Femoral neck shortening impairs gait velocity after internal fixation of a femoral neck fracture

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Abstract

Knowledge on long-term physical limitations in patients after internal fixation of a femoral neck fracture is limited. The aim of this study was to assess femoral neck shortening and its consequences on gait pattern and muscle strength in femoral neck fracture patients treated with internal fixation. Patients were selected from a multicenter RCT. Patient characteristics, SF-12, and WOMAC scores were collected. Femoral neck shortening was measured radiologically. Gait parameters were measured using plantar pressure measurement. Maximum isometric forces of the hip muscles were measured using handheld dynamometry. Differences between the fractured leg and the contralateral leg were calculated. Variables of patients with little or no shortening (<0.75 cm), moderate shortening (0.75-1.50 cm), and severe shortening (>1.50 cm) were compared using univariate and multivariate analyses. Seventy-six patients (median age 68 years) were included. The median femoral neck shortening was 1.1 cm. Overall, subtle changes in gait pattern, a reduced gait velocity (median 1.1 m/s), and reduced abductor muscle strength (median -20 N) were observed. Patient self-reported functioning was good (median WOMAC score 86.5). 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. Concluding, 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.

Introduction

The worldwide incidence of hip fractures is increasing, from an estimated 1.6 million persons per year in 1990 to 6.3 million 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 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 (*e.g.*, Short-Form 12 (SF-12), EuroQol 5D (EQ-5D)), or disease specific questionnaires (*e.g.*, Harris Hip Score (HHS), Western Ontario McMaster Osteoarthritis (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 a 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 early to an axial loading force 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 back out, and affecting standing posture or gait.[11-16]

We hypothesized that femoral neck shortening would occur in femoral neck fracture patients treated with internal fixation, leading to long-term functional impairment by reduced muscle strength and an asymmetrical gait pattern. The aim of the present study was therefore to determine the level of femoral neck shortening and asymmetry in gait and muscle strength in patients who sustained a femoral neck fracture treated with internal fixation at least one year before. Risk factors for femoral neck shortening and the effect of femoral neck shortening on physical functioning were determined.

Patients and Methods

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 impact of sliding hip screw versus cancellous screw fixation on rates of revision surgery at two years in elderly patients with femoral neck fractures. In the Netherlands 14 hospitals participated and enrolled 250 patients (February 2008-August 2009). Patients were recruited for the Dutch FAITH trial if they (1) were adults aged ≥50 years, (2) had a radiologically confirmed femoral neck fracture (*i.e.*, undisplaced fracture or displaced fracture in ASA 1-2 patients (American Society of Anesthesiologists classification), aged 50-80 years, with a fracture that could be closed reduced) (3) had a low energetic fracture without other major trauma, and (4) were ambulatory pre-fracture (with or without aid). Patients were excluded if they (1) had a fracture not suitable for internal fixation (*e.g.,* 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 pre-fracture, (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 initial surgery.

Patients were included in the current study at least one year after internal fixation, because it is generally believed that only little functional improvement can be expected after one year. Exclusion criteria for this study were:

- Revision surgery or conversion to arthroplasty
- Patient not capable of walking several meters independently (with or without ambulatory aid)
- Other lower limb abnormalities that could be expected to influence gait pattern (*e.g.*, other lower extremity fractures/neurological diseases)
- History of previous internal fixation or arthroplasty of the contralateral (control) hip
- X-rays 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 X-rays using graphic software (Photoshop CS3 Graphic, Adobe, San Jose, USA) as described previously.[12, 13] The most recent anterior-posterior X-ray of the fractured hip was compared with the contralateral hip on X-rays 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 in order to correct for differences in magnification of the X-rays.

Gait analysis was measured using a calibrated pressure plate (footscan®, RSscan International, Olen, Belgium; 2.0 x 0.4m, 125 Hz). Patients were instructed to walk barefoot across the plate at their preferred speed. All patients completed this task without an aid. Five measurements were performed per patient. The combination of at least three gait measurements that were most representative were selected based upon 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 of the fractured leg were compared with the contralateral side (as usual in gait studies). The difference was computed using the formula: Parameter $_{\text{fractured leg}}$ – Parameter $_{\text{contralateral leg}}$.

