Femoral Neck Shortening After Internal Fixation of a Femoral Neck Fracture

STEPHANIE M. ZIELINSKI, MD; NOËL L. KEJSERS, PHD; STEPHAN F.E. PRAET, MD, PHD; MARTIN J. HEETVELD, MD, PHD; MOHIT BHANDARI, MD, PHD; JEAN PIERRE WILSENS; PETER PATKA, MD, PHD; ESTHER M.M. VAN LIESHOUT, PHD, ON BEHALF OF THE FAITH TRIAL INVESTIGATORS

Abstract

This study assesses femoral neck shortening and its effect on gait pattern and muscle strength in patients with femoral neck fractures treated with internal fixation. Seventy-six patients from a multicenter randomized controlled trial participated. Patient characteristics and Short Form 12 and Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) scores were collected. Femoral neck shortening, gait parameters, and maximum isometric forces of the hip muscles were measured and differences between the fractured and contralateral leg were calculated. Variables of patients with little or no shortening, moderate shortening, and severe shortening were compared using univariate and multivariate analyses. Median femoral neck shortening was 1.1 cm. Subtle changes in gait pattern, reduced gait velocity, and reduced abductor muscle strength were observed. Age, weight, and Pauwels classification were risk factors for femoral neck shortening. Femoral neck shortening decreased gait velocity and seemed to impair gait symmetry and physical functioning. In conclusion, internal fixation of femoral neck fractures results in permanent physical limitations. The relatively young and healthy patients in our study seem capable of compensating. Attention should be paid to femoral neck shortening and proper correction with a heel lift, as inadequate correction may cause physical complaints and influence outcome.

The authors are from the Departments of Surgery-Traumatology (SMZ, EMVVL), Rehabilitation Medicine & Physical Therapy (SFEP), and Emergency Medicine (PP), Erasmus MC, University Medical Center Rotterdam, Rotterdam; the Department of Research, Development and Education (NLK), Sint Maartenskliniek, Nijmegen; the Department of Surgery (MJH), Kennemer Gasthuis, Haarlem, the Netherlands; the Department of Clinical Epidemiology and Biostatistics (MB), McMaster University, Hamilton, Ontario, Canada; and the RSscan International (JPW), Lammerdries-Oost, Olen, Belgium.

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A list of study investigators and participating centers of the FAITH Trial appears at the end of the article.

Correspondence should be addressed to: Esther M.M. Van Lieshout, PhD, Department of Surgery-Traumatology, University Medical Center Rotterdam, P.O. Box 2040, 3000 CA Rotterdam, the Netherlands (e.vanlieshout@erasmusmc.nl).

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The worldwide incidence of hip fractures is increasing, from an estimated 1.6 million people per year in 1990 to 6.3 million people per year by 2050. The disability adjusted life-years lost as a result of hip fractures ranks in the top 10 of all-cause disability globally.1-3 Femoral neck fractures can be treated with internal fixation. A sliding hip screw or multiple cancellous screws are the implants of choice.4 Research on the treatment of femoral neck fractures with internal fixation is traditionally aimed at fracture healing, revision surgery, morbidity, and mortality.5-6 In addition, self-reported functional outcome is often measured using health-related quality of life questionnaires (eg, Short Form 12 [SF-12] and EuroQol 5D) or disease-specific questionnaires (eg, Harris Hip Score and Western Ontario and McMaster Universities Osteoarthritis Index [WOMAC]).5,7,8

However, little is known about the physical limitations that may result from internal fixation following femoral neck fractures. Surgery, immobilization after surgery, and pain may cause an abnormal or asymmetrical gait pattern and reduced muscle strength. It is unknown to what extent internal fixation patients show adequate recovery. Asymmetries in gait pattern and muscle strength have never been measured and can be plausible explanations for reduced mobility and quality of life. Gait analysis may even add information to the results from functional questionnaires such as the WOMAC.9 Its value has been proven in clinical studies after other surgical interventions, such as hip arthroplasty.10

Femoral neck shortening is another potentially important limitation that may arise and affect gait pattern and muscle strength. Implants allow fracture fragments to slide along the implant and permit impaction at the fracture site, especially when subjected to an axial loading force early during weight bearing. The biomechanical rationale behind these implants is that compression of fracture fragments will stimulate fracture consolidation. However, this may also lead to femoral neck shortening and leg-length discrepancy, changing the abductor muscles moment arm, causing screw backout, and affecting standing posture or gait.11-16

The current authors hypothesized that femoral neck shortening would occur in patients with femoral neck fractures treated with internal fixation, leading to long-term functional impairment with reduced muscle strength and an asymmetrical gait pattern. The goal of this study was to determine the level of femoral neck shortening and asymmetry in gait and muscle strength in patients who sustained femoral neck fractures treated with internal fixation at least 1 year before. Risk factors for femoral neck shortening and the effect of femoral neck shortening on physical function were determined.

