Reduced Hip Extension During Walking: Healthy Elderly and Fallers Versus Young Adults

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Objectives: To test the hypothesis that reduced hip extension range during walking, representing a limiting impairment of hip tightness, is a consistent dynamic finding that (1) occurs with increased age and (2) is exaggerated in elderly people who fall.

Design: Using a 3-dimensional optoelectronic motion analysis system, we compared full sagittal plane kinematic (lower extremity joint motion, pelvic motion) data during walking between elderly and young adults and between elderly fallers and nonfallers. Comparisons were also performed between comfortable and fast walking speeds within each elderly group.

Setting: A gait laboratory.

Participants: Twenty-three healthy elderly subjects, 16 elderly fallers (otherwise healthy elderly subjects with a history of recurrent falls), and 30 healthy young adult subjects.

Main Outcome Measures: All major peak joint angle and pelvic position values.

Results: Peak hip extension was the only leg joint parameter measured during walking that was both significantly lower in elderly nonfallers and fallers than in young adult subjects and was even lower in elderly fallers compared with nonfallers (all p < .05). Peak hip extension ± standard deviation during comfortable walking speed averaged 20.4° ± 4.0° for young adults, 14.3° ± 4.4° for elderly nonfallers, and 11.1° ± 4.8° for elderly fallers. Peak hip extension did not significantly improve when elderly subjects walked fast.

Conclusion: An isolated and consistent reduction in hip extension during walking in the elderly, which is exaggerated in fallers, implies the presence of functionally significant hip tightness, which may limit walking performance. Overcoming hip tightness with specific stretching exercises is worthy of investigation as a simple intervention to improve walking performance and to prevent falls in the elderly.

Key Words: Accidental falls; Aged; Hip; Walking; Rehabilitation.

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Although the idea of directed rehabilitative therapy to improve walking performance of elderly persons and to prevent falls is attractive given the serious impact of these problems,1-3 it has been difficult to target specific walking abnormalities.4,5 Although reduced joint motion during walking has been previously reported for elderly populations,6-12 many of these reductions are likely caused by slower walking speeds.7,13 However, we previously showed in healthy elderly subjects a reduction in peak hip extension during walking that persists when elderly subjects walk fast.14 We also found that elderly fallers have different kinetic parameters (joint torques, powers) during walking than nonfallers.2,15,16 The purpose of the present study is to show, by means of optoelectronic motion assessment,17 that limited hip extension during walking, representing a functionally significant impairment necessitating a shortened stride length,18-20 is the only kinematic (joint motion) finding in the elderly that is exaggerated in fallers. This finding would be clinically important because limited hip extension is a relatively straightforward target for preventive and therapeutic strategies18 to maintain and/or improve walking performance in the elderly.

We hypothesized that: (1) a reduction in peak hip extension during walking is present in both healthy elderly people and in a group of well-screened, otherwise healthy elderly people with a history of recurrent falls; (2) peak hip extension does not improve when elderly persons walk fast at speeds similar to those of young adults; and (3) the limitation in peak hip joint extension is greater in elderly fallers than in nonfallers. We also hypothesized that reduced peak hip joint extension is related to increased peak anterior pelvic tilt, which together help predict the degree of reduction in stride length and walking speed.