In order to analyze the plantar pressure, data were normalized for foot size, width, and progression angle as described by Keijsers *et al.*[17] This is a validated method, which allows for a more detailed and standardized comparison of the fractured side with the contralateral side (intraclass correlation ≥ 0.85). Figures were computed that show the difference in pressure distribution between the legs by subtracting pressure in the contralateral leg from the pressure in the fractured leg, for each activated sensor. A 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.[18, 19] SF-12 scores were converted to a norm-based score and compared with the norms for the general population of the United States (1998), as weighing factors for the Dutch population were not available. Patient satisfaction with their gait pattern was measured using a VAS (Visual Analog Scale) score, ranging from zero (extremely dissatisfied) to ten (completely satisfied). A VAS was also used to measure to which extent patients were hampered due to the leg length difference, ranging from zero (free of complaints) to ten (very much hampered).

Data analysis

Analyses were performed using SPSS (version 16.0, SPSS Inc., Chicago, IL, USA). 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, categorical variables as numbers and percentage. In order to study femoral neck shortening the study population was divided in tertiles: patients with little or no femoral neck shortening (<0.75 cm), moderate shortening (0.75-1.50 cm) and severe shortening (>1.50 cm). Groups were compared using a Kruskal-Wallis Analysis of Variance (ANOVA; numeric variables) or a Chi-squared analysis (categorical variables). In order to assess if femoral neck shortening independently influences gait velocity and patient functioning (WOMAC score), a multivariable regression analysis was performed, using a backward stepwise approach. Variables that displayed a P-value <0.1 in the univariate analyses and variables which were likely to influence the outcome variable were entered as covariate. Results with P<0.05 (two-sided test) were regarded as statistically significant.

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Results

Demographic description of patients

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

Femoral neck shortening, gait pattern and muscular strength in the study population

The 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 a median 4.0 on a VAS (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 the patients the implant had been removed because of implant-related complaints (Table 2).

The gait parameters differed by less than one percent between both legs, excepted stance time, which was 1.5% of the total gait cycle shorter for the fractured leg. The median gait velocity was 1.1 m/s P_{25}-P_{75} 0.9-1.2; Table 2). The average plantar pressure seemed reduced under metatarsals 1 and 2 (MT1 and MT2) and increased under the hallux, toes, and heel (Figure 2; P>0.05). Patients scored their satisfaction with their gait pattern a median 7.5 on a VAS (P_{25}-P_{75} 5.1-7.8).

The muscle strength of the flexor, extensor and adductor muscles decreased <10 N in the fractured leg compared with the contralateral side. The 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 pre-fracture situation). Also, 18% of the patients still received physical therapy. The median SF-12 score was 102.1 (P_{25}-P_{75} 92.3-108.0) and the median WOMAC score was 86.5 (P_{25}-P_{75} 72.9-97.4; Table 2).

Risk factors for femoral neck shortening

Male gender and a higher weight were associated with an increased femoral neck shortening (32% male versus 42% versus 72%, P=0.013; median weight 65.0 kg versus 72.5 versus 80.0, P=0.003; Table 3). The same was found for a displaced fracture (Garden III-IV) and a Pauwels 3 fracture (12% displaced versus 42% versus 56%, P=0.009; 4% Pauwels 3 versus 27% versus 52%, P=0.001). 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 x age[year]) + (0.02 x weight[kg]) + (0.54 x Pauwels 3; Table 3).

Consequences of femoral neck shortening

Femoral neck shortening was associated with an increased feeling of leg length discrepancy (20% versus 27% versus 76%, P<0.001) and increased use of a heel lift (12% versus 15% versus 64%, P<0.001). More patients tended to have their implant removed if the femoral neck had shortened increasingly (28% versus 35% versus 44%, P>0.05).

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 an 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), a shorter step length (median -0.5 cm), a shorter center of pressure line (COP) (median -4.4 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 hallux, 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 versus 7.3 versus 7.3, P>0.05).

Muscle strength was not significantly different between the groups. In all groups the decrease in flexor, extensor and adductor muscles was <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 towards an increased use of aids for mobilization (16% versus 15% versus 32%; P>0.05) and a longer use of physical therapy (4% versus 23% versus 28%;, P>0.05) was seen. Similarly, the WOMAC tended to decrease (median WOMAC score 96 versus 89 versus 81, P>0.05; 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 x femoral neck shortening[mm]) – (0.01 x age[year]) – (0.27 x 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 x use of aids for mobilization) + (17.87 x gait velocity[m/s]; Table 3).