**Materials and Methods**

**Study Population**

This study (clinical trial registration number, NL32419.078.10) was a secondary cohort study to the Dutch sample of an international randomized controlled trial, the FAITH trial (Fixation using Alternative Implants for the Treatment of Hip fractures, NCT00761813). The primary objective of the FAITH trial was to assess the effect of sliding hip screw versus cannulated screw fixation on rates of revision surgery at 2 years in elderly patients with femoral neck fractures. Fourteen hospitals in the Netherlands enrolled 250 patients between February 2008 and August 2009. Patients were included for the Dutch FAITH trial if they (1) were adults aged 50 years or older, (2) had a radiologically confirmed femoral neck fracture (ie, undisplaced or displaced fracture in patients with an American Society of Anesthesiologists [ASA] classification of 1 or 2, aged 50 to 80 years, with a fracture that could be closed reduced), (3) had a low energetic fracture with no other major trauma, and (4) were ambulatory prefracture (with or without aid). Patients were excluded if they (1) had a fracture not suitable for internal fixation (eg, pathological fracture, rheumatoid arthritis, or osteoarthritis), (2) had associated major injuries of the lower extremities, (3) had retained hardware around the hip, (4) had an infection around the hip, (5) had a bone metabolism disorder other than osteoporosis, (6) were moderately or severely cognitively impaired prefracture, (7) had dementia or Parkinson’s disease severe enough to compromise the rehabilitation process, or (8) were not likely to be able to complete follow-up. All patients had an acceptable fracture reduction according to their surgeon and were allowed weight bearing as tolerated after the initial surgery.

Patients were included in the current study at least 1 year after internal fixation because it is generally believed that only little functional improvement can be expected after 1 year. Exclusion criteria for this study were (1) revision surgery or conversion to arthroplasty, (2) patient not capable of walking several meters independently (with or without ambulatory aid), (3) other lower limb abnormalities that could be expected to influence gait pattern (eg, other lower extremity fractures/neurological diseases), (4) history of previous internal fixation or arthroplasty of the contralateral (control) hip, and (5) radiographs inadequate for measuring femoral neck shortening.

The study was approved by all local medical research ethics committees.

**Measurements**

Measurements and data collection were performed during a single visit to the outpatient clinic. Femoral neck shortening was measured on digital radiographs using graphic software (Photoshop CS3 Graphic; Adobe, San Jose, California), as described previously.12,13 The most recent anteroposterior radiograph of the fractured hip was compared with the contralateral hip on radiographs taken at the time of the injury. The uninjured side was outlined, overlapped over the fractured...
side, and adjusted for differences in size. Femoral neck shortening was measured in the vertical plane. Known diameters of screws were used to correct for differences in radiograph magnification.

Gait analysis was measured using a calibrated pressure plate (2.0×0.4 m, 125 Hz) (footscan; RSscan International, Olen, Belgium). Patients were instructed to walk barefoot across the plate at their preferred speed. All patients completed this task without aid. Five measurements were performed per patient. The combination of at least 3 gait measurements that were most representative were selected based on the coefficient of variation and used for analysis. The following temporospatial gait parameters were analyzed: step length, duration of stance phase, single and double support phase, foot axis, progression of the center of pressure line (COP), and gait velocity. Data from the fractured leg were compared with those from the contralateral side. The difference was computed using the formula: Parameter\textsubscript{fractured leg} − Parameter\textsubscript{contralateral leg}.

To analyze the plantar pressure, data were normalized for foot size, width, and progression angle as described by Keijzers et al.\textsuperscript{17} This is a validated method that allows for a more detailed and standardized comparison of the fractured side with the contralateral side (intraclass correlation, ≥0.85).

Figures were computed that showed the difference in pressure distribution between the legs by subtracting pressure in the fractured leg from the pressure in the fractured leg for each activated sensor. Student’s t test was used to detect significant differences in plantar pressure distribution.

Maximum isometric forces of the hip muscles were measured using a handheld dynamometer (MicroFET; Biometrics BV, Almere, the Netherlands). Flexion, extension, abduction, and adduction strength were measured in a supine position. The means of triplicate measurements were calculated, and the differences between the affected extremity and control side were computed.

Baseline characteristics, surgical data, rehabilitation data, and WOMAC and SF-12 scores were available from the FAITH trial.\textsuperscript{18,19} The SF-12 scores were converted to a norm-based score and compared with the norms for the general population of the United States in the year 1998 because weighing factors for the Dutch population were not available. Patients’ satisfaction with their gait pattern was measured using a visual analog scale (VAS) score, ranging from 0 (extremely dissatisfied) to 10 (completely satisfied). A VAS was also used to measure the extent to which patients were hampered due to the leg-length discrepancy, ranging from 0 (no complaints) to 10 (very hampered).