METHODS

The means of recruitment, inclusion and exclusion criteria, and demographics of elderly fallers and nonfallers for the present study have been detailed previously.16 Elderly fallers actively recruited over a 1-year period had at least 2 falls of unspecified cause within the previous 6 months, with at least 1 fall occurring while the person was walking on a level surface. The study, approved by the Spaulding Rehabilitation Hospital Institutional Review Board, included 16 elderly fallers (8 men, 8 women; mean age, 77 ± 7.8yr), 23 healthy elderly nonfallers (10 men, 13 women; mean age, 73.2 ± 5.6yr), and 30 young adults (15 men, 15 women; mean age; 28.1 ± 4.2yr). The slight difference in age between elderly fallers and nonfallers was not statistically significant (p = .09). All subjects walked barefoot at their comfortable speed across a gait laboratory walkway. In addition, the elderly subjects were asked to “walk fast.” Temporal gait characteristics of each group are listed in table 1. Pelvic and bilateral lower extremity joint kinematic data over 3 walking trials were collected and averaged for each subject at each walking speed. The specific protocol has been described.
in detail elsewhere. An optoelectronic motion analysis system, which measured the 3-dimensional position of markers at 100 frames per second during walking, was attached to various bony landmarks on the pelvis and lower extremities. We calculated lower extremity joint angular motion and pelvic motion in the sagittal plane by means of a commercialized biomechanical model, SAFLo (Servizio di Analisi della Funzionalita' Locomotoria). As shown in figure 1, pelvic kinematics were defined by 3 markers placed over the left and right posterior iliac spines and sacrum. A virtual hip marker, defined in the pelvic coordinate system, was common to both the pelvic and thigh segments. The thigh segment was further defined by a lateral condyle marker and an extended knee marker. A virtual medial condyle marker and the knee joint center were defined by a static trial. Anterior pelvic tilt (equivalent to an increase in lumbar lordosis) was defined as rotation of the pelvic segment about the laboratory Z axis. Hip flexion and extension were measured as rotation of the thigh segment with respect to the pelvic Z axis. Gait velocity and stride length were also obtained using force platforms imbedded within the walkway along with kinematic information to define initial foot contact times and distance.

Averaged lower extremity joint motion values were obtained for each subject, at each walking speed, from 3 trials on both sides (ie, 6 values for each subject at each speed). Averaged peak pelvic motion values for each subject at each speed were obtained from 3 trials (ie, average of both right and left sides of pelvis, providing an average of 6 values at each speed). For peak hip extension and all other major peak kinematic values measured at comfortable walking speed (table 2), we made comparisons by means of unpaired Student’s t tests between the elderly groups and young adult subjects at comfortable walking speed. We also made comparisons within each elderly group using paired t tests between fast and comfortable walking speeds.

Pelvic and joint angular motion data for the young adults walking at comfortable speed and for the elderly nonfallers and fallers walking at both comfortable and fast speeds were graphed over the walking cycle (at 2% intervals over 100% for joint angular motion, 50% for pelvic motion, reflecting the average of both sides). The apparent peaks on each graph do not reflect precisely the true mean peak values that we used for statistical calculations because the peaks in the graphs, calculated as an average at each 2% interval, do not necessarily reflect the individual trials’ true peaks, which could occur outside this 2% interval. This phenomenon is particularly evident for pelvic tilt in which the timing of peaks for individual subjects is most variable.

Within the elderly groups, at comfortable and fast walking speeds, regression analyses were performed between peak hip extension and anterior pelvic tilt. We also performed multiple regressions with stride length and walking speed as the dependent variables and peak hip extension and anterior pelvic tilt as the independent variables.

Table 1: Temporal Gait Characteristics of Participants, by Group

<table>
<thead>
<tr>
<th>Gait Characteristics</th>
<th>Elderly Nonfallers (n = 23)</th>
<th>Elderly Fallers (n = 16)</th>
<th>Young Adults (n = 30)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Comfortable</td>
<td>Fast</td>
<td>Comfortable</td>
</tr>
<tr>
<td>Velocity (m/s)</td>
<td>1.21 (.12)</td>
<td>1.57 (.16)</td>
<td>0.89 (.22)</td>
</tr>
<tr>
<td>Cadence (steps/min)</td>
<td>120 (7)</td>
<td>140 (12)</td>
<td>107 (12)</td>
</tr>
<tr>
<td>Stride length (m)</td>
<td>1.22 (.12)</td>
<td>1.34 (.15)</td>
<td>0.98 (.17)</td>
</tr>
</tbody>
</table>

Values presented are means (standard deviations).