Discussion

Internal fixation of femoral neck fractures results in functional limitations, even after two years. In the studied population, the median femoral neck shortening at 22 months was 1.1 cm in the fractured leg. Over 50% of the patients healed with >1.0 cm shortening of the femoral neck, a shortening of >1.5 cm occurred in one third of our patients. This is a substantially higher percentage than the 30% healed with >1.0 cm shortening previously reported in a similar population.[13] 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)[20]) and subtle changes in the gait pattern. The abductor strength was reduced by 20N in the fractured leg, compared with the contralateral leg. The degree of shortening increased as patient age, weight and the Pauwels classification of the fracture increased. As all patients were permitted immediate weight bearing, healed without major complications or a need for revision surgery, and unite within a reasonable period of time it is not expected that any of these parameters significantly impacted 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 <1%). Although left-right differences in gait parameters were small, previous research has indicated that these subtle difference have clinical relevance.[21] The presence of a unilateral femoral neck fracture may also alter the gait characteristics of the contra-lateral intact limb to which it is being compared, influencing left-right differences.

Femoral neck shortening proved to have an independent negative influence on gait velocity in a multivariable comparison. Gait velocity is an important gait parameter that has proven to influence patient functioning, and is related to many other gait parameters.[22, 23] The correlation between impaired walking speed and reduced function scores in our patients confirms the importance of gait velocity as a predictor of patient function.

There is currently no information in the literature that contributes to interpreting the observed asymmetry in plantar pressure patterns. From a biomechanical perspective, the observed changes in the fractured leg could match a gait pattern with increased inversion of the foot (to compensate for a leg length discrepancy), or with enhanced stiffening in the first metatarso-phalangeal-joint. This gait mechanism can increase balance during walking, but is also influenced by gait velocity. In patients with severe shortening (>1.50 cm) a more flat gait pattern with decreased inversion and exorotation of the foot was seen (confirmed by the change in foot axis), and a decreased roll-of (confirmed by the shortening of the COP), probably associated with a wider gait pattern. This could be due to the decreased abductor strength and balance as a result of the femoral neck shortening, and seems a more extensive compensatory mechanism to increase balance, but decreases gait economy. Consequently, patients with a severe femoral neck shortening tend to use more aids for mobilization and require longer use of physical therapy.

There was a trend towards a decreased patient functioning (SF-12 and WOMAC) with increased femoral neck shortening, but the association was less strong as reported before.[13] In general, patients had relatively high SF-12 and WOMAC scores, indicating good functioning. Coping strategies may play a role, indicated by the high SF-12 mental component score. Patients may have adapted their activities to their limitations, or were capable of developing sufficient compensatory strategies, because they were relatively young and healthy. Femoral neck shortening may affect older, more disabled patients to a larger extent, as they may be less capable of adapting. The results of this study should therefore not be generalized. There was no selection bias, as characteristics of the non-participating patients (*i.e.,* age, ASA-score and pre-fracture use of aids) did not differ significantly from those in the included population. To promote adaption 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 (*i.e.;* age, weight and Pauwels classification).

The consequences of femoral neck shortening can be partially compensated through the use of a heel lift. There was a low observed incidence of heel lift use (30% in the overall group, 64% in the severe shortening group). Out of 31 patients that indicated discomfort resulting from a leg length discrepancy 32% did not have a heel lift. Physicians should therefore pay more 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 present 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 as osteoporosis data were unavailable. However, following the study treatment protocol, all patients were screened for osteoporosis and treated if necessary. Because available X-rays were used, taken in different rotational angles, the abductor moment arm shortening could not be measured reliably. Secondly, 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 do 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 since the latter may help interpreting the kinetic data.

Conclusion

Internal fixation of a femoral neck fracture results in femoral neck shortening in the majority of patients. This 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 the Pauwels classification. The relatively young and healthy population included in our study seems 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. We recommend that future studies should not only consider patient-reported functioning, but also include objective functional outcome measurements, particularly femoral neck shortening, muscle strength and gait velocity, as these are more specific.

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Table 1. Patient and fracture characteristics

