographic signal of the stance-side gluteus medius (a hip abductor) are highly synchronized.[36] If we assume the muscle activation patterns we found are similar to those reported in previous gait studies, in perturbation-induced stepping one would expect a rapid sequence of concentric adductor muscle activity to stabilize the hip at ground contact; this activity would then be followed by eccentric contraction of the abductor muscle to stabilize the pelvis during single-limb support.[24,37] Finally, at terminal stance the concentric abductor muscle's activity initiates the relative abduction of the hip.[24] Thus, gait (and, likely, protective stepping) have embedded in their task requirements a need for rapidly coordinated alterations in the development of abduction and adduction torque.

Studies[8,9] of age and strength changes have provided conflicting interpretations about the etiology of the decline in strength with age. Some have theorized that it can be explained primarily by sarcopenia, an age-related decrease in muscle mass, or other physiologic phenomena. Because we did not estimate muscle mass for this investigation, we could not determine if decreasing muscle mass accounted for the age-related torque-time changes in hip abduction and adduction. Others have postulated that type II muscle fiber atrophy,[6,38] alterations in neural drive,[35] changes in agonist-antagonist coactivation,[39] and impaired coordination[40] contribute to torque-time aging changes. Interestingly, in a recent study by Sato et al,[38] severe fiber type II atrophy of the gluteus medius, an important hip abductor muscle, was an independent risk factor for hip fractures because of falls. The mechanisms that underlie the strength changes that occur at the hip must be further understood in relation to gait stability,[41] protective stepping balance recovery,[23,42] physical frailty,[43] and risk of falls and associated fractures.[23,38,42]

The results further highlight the need to implement training regimens for the hip abductor and adductor musculature for older women, especially for those who are experiencing balance problems and are at increased risk for falls. A training program for these muscle groups will incorporate strengthening exercises that have moderate to high force and high-speed demands, are performed in weight bearing, and include rapid lateral stepping maneuvers.

Further testing is needed to look at differences in a more frail elderly population, to study gender effects, and to examine longitudinal changes in muscle performance. Because cross-sectional data tend to underestimate aging changes in muscle strength, we may expect to find even greater declines in future longitudinal studies.[10] The present investigation may be limited by not testing more positions, additional velocities, or eccentric contractions. However, our pilot studies led us to the present protocol to limit fatigue and symptoms of muscle soreness. Previous studies of strength assessments at other joints have documented that eccentric strength is better preserved with aging than isometric or concentric strength.[1] Future investigations should clarify what functionally necessary levels of hip abduction-adduction torque-time production are required for effective balance recovery. Such data would enable a fuller interpretation of the importance of the aging changes described here.

CONCLUSIONS

Aging-related changes occur in hip abduction and adduction muscle strength visible in reductions in both the magnitude and rate of torque production. The standing position method we used permits a more functionally relevant assessment of these muscle groups, and the custom body frame provides control for alignment and stability. Our ongoing studies seek to further elucidate the mechanisms underlying force/torque-time changes with aging of the hip abductor and adductor musculature and to determine the effects of aging on lateral postural stability in relation to the risk of falling.

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