Fig 1. Pelvic kinematics markers: left and right posterior iliac spines (PSIS) and sacrum, hip marker (Hip), lateral condyle (LC) marker, extended (Ext) knee marker, medial condyle (MC), knee joint center (Knee). Anterior pelvic tilt: rotation of the pelvic segment about the laboratory Z axis (Zlab). Hip flexion and extension: rotation of the thigh segment with respect to the pelvic Z axis (Zp).
RESULTS

Superimposed plots of averaged hip, knee, and ankle joint kinematics at comfortable walking speed for the elderly nonfallers, fallers, and young adults (fig 2) show several differences in peak joint ranges for the 2 elderly groups compared with the young adult group. Table 2 lists all average peak values for all lower extremity joint parameters. The only measurements that were significantly different in both elderly groups, compared with young adults, were peak hip extension and ankle plantarflexion. Of these 2 measures, only peak hip extension did not significantly improve at fast versus comfortable walking speed for either the elderly nonfaller or faller groups (p = .912, p = .506, respectively). Only peak hip extension was more reduced in the elderly fallers than in the nonfallers (p = .038).

Peak anterior pelvic tilt was significantly greater in both the elderly fallers (2.6° ± 4.8° anterior at comfortable walking speed) and the nonfallers (3.1° ± 2.7° anterior) compared with young adults (0.2° ± 3.3° posterior). Peak anterior pelvic tilt increased significantly with fast walking speed in the fallers (to 3.8° ± 5.9° anterior, p = .007) and also tended to increase in the nonfallers (to 4.3° ± 3.4° anterior), although the difference was not statistically significant (p = .103). Plots of sagittal plane pelvic motion at fast versus comfortable walking speed for the fallers and nonfallers, with young adult pelvic motion for reference, are shown in figure 3A and B, respectively.

Peak hip extension significantly correlated with anterior pelvic tilt at comfortable speed (r = .69, p < .001) and at fast speed (r = .66, p < .001). Peak hip extension and peak anterior pelvic tilt each contributed significantly (p < .001) to a linear

<table>
<thead>
<tr>
<th>Joint ROM (deg)</th>
<th>Elderly Nonfallers (n = 23)</th>
<th>Elderly Fallers (n = 16)</th>
<th>Young Adults (n = 30)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Comfortable Speed Fast Speed</td>
<td>Comfortable Speed Fast Speed</td>
<td>Comfortable Speed</td>
</tr>
<tr>
<td>Hip Flexion</td>
<td>26.4 (4.7) 30.1 (5.4)</td>
<td>21.4 (8.2) 24.6 (9.3)</td>
<td>24.0 (4.0)</td>
</tr>
<tr>
<td>Extension*</td>
<td>14.3 (4.4) 14.4 (4.5)</td>
<td>11.1 (4.8) 11.8 (6.4)</td>
<td>20.4 (4.3)</td>
</tr>
<tr>
<td>Knee Flexion stance</td>
<td>16.5 (6.6) 21.4 (6.2)</td>
<td>11.1 (5.5) 16.2 (5.5)</td>
<td>17.7 (5.3)</td>
</tr>
<tr>
<td>Extension terminal stance</td>
<td>1.7 (3.9) 2.2 (4.0)</td>
<td>1.8 (4.0) 2.8 (4.1)</td>
<td>1.6 (3.6)</td>
</tr>
<tr>
<td>Flexion swing</td>
<td>58.3 (4.9) 60.6 (4.7)</td>
<td>52.1 (7.8) 55.0 (7.2)</td>
<td>60.1 (4.8)</td>
</tr>
<tr>
<td>Extension terminal swing</td>
<td>2.5 (5.2) 6.3 (5.7)</td>
<td>2.2 (5.1) 3.4 (4.5)</td>
<td>1.6 (4.1)</td>
</tr>
<tr>
<td>Ankle Plantarflexion initial stance</td>
<td>8.4 (2.9) 7.5 (3.1)</td>
<td>8.4 (1.9) 7.7 (2.4)</td>
<td>7.8 (3.2)</td>
</tr>
<tr>
<td>Dorsiflexion midstance</td>
<td>8.6 (3.6) 6.7 (2.8)</td>
<td>8.0 (1.5) 5.9 (1.8)</td>
<td>7.7 (3.5)</td>
</tr>
<tr>
<td>Plantarflexion</td>
<td>14.7 (6.5) 15.9 (6.1)</td>
<td>13.5 (5.1) 14.1 (6.2)</td>
<td>21.6 (6.5)</td>
</tr>
<tr>
<td>Dorsiflexion swing</td>
<td>2.4 (3.9) 2.4 (3.5)</td>
<td>1.8 (2.3) 1.5 (3.5)</td>
<td>1.8 (3.4)</td>
</tr>
</tbody>
</table>

Values presented are mean (standard deviation) degrees of ROM.
* Only joint parameter that is both (1) significantly reduced (p < .05) in elderly nonfallers and fallers compared with young adult subjects and (2) significantly reduced in elderly fallers compared with nonfallers.