**Data Analysis**

Analyses were performed using SPSS version 16.0 statistical software (SPSS Inc, Chicago, Illinois). Patient and fracture characteristics, femoral neck shortening, gait parameters, muscle strength, and quality of life scores were determined for the study sample. Continuous variables are presented as medians with interquartile ranges, and categorical variables are presented as numbers and percentages. To study femoral neck shortening, the study population was divided in tertiles: patients with little or no femoral neck shortening (less than 0.75 cm), moderate shortening (0.75-1.50 cm) and severe shortening (more than 1.50 cm). Groups were compared using a Kruskal-Wallis analysis of variance (ANOVA) (numeric variables) or a chi-squared analysis (categorical variables). To assess whether femoral neck shortening independently influences gait velocity and patient functioning (WOMAC score), a multivariable regression analysis was performed using a backward stepwise approach. Variables with a P value less than .1 in the univariate analyses and variables that were likely to influence the outcome variable were entered as covariate. Results with a P value less than .05 (2-sided test) were regarded as statistically significant.

**RESULTS**

**Patient Demographics**

Of the initial group of 250 patients, 114 patients met the exclusion criteria and were excluded. Of the remaining 136 patients, 76 participated (Figure 1). An additional hospital visit was the main reason for refused participation. Characteristics of the nonparticipating patients (ie, age, ASA score, and prefracture use of aids) did not differ significantly from those in the included population. The study population consisted of relatively young and healthy patients with femoral neck fractures (median age, 68.3 years). Only 7% had severe comorbidities (ASA score higher than 2). Prior to the fracture, 1% of the patients were institutionalized and 8% used an aid for mobilization. Approximately 35% of all fractures were displaced, and 29% were Pauwels 3 fractures. Femoral neck shortening measurements were performed a median 11.7 months after the initial surgery. Gait and strength measurements were performed a median 22.4 months after initial surgery.
surgery (Table 1). At that time, all fractures had healed.

Femoral Neck Shortening, Gait Pattern, and Muscular Strength

Median femoral neck shortening was 1.1 cm ($P_{25}-P_{75}$: 0.5–1.7). Forty percent of patients felt a leg-length discrepancy and scored their resulting complaints with a median VAS score of 4.0 ($P_{25}-P_{75}$: 1.5–7.2). Approximately one-third of patients used a heel lift with a median height of 1.0 cm ($P_{25}-P_{75}$: 0.5–1.5). In 36% of patients, the implant had been removed because of implant-related complaints (Table 2).

The gait parameters differed by less than 1% between both legs, except stance time, which was 1.5% of the total gait cycle shorter for the fractured leg. Median gait velocity was 1.1 m/s ($P_{25}-P_{75}$: 0.9–1.2) (Table 2). Average plantar pressure seemed reduced under metatarsals 1 and 2 ($MT_1$, and $MT_2$) and increased under the hallux, toes, and heel ($P>.05$) (Figure 2). Patients scored their satisfaction with their gait pattern with a median VAS score of 7.5 ($P_{25}-P_{75}$: 5.1–7.8).

The muscle strength of the flexor, extensor, and adductor muscles decreased less than 10 N in the fractured leg compared with the contralateral side. Median decrease in strength for the abductor muscles was 20.9 N ($P_{25}-P_{75}$: 0.0–35.1) (Table 2).

At the time of the measurements, 4% of the patients were institutionalized and 21% used an aid for mobilization (a 13% increase compared with the prefracture situation). Also, 18% of the patients still received physical therapy. Median SF-12 score was 102.1 ($P_{25}-P_{75}$: 92.3–108.0), and median WOMAC score was 86.5 ($P_{25}-P_{75}$: 72.9–97.4) (Table 2).

Risk Factors for Femoral Neck Shortening

Male sex and a higher weight were associated with increased femoral neck shortening (32% of men with little or no femoral neck shortening vs 42% with moderate femoral neck shortening vs 72% with severe femoral neck shortening; $P=.013$) (median weight, 65.0 vs 72.5 vs 80.0 kg, respectively; $P=.003$) (Table 3). The same was found for a displaced fracture (Garden III-IV) and a Pauwels 3 fracture (12% displaced vs 42% vs 56%, respectively; $P=.009$) (4% Pauwels 3 vs 27% vs 52%, respectively; $P=.001$). In a multivariable regression model age, weight, and a Pauwels 3 fracture were independently associated with femoral neck shortening (femoral neck shortening = $-2.65 + (0.02 \times \text{age, year}) + (0.02 \times \text{weight, kg}) + (0.54 \times \text{Pauwels 3})$) (Table 3).