	Total (N=76)	Little or none FNS (<0.75 cm) (N=25)	Moderate FNS (0.75-1.50 cm) (N=26)	Severe FNS (>1.50 cm) (N=25)	P-value
Age (yrs)[1]	68.3 (61.6-78.4)	70.5 (62.4-79.5)	69.4 (61.7-77.2)	67.1 (60.6-78.7)	0.882
Gender (Male)[2]	37 (48.7)	8 (32.0)	11 (42.3)	18 (72.0)	0.013
Weight (kg)[1]	75.0 (63.0-83.0)	65.0 (56.5-76.5)	72.5 (62.3-83.0)	80.0 (73.5-90.0)	0.003
BMI (kg/m^2)[1]	24.3 (21.9-26.0)	23.6 (21.1-25.5)	24.0 (21.4-25.3)	25.8 (23.5-28.4)	0.021
ASA score (ASA>2)[2]	5 (6.6)	1 (4.0)	1 (3.8)	3 (12.0)	0.465
Institutionalized pre-fracture[2]	1 (1.3)	0 (0.0)	0 (0.0)	1 (4.0)	0.356
Pre-fracture use of aids[2]	6 (7.9)	1 (4.0)	2 (7.7)	3 (12.0)	0.576
Subcapital fracture[2]	36 (47.4)	15 (60.0)	12 (46.2)	9 (36.0)	0.346
Displaced fracture (Garden III-IV)[2]	27 (35.5)	3 (12.0)	11 (42.3)	13 (52.0)	0.009
Pauwels class 3[2]	22 (28.9)	1 (4.0)	7 (26.9)	14 (56.0)	0.001
Time FNS measurements since surgery	11.7 (11.2-12.4)	11.7 (11.5-12.3)	11.5 (10.5-12.3)	11.8 (11.2-12.9)	0.448

(months)[1]					
Time gait measurements since surgery (months)[1]	22.3 (18.9-24.3)	22.9 (20.0-27.0)	22.0 (18.2-23.7)	21.5 (17.8-23.2)	0.187

FNS, Femoral Neck Shortening; BMI, Body Mass Index; ASA, American Society of Anesthesiologists.

Differences between the three groups were tested with the Kruskal-Wallis ANOVA for continuous variables, and with the Chi-squared test for categorical variables.

[1] Data are presented as median with P_{25}-P_{75} given between brackets. [2] Data are presented as number with percentages.

Table 2. Data on femoral neck shortening, gait parameters, muscle strength and self-reported patient functioning

	Total N=76	Little or none FNS (<0.75 cm) N=25	Moderate FNS (0.75-1.50 cm) N=26	Severe FNS (>1.50 cm) N=25	P-value
Femoral neck shortening (cm)[1]	1.1 (0.5-1.7)	0.4 (0.1-0.5)	1.1 (0.9-1.3)	2.0 (1.7-2.3)	<0.001
Feeling of LLD[2]	31 (40.8)	5 (20.0)	7 (26.9)	19 (76.0)	<0.001
VAS score complaints LLD[1]*	4.0 (1.5-7.2)	2.3 (0.5-7.1)	4.9 (4.8-8.0)	3.9 (1.9-7.0)	0.242
Heel lift use[2]	23 (30.3)	3 (12.0)	4 (15.4)	16 (64.0)	<0.001
Height Heel lift (cm)[1]**	1.0 (0.5-1.5)	0.5 (0.5-1.0)	0.8 (0.2-1.8)	1.2 (1.0-1.7)	0.161
Implant removed[2]	27 (35.5)	7 (28.0)	9 (34.6)	11 (44.0)	0.412
Weight distribution in stance (%)[1§]	0.5 (-5.5-5.4)	-0.5 (-5.3-5.2)	-0.7 (-7.4-5.4)	1.1 (-2.2-6.7)	0.439
Foot axis (°)[1§]	0.5 (-5.5-4.6)	2.4 (-1.2-7.4)	-2.8 (-7.3-3.9)	-1.8 (-6.5-4.8)	0.034
Stance time (% of gait cycle)[1§]***	-1.5 (-3.8- -0.1)	-1.9 (-4.0- -0.4)	-0.5 (-2.4-0.5)	-2.8 (-5.1- -0.1)	0.116
Single support phase (% of gait cycle)[1§]***	-0.5 (-4.4-1.0)	-0.3 (-4.5-0.7)	0.1 (-3.7-1.8)	-3.0 (-5..4-0.5)	0.519
Double support phase (% of gait cycle)[1§]***	0.2 (-2.1-2.6)	0.4 (-0.6-1.1)	-0.5 (-2.6-3.5)	1.0 (-2.4-3.5)	0.806