Fig 2. Hip, knee, and ankle sagittal plane motion during comfortable walking speed, plotted over 100% of gait cycle for elderly fallers, elderly nonfallers, and young adults.
model predicting both stride length \( R^2 = .51 \) at comfortable speed, \( R^2 = .43 \) at fast speed) and walking speed \( R^2 = .41 \) at comfortable speed, \( R^2 = .38 \) at fast speed).

**DISCUSSION**

We show here that peak hip extension during walking is consistently lower in both elderly nonfallers and fallers than in young adults and does not improve when elderly subjects walk at fast speeds that are the same or greater than those of young adults walking at a comfortable speed. Moreover, peak hip extension is the only joint parameter that is both (1) significantly lower in elderly persons than in young adults and (2) even lower in elderly fallers than in elderly nonfallers. The present gait analysis study is the first to compare hip extension between elderly groups. Although 2 previous, video-based gait studies comparing fallers with nonfallers\(^4,22\) reported no joint kinematic differences, neither used the optoelectronic motion analysis methods\(^17\) that distinguish true extension about the hip from compensatory increases in pelvic motion.

The consistently low peak hip extension findings, in association with dynamic increases in anterior pelvic tilt, implies the presence of functionally significant hip tightness or hip flexion contractures preventing the hip from achieving full extension during walking.\(^18-20\) Reductions in static joint range of motion (ROM) with aging have been documented generally throughout the lower extremities,\(^23-25\) including a 6° loss of active hip extension range.\(^24\) However, the reduction in peak hip extension range is particularly significant in terms of function because normally, the hip joint’s entire ROM is exercised during walking.\(^26\) Moreover, the only regular daily activity that extends the hip to its maximum and thereby stretches the hip flexors is gait, ie, walking or running.\(^18\) Thus, a decline in walking activity, persistent reduction in step length, and/or lumbosacral postural changes will mean less regular stretching of the hip flexors, which will contribute to hip flexor tightness and contracture.

Because the present study is cross-sectional, we cannot state with certainty the cause of reduced hip extension, poor walking performance, and propensity for falling. A reduction in hip extension, partially compensated for by an increase in anterior pelvic tilt, may be a primary mechanism underlying the decrease in stride length and walking speed in elderly people. Alternatively, reduced stride length itself may be the initial cause, perhaps as a compensation for poor balance. Regardless, walking continually with a shortened stride length will likely propagate a hip contracture, as will a hip contracture reduce stride length, thus propagating a continuous downward spiral of walking disability. A reduction in hip extension range and reduced ability to take a longer stride may be particularly important in situations requiring rapid changes in stride length encountered when, for instance, attempting to change walking speeds rapidly, or when faced with uneven surfaces or obstacles. Moreover, an increase in anterior pelvic tilt as a compensatory attempt to increase an otherwise shortened stride length theoretically predisposes to low back pain and postural or spinal deformity.\(^18-20\)

**CONCLUSION**

Future research to study the effect of a specific hip flexor stretching exercise program\(^19\) on walking performance in the elderly is warranted. In a previous study,\(^27\) investigators reported that static hip extension ROM can improve with directed stretching exercises to the hip flexors.\(^22\) If hip tightness can be simply prevented or treated, this specific functionally significant impairment in the elderly, which is exaggerated in fallers, is clinically important and merits further investigation.

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**References**


Suppliers
a. Bioengineering Technology Systems, Via Cristofo Colombo 1A, Corsico, Milan 20094, Italy.
b. Advanced Mechanical Technology Inc, 151 California St, Newton, MA 02158.