Consequences of Femoral Neck Shortening

Femoral neck shortening was associated with an increased feeling of leg-length discrepancy (20% vs 27% vs 76%; $P<.001$) and increased use of a heel lift

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**Table 1**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Total (N=76)</th>
<th>Little or No FNS a</th>
<th>Moderate FNS b</th>
<th>Severe FNS c</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y d</td>
<td>68.3 (61.6-78.4)</td>
<td>70.5 (62.4-79.5)</td>
<td>69.4 (61.7-77.2)</td>
<td>67.1 (60.6-78.7)</td>
<td>.882</td>
</tr>
<tr>
<td>Male sex e</td>
<td>37 (48.7)</td>
<td>8 (32.0)</td>
<td>11 (42.3)</td>
<td>18 (72.0)</td>
<td>.013</td>
</tr>
<tr>
<td>Weight, kg f</td>
<td>75.0 (63.0-83.0)</td>
<td>65.0 (56.5-76.5)</td>
<td>72.5 (62.3-83.0)</td>
<td>80.0 (73.5-90.0)</td>
<td>.003</td>
</tr>
<tr>
<td>BMI, kg/m² d</td>
<td>24.3 (21.9-26.0)</td>
<td>23.6 (21.1-25.5)</td>
<td>24.0 (21.4-25.3)</td>
<td>25.8 (23.5-28.4)</td>
<td>.021</td>
</tr>
<tr>
<td>ASA score $&gt;$2 e</td>
<td>5 (6.6)</td>
<td>1 (4.0)</td>
<td>3 (1.8)</td>
<td>7 (12.0)</td>
<td>.465</td>
</tr>
<tr>
<td>Institutionalized prefracture e</td>
<td>1 (1.3)</td>
<td>0 (0.0)</td>
<td>0 (0.0)</td>
<td>1 (4.0)</td>
<td>.356</td>
</tr>
<tr>
<td>Prefracture use of aids e</td>
<td>6 (7.8)</td>
<td>1 (4.0)</td>
<td>2 (7.7)</td>
<td>3 (12.0)</td>
<td>.576</td>
</tr>
<tr>
<td>Subcapital fracture e</td>
<td>36 (47.4)</td>
<td>15 (60.0)</td>
<td>12 (46.2)</td>
<td>9 (36.0)</td>
<td>.346</td>
</tr>
<tr>
<td>Displaced fracture (Garden III-IV) e</td>
<td>27 (35.5)</td>
<td>3 (12.0)</td>
<td>11 (42.3)</td>
<td>13 (52.0)</td>
<td>.009</td>
</tr>
<tr>
<td>Pauwels class 3 e</td>
<td>22 (28.9)</td>
<td>1 (4.0)</td>
<td>7 (26.9)</td>
<td>14 (56.0)</td>
<td>.001</td>
</tr>
<tr>
<td>Time FNS measurements since surgery, mo²</td>
<td>11.7 (11.2-12.4)</td>
<td>11.7 (11.5-12.3)</td>
<td>11.5 (10.5-12.3)</td>
<td>11.8 (11.2-12.9)</td>
<td>.448</td>
</tr>
<tr>
<td>Time gait measurements since surgery, mo²</td>
<td>22.3 (18.9-24.3)</td>
<td>22.9 (20.0-27.0)</td>
<td>22.0 (18.2-23.7)</td>
<td>21.5 (17.8-23.2)</td>
<td>.187</td>
</tr>
</tbody>
</table>

**Abbreviations:** ASA, American Society of Anesthesiologists; BMI, body mass index; FNS, femoral neck shortening.

a $<0.75$ cm.

b $0.75-1.50$ cm.

c $>1.50$ cm.

d Data presented as median ($P_{25}-P_{75}$).

e Data presented as No./%.
Table 2

Data on Femoral Neck Shortening, Gait Parameters, Muscle Strength, and Self-reported Patient Functioning