Step length (cm)[1§]	0.0 (-3.2-3.8)	0.3 (-3.1-4.8)	0.0 (-2.7-3.6)	-0.5 (-3.4-3.4)	0.802
COP ΔY (cm)[1§]	0.5 (-7.9-6.9)	3.1 (-4.9-6.8)	0.5 (-8.0-7.7)	-4.4 (-11.6-9.8)	0.406
Gait velocity (m/s)[1]	1.1 (0.9-1.2)	1.1 (1.0-1.3)	1.1 (0.8-1.3)	1.0 (0.8-1.2)	0.165
VAS score satisfaction with gait pattern[1]	7.5 (5.1-8.7)	8.0 (6.5-9.0)	7.3 (5.3-8.3)	7.3 (4.3-8.0)	0.086
Flexion (N)[1§]	-1.3 (-13.5-3.9)	0.0 (-7.5-3.9)	-3.6 (-14.8-0.0)	-1.3 (-19.3-7.2)	0.474
Extension (N)[1§]	-3.9 (-27.6-13.7)	-6.5 (-32.7-13.1)	-4.2 (-18.4-8.7)	2.4 (-41.9-15.5)	0.701
Adduction (N)[1§]	-3.5 (-29.8-15.2)	-2.8 (-30.3-13.1)	-8.4 (-33.1-18.2)	-1.9 (-30.1-17.7)	0.891
Abduction (N)[1§]	-20.9 (-35.1-0.0)	-21.0 (-29.2-1.0)	-21.8 (-38.6-0.2)	-19.1 (-34.7- -3.5)	0.934
SF-12 score[1]	102.1 (92.3-108.0)	102.4 (98.3-108.8)	101.7 (92.9-106.2)	99.8 (83.9-108.2)	0.439
WOMAC score[1]	86.5 (72.9-97.4)	95.6 (80.2-99.0)	88.5 (73.8-97.9)	81.2 (58.9-92.4)	0.059
Currently institutionalized[2]	3 (3.9)	1 (4.0)	1 (3.8)	1 (4.0)	0.999
Currently using aids [2]	16 (21.1)	4 (16.0)	4 (15.4)	8 (32.0)	0.261
Currently receiving physical therapy[2]	14 (18.4)	1 (4.0)	6 (23.1)	7 (28.0)	0.069

FNS, Femoral Neck Shortening; LLD, Leg Length Discrepancy; VAS, Visual Analog Scale; COP, Center of Pressure line; SF-12, Short Form 12; WOMAC, Western Ontario McMaster Osteoarthritis Index.

Differences between the three groups were tested with the Kruskal-Wallis ANOVA for continuous variables, and with the Chi-squared test for categorical variables.

[1] Data are presented as median with P_{25}-P_{75} given between brackets. [2] Data are presented as number with percentages.

* The VAS score for complaints as a result of a LLD was only measured in the 31 patients that indicated they the feeling of a LLD. ** The height of the heel lift was only measured in the 23 patients that used a heel lift. *** These 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%).

[§] The values displayed for these variables represent the difference between the two legs (Difference = $\text{Parameter}_{\text{fractured leg}} - \text{Parameter}_{\text{contralateral leg}}$). A negative value therefore represents a decrease in the fractured leg, a positive value an increase.

Table 3. Regression coefficients for the factors that influence femoral neck shortening, gait velocity and WOMAC score

Determinant	Femoral neck shortening[1]		Gait velocity[2]		WOMAC score[3]	
	beta (95% CI)	P-value	beta (95% CI)	P-value	beta (95% CI)	P-value
Constant	-2.65 (-4.60- - 0.70)	0.009	1.36 (0.86-1.85)	<0.001	50.62 (36.55-64.68)	<0.001
Age (years)	0.02 (0.00-0.04)	0.048	-0.01 (-0.01-0.00)	0.036		
Weight (kg)	0.02 (0.00-0.03)	0.012				
Pauwels 3	0.54 (0.20-0.88)	0.002				
Femoral neck shortening (cm)			-0.07 (-0.14- -0.01)	0.034		
Current use of aids			-0.27 (-0.42- -0.12)	0.001	-16.03 (-25.70- -6.36)	0.001
Gait velocity (m/s)					17.87 (3.76-31.97)	0.014

Multivariable regression models using a backward stepwise approach

[1] Variables not in the equation: level of fracture, gender and Garden classification (undisplaced/displaced)

[2] Variables not in the equation: time since initial surgery, Garden classification (undisplaced/displaced) and gender

[3] Variables not in the equation: time since initial surgery, Garden classification (undisplaced/displaced), gender, femoral neck shortening, and age