<table>
<thead>
<tr>
<th>Variable</th>
<th>Total (N=76)</th>
<th>Little or No FNSa (n=25)</th>
<th>Moderate FNSb (n=26)</th>
<th>Severe FNSc (n=25)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Femoral neck shortening, cmd</td>
<td>1.1 (0.5 to 1.7)</td>
<td>0.4 (0.1 to 0.5)</td>
<td>1.1 (0.9 to 1.3)</td>
<td>2.0 (1.7 to 2.3)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Feeling of LLDa</td>
<td>31 (40.8)</td>
<td>5 (20.0)</td>
<td>7 (26.9)</td>
<td>19 (76.0)</td>
<td>.001</td>
</tr>
<tr>
<td>VAS score complaints of LLDed</td>
<td>4.0 (1.5 to 7.2)</td>
<td>2.3 (0.5 to 7.1)</td>
<td>4.9 (4.8 to 8.0)</td>
<td>3.9 (1.9 to 7.0)</td>
<td>.242</td>
</tr>
<tr>
<td>Heel lift useb</td>
<td>23 (30.3)</td>
<td>3 (12.0)</td>
<td>4 (15.4)</td>
<td>16 (64.0)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Height heel lift, cmfc</td>
<td>1.0 (0.5 to 1.5)</td>
<td>0.5 (0.5 to 1.0)</td>
<td>0.8 (0.2 to 1.8)</td>
<td>1.2 (1.0 to 1.7)</td>
<td>.161</td>
</tr>
<tr>
<td>Implant removedc</td>
<td>27 (35.5)</td>
<td>7 (28.0)</td>
<td>9 (34.6)</td>
<td>11 (44.0)</td>
<td>.412</td>
</tr>
<tr>
<td>Weight distribution in stance, %dh</td>
<td>0.5 (-5.5 to 5.4)</td>
<td>-0.5 (-5.3 to 5.2)</td>
<td>-0.7 (-7.4 to 5.4)</td>
<td>1.1 (-2.2 to 6.7)</td>
<td>.439</td>
</tr>
<tr>
<td>Foot axis, degelh</td>
<td>0.5 (-5.5 to 4.6)</td>
<td>2.4 (-1.2 to 7.4)</td>
<td>-2.8 (-7.3 to 3.9)</td>
<td>-1.8 (-6.5 to 4.8)</td>
<td>.034</td>
</tr>
<tr>
<td>Stance time, % of gait cyclef,i</td>
<td>-1.5 (-3.8 to -0.1)</td>
<td>-1.9 (-4.0 to -0.4)</td>
<td>-0.5 (-2.4 to 0.5)</td>
<td>-2.8 (-5.1 to -0.1)</td>
<td>.116</td>
</tr>
<tr>
<td>Single support phase, % of gait cyclef,i</td>
<td>-0.5 (-4.4 to 1.0)</td>
<td>-0.3 (-4.5 to 0.7)</td>
<td>0.1 (-3.7 to 1.8)</td>
<td>-3.0 (-5.4 to 0.5)</td>
<td>.519</td>
</tr>
<tr>
<td>Double support phase, % of gait cyclef,i</td>
<td>0.2 (-2.1 to 2.6)</td>
<td>0.4 (-0.6 to 1.1)</td>
<td>-0.5 (-2.6 to 3.5)</td>
<td>1.0 (-2.4 to 3.5)</td>
<td>.806</td>
</tr>
<tr>
<td>Step length, cmgh</td>
<td>0.0 (-3.2 to 3.8)</td>
<td>0.3 (-3.1 to 4.8)</td>
<td>0.0 (-2.7 to 3.6)</td>
<td>-0.5 (-3.4 to 3.4)</td>
<td>.802</td>
</tr>
<tr>
<td>COP ΔY, cmgh</td>
<td>0.5 (-7.9 to 6.9)</td>
<td>3.1 (-4.9 to 6.8)</td>
<td>0.5 (-8.0 to 7.7)</td>
<td>-4.4 (-11.6 to 9.8)</td>
<td>.406</td>
</tr>
<tr>
<td>Gait velocity, m/sf</td>
<td>1.1 (0.9 to 1.2)</td>
<td>1.1 (1.0 to 1.3)</td>
<td>1.1 (0.8 to 1.3)</td>
<td>1.0 (0.8 to 1.2)</td>
<td>.165</td>
</tr>
<tr>
<td>VAS score satisfaction with gait patternf</td>
<td>7.5 (5.1 to 8.7)</td>
<td>8.0 (6.5 to 9.0)</td>
<td>7.3 (5.3 to 8.3)</td>
<td>7.3 (4.3 to 8.0)</td>
<td>.086</td>
</tr>
<tr>
<td>Flexion, Nth</td>
<td>-1.3 (-13.5 to 3.9)</td>
<td>0.0 (-7.5 to 3.9)</td>
<td>-3.6 (-14.8 to 0.0)</td>
<td>-1.3 (-19.3 to 7.2)</td>
<td>.474</td>
</tr>
<tr>
<td>Extension, Nth</td>
<td>-3.9 (-27.6 to 13.7)</td>
<td>-6.5 (-32.7 to 13.1)</td>
<td>-3.6 (-18.4 to 8.7)</td>
<td>2.4 (-41.9 to 15.5)</td>
<td>.701</td>
</tr>
<tr>
<td>Adduction, Nth</td>
<td>-3.5 (-29.8 to 15.2)</td>
<td>-2.8 (-30.3 to 13.1)</td>
<td>-3.5 (-33.1 to 18.2)</td>
<td>-2.1 (-30.1 to 17.7)</td>
<td>.891</td>
</tr>
<tr>
<td>Abduction, Nth</td>
<td>-19.9 (-35.1 to 0.0)</td>
<td>-21.0 (-29.2 to 1.0)</td>
<td>-21.8 (-38.6 to 0.2)</td>
<td>-19.1 (-34.7 to -3.5)</td>
<td>.934</td>
</tr>
<tr>
<td>SF-12 scored</td>
<td>102.1 (92.3 to 108.0)</td>
<td>102.4 (98.3 to 108.8)</td>
<td>101.7 (92.2 to 106.7)</td>
<td>99.8 (83.9 to 108.2)</td>
<td>.439</td>
</tr>
<tr>
<td>WOMAC scoreed</td>
<td>86.5 (72.9 to 97.4)</td>
<td>95.6 (80.2 to 99.0)</td>
<td>88.5 (73.8 to 97.9)</td>
<td>81.2 (58.9 to 92.4)</td>
<td>.059</td>
</tr>
<tr>
<td>Currently institutionalizede</td>
<td>3 (3.9)</td>
<td>1 (4.0)</td>
<td>1 (3.8)</td>
<td>1 (4.0)</td>
<td>.999</td>
</tr>
<tr>
<td>Currently using aidsf</td>
<td>16 (21.1)</td>
<td>4 (16.0)</td>
<td>4 (15.4)</td>
<td>8 (32.0)</td>
<td>.261</td>
</tr>
<tr>
<td>Currently receiving physical therapyf</td>
<td>14 (18.4)</td>
<td>1 (4.0)</td>
<td>6 (23.1)</td>
<td>7 (28.0)</td>
<td>.069</td>
</tr>
</tbody>
</table>

Abbreviations: COP, center of pressure line; deg, degrees; FNS, femoral neck shortening; LLD, leg-length discrepancy; SF-12, Short Form 12; VAS, visual analog scale; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index.

a<0.75 cm.
b0.75-1.50 cm.
c>1.50 cm.
dData presented as median (P25–P75).
eData presented as No. (%).
fThe height of the heel lift was measured in the 23 patients who used a heel lift.
gThe VAS score for complaints as a result of LLD was measured in the 31 patients who indicated the feeling of LLD.
hThe values displayed for these variables represent the difference between the 2 legs (Difference = Parameterfractured leg − Parametercontralateral leg). A negative value represents a decrease in the fractured leg and a positive value represents an increase.
iThese variables had >10% missing data because they require a completely measured gait cycle for both legs, which was often not feasible (stance time 13% missing and single/double support phase 61%).

(12% vs 15% vs 64%; P<.001). More patients tended to have their implant removed if the femoral neck had shortened increasingly (28% vs 35% vs 44%; P>.05).

None of the gait parameters were significantly different between the femoral
neck shortening groups; heterogeneity across patients was high. Patients with severe femoral neck shortening tended to show increased weight bearing on the fractured leg in stance (median increase, 1.1% of total weight), a more endorotated foot axis (median axis, −1.8°), a shorter stance time (median, −2.8% of the gait cycle), a shorter single support phase and longer double support phase (median, −3.0% and 1.0% of the gait cycle, respectively), a shorter step length (median, −0.5 cm), a shorter COP line (median, −1.0 cm), and a lower gait velocity (median, 1.0 m/s) (Table 2). As femoral neck shortening increased, the pressure under the metatarsals tended to decrease, whereas the pressure under the halluc, toes, and heel of the fractured leg tended to increase (Figure 3). However, none of these trends reached statistical significance. As femoral neck shortening increased, patient satisfaction with their gait pattern tended to decrease (median VAS score, 8.0 vs 7.3 vs 7.3; P < .05).

Muscle strength was not significantly different between the groups. In all groups, the decrease in flexor, extensor, and adductor muscles was less than 10 N in the fractured leg. The decrease in abductor strength was approximately 20 N in all groups (Table 2).

With an increased femoral neck shortening, a trend toward an increased use of aids for mobilization (16% vs 15% vs 32%; P > .05) and a longer use of physical therapy (4% vs 23% vs 28%; P > .05) was seen. Similarly, the WOMAC score tended to decrease (median, 96 vs 89 vs 81; P > .05) (Table 2).

In a multivariable model, gait velocity was significantly associated with femoral neck shortening, age, and the use of aids for mobilization (gait velocity, m/s = 1.36 − (0.07 × femoral neck shortening, mm) − (0.01 × age, year) − (0.27 × use of aids for mobilization). The WOMAC score was influenced by the use of aids for mobilization and gait velocity but was not significantly affected by femoral neck shortening (WOMAC score = 50.62 − (16.03 × use of aids for mobilization) + (17.87 × gait velocity, m/s) (Table 3).

Table 3

<table>
<thead>
<tr>
<th>Determinant</th>
<th>Femoral Neck Shortening, a Beta (95% CI)</th>
<th>P</th>
<th>Gait Velocity, b Beta (95% CI)</th>
<th>P</th>
<th>WOMAC Score, c Beta (95% CI)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>−2.65 (−4.60 to −0.70)</td>
<td>.009</td>
<td>1.36 (0.86 to 1.85)</td>
<td>&lt;.001</td>
<td>50.62 (36.55 to 64.68)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Age, y</td>
<td>0.02 (0.00 to 0.04)</td>
<td>.048</td>
<td>−0.01 (−0.01 to 0.00)</td>
<td>.036</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight, kg</td>
<td>0.02 (0.00 to 0.03)</td>
<td>.012</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pauwels 3</td>
<td>0.54 (0.20 to 0.88)</td>
<td>.002</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Femoral neck shortening, cm</td>
<td>−0.07 (−0.14 to −0.01)</td>
<td>.034</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Current use of aids</td>
<td>−0.27 (−0.42 to −0.12)</td>
<td>.001</td>
<td>−16.03 (−25.70 to −6.36)</td>
<td>.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gait velocity, m/s</td>
<td></td>
<td></td>
<td>17.87 (3.76 to 31.97)</td>
<td>.014</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Abbreviations: CI, confidence interval; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index.

aVariables not in the equation: level of fracture, sex, and Garden classification (undisplaced/displaced).
bVariables not in the equation: time since initial surgery, Garden classification (undisplaced/displaced), and sex.
cVariables not in the equation: time since initial surgery, Garden classification (undisplaced/displaced), sex, femoral neck shortening, and age.
The shortening caused complaints in 40% of patients and heel lift use in 30% of patients. Patients also had a reduced gait velocity (1.1 m/s) (normal gait velocity, 1.3-1.5 m/s) and subtle changes in the gait pattern. Abductor strength was reduced by 20 N in the fractured leg compared with the contralateral leg. The degree of shortening increased as patient age, weight, and Pauwels classification of the fracture increased. Because all patients were permitted immediate weight bearing, healed without major complications or a need for revision surgery, and united within a reasonable period of time, it is not expected that any of these parameters significantly affected gait and muscle strength.

Although none of the individual gait parameters reached statistical significance when comparing the femoral neck shortening groups, femoral neck shortening seemed to impair overall symmetry of gait. The increased double support phase and decreased stance phase in patients with severe shortening fit the characteristics of an abnormal gait pattern. Reaching statistical significance was hampered by a high heterogeneity across patients and subtle differences between the legs (often less than 1%). Although left–right differences in gait parameters were small, previous research has indicated that these subtle differences results in functional limitations, even after 2 years. In the studied population, median femoral neck shortening at 22 months was 1.1 cm in the fractured leg. More than 50% of the patients healed with more than 1.0 cm shortening of the femoral neck; a shortening of more than 1.5 cm occurred in one-third of the patients. This is a substantially higher percentage than the 30% who healed with more than 1.0 cm shortening previously reported in a similar population. The shortening caused complaints in 40% of patients and heel lift use in 30% of patients. Patients also had a reduced gait velocity (1.1 m/s) (normal gait velocity, 1.3-1.5 m/s) and subtle changes in the gait pattern. Abductor strength was reduced by 20 N in the fractured leg compared with the contralateral leg. The degree of shortening increased as patient age, weight, and Pauwels classification of the fracture increased. Because all patients were permitted immediate weight bearing, healed without major complications or a need for revision surgery, and united within a reasonable period of time, it is not expected that any of these parameters significantly affected gait and muscle strength.

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those in the included population. To promote adaptation and coping, patients should be informed about the expected long-term limitations as early as possible. Surgeons could even consider a primary arthroplasty in high-risk patients, taking the risk factors for femoral neck shortening into account (ie, age, weight, and Pauwels classification).

The consequences of femoral neck shortening can be partially compensated through the use of a heel lift. A low incidence of heel lift use was observed (30% in the overall group, 64% in the severe shortening group). Of 31 patients who indicated discomfort resulting from a leg-length discrepancy, 32% did not have a heel lift. Therefore, physicians should pay attention to femoral neck shortening after internal fixation of a femoral neck fracture and consider the option of a heel lift with all patients.

The current study is the first attempt to quantify gait characteristics in relation to femoral neck shortening following a femoral neck fracture. This study has several limitations. The effect of osteoporosis on femoral neck shortening could not be determined because osteoporosis data were unavailable. However, following the study treatment protocol, all patients were screened for osteoporosis and treated if necessary. Because available radiographs taken in different rotational angles were used, the abductor moment arm shortening could not be measured reliably. Second, gait was measured over a relatively narrow force measurement plate of 40 cm, which compromised a reliable measurement of gait width. Finally, gait parameters and plantar pressure patterns not only reflect changes in the hip but can be influenced by many factors throughout the kinetic chain. Future studies should combine force and pressure measurements with video assessment because the latter may help interpret the kinetic data.

**CONCLUSION**

Internal fixation of a femoral neck fracture results in femoral neck shortening in the majority of patients. It also results in several long-term physical limitations. Femoral neck shortening impairs gait velocity and causes complaints in some patients. The degree of shortening increases with patient age, weight, and Pauwels classification. The relatively young and healthy population included in this study seemed capable of compensating for these limitations. However, attention should be paid to adequate compensation of a shortened femoral neck, and patients should be informed about the consequences as early as possible. Surgeons could even consider a primary arthroplasty in high-risk patients. Future studies should consider patient-reported functioning and include objective functional outcome measurements, particularly femoral neck shortening, muscle strength, and gait velocity because these are more specific.

**REFERENCES**

The authors would like to acknowledge the contributions of the following:

FATH trial study group:
Steering Committee: Mohit Bhandari (chair), Philip J. Devereaux, Gordon Gayatt, Martin J. Heetveeld, Kyle Jeray, Susan Liew, Martin J. Rich-ardson, Emil H. Schemitsch, Marc Swiontkowski, Paul Tornetta III, Stephen Walker.
Methods Centre and Coordination of Cana-dian/International Sites Supported under the PSI and CIHR Grants: McMaster University, Ham-ilton, ON: Mohit Bhandari, Sheila Sprague, Helena Viveros Nicole Simunicov, Diane Heels-Andsell, Lisa Buckingham, Aravin DuraiKannan.
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Country Coordination of Dutch Sites Sup-ported under the Fonds NutsOhra Grant: Eeras-mus MC, Rotterdam: Esther M.M. Van Lieshout, Stephanie M. Zielinski.

Investigators—The Netherlands (site prin-cipal investigator is marked with an asterisk):
Academic Medical Center, Amsterdam: J Carel Goslings*, Robert Haverlag, Kees Jan Ponsen.
Erasmus MC, University Medical Center Rot-terdam: Peter Patka*, Martin G. Ever-sjik, Rolf Peters, Dennis Den Hartog, Oscar J.F. Van Waes, Pim Oprel.

Investigators—Canada (site principal investi-gator is marked with an asterisk):
Foothills Medical Center, Calgary, AB: Rich-ard E. Buckley*, Paul Duffy, Robert Korley, Kelly Johnston, Shannon Paloski, Kimberly Carcary.
Henderson Hospital, Hamilton, ON: Victoria Avram*.
Kingston General Hospital, Kingston, ON: Ryan Bicknell*, Jeff Yach, Davide Bardana, Sue Lambert.
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Sunnybrook Health Sciences Centre, Toronto, ON: Hans J. Kreder*, David J.G. Stephen*, Markku Nousianninen, Ria Cagaanan, Monica Kanz.
Toronto Western Hospital, Toronto, ON: Kha-lid Syed*, Tania Azad.
Queen Elizabeth II Health Sciences Centre, Halifax, NS: Chad Cole*, Ross Leighton*, David Johnstone, Mark Glazebrook, David Alexander, Kelly Trask, Gwendolyn Dobbin.

Investigators—United States (site principal investigator is marked with an asterisk):
Boone Hospital Center – Columbia Orthopae-dic Group, Columbia, MO: Todd M Oliver*, Vicky Jones, James Ronan.
Boston University Medical Center, Boston, MA: Paul Tornetta III*, Desmond T. Brown, Hope Carlisle, Lisa Shaugnessy.
Duke University Medical Center, Durham, NC: Robert Zarra*, Maria J. Manson.
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Indiana University - Wishard Health Services, Indianapolis, IN: Brian Mullis*, J.P. Ertl, Karl Shively, Valda Frizzel.


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OrthoIndy, Indianapolis, IN: Joseph Baele*, Tim Weber, Matt Edison, Dana Musapatika.

Orthopaedic Associates of Michigan, Grand Rapids, MI: Clifford Jones*, James Ringer, Terrance Endres, Martin Gelbke, Michael Jabara, Debra L. Sietsma, Susan M. Engerman.

Regions Hospital, St Paul, MN: Julie A. Switzer*, Mangnai Li, Scott Marston, Peter Cole, Sandy X. Vang, Amy Foley.

Santa Clara Valley Medical Center, San Jose, CA: Jessica McBeth*, Curt Comstock, Navid Ziran.

St Elizabeth Health Center, Youngstown, OH: James Shuer*, Barbara Hileman.

St Louis University Hospital, St Louis, MO: David Karges*, Lisa Cannada*, Djoldas, Kaldjanov, John Tracy Watson, Emily Mills, Tiffany Simon.

Texas Tech University Health Sciences Center – El Paso, El Paso, TX: Amr Abdelgawad*, Juan Shunia.

Texas Tech University Health Sciences Center – Lubbock, Lubbock, TX: Mark Jenkins*, Mimi Zumwalt, Amanda West Romero.

University of Alabama, Birmingham, AL: Jason Lowe*, Jessica Goldstein.

University of California Irvine Medical Center, Orange, CA: David P. Zamorano*, Deanna Lawson.

University of Cincinnati Medical Center, Cincinnati, OH: Michael Archdeacon*, John Wyrick, Shelley Hampton.

University of Connecticut, Hartford, CT: Courtland G. Lewis*, Arben Ademi, Raymond Sullivan, Stephanie Caminiti.

University of Mississippi Medical Center Jackson, MS: Matthew Graves*, Lori Smith.


University Orthopaedic Associates, New Brunswick, NJ: Carlos Sagebien*, Patricia Seuffert.


University of Pittsburgh, Pittsburgh, PA: Ivan Tarkin*, Peter Siska, Arlene Lather, James Irgang, Dana Farrell.


University of Texas Health Sciences Center, San Antonio, TX: Animesh Agarwal*, Rebecca Wright.

US Army Institute of Surgical Research and Brooke Army Medical Center, Fort Sam Houston, TX: Joseph R. Hsu*, James R. Ficke, Matthew A. Napierala, Michael T. Charleston, Mary K. Fan.

Vanderbilt University Medical Center, Nashville, TN: William T. Obremskey*, Justin E. Richards, Kenya Robinson.

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