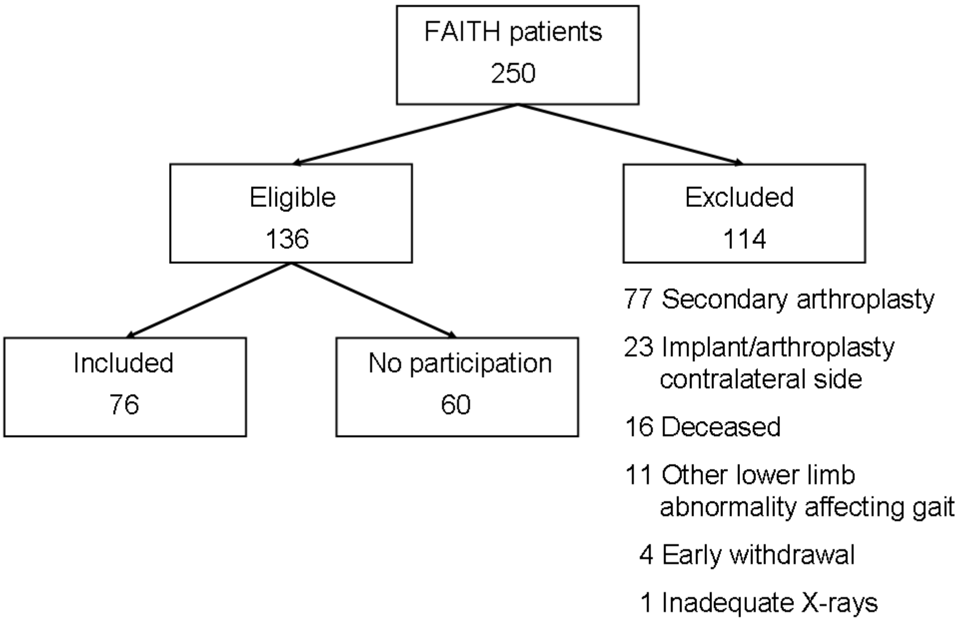

Figure 1. Flowchart of patients participating in this study.

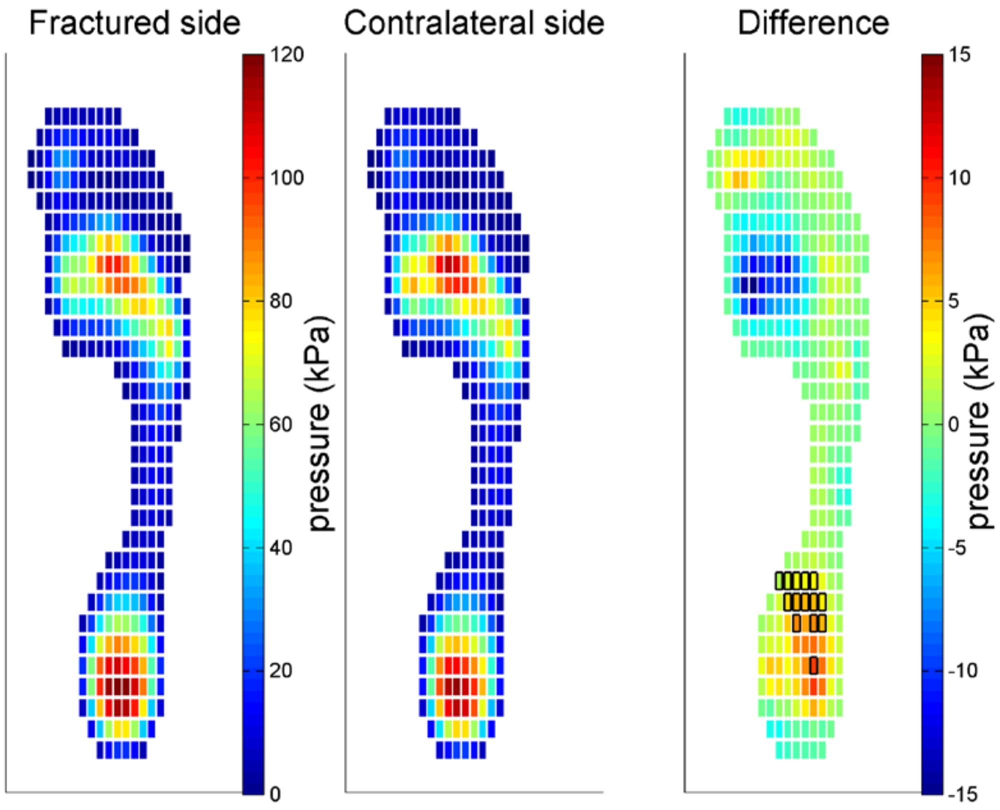

Figure 2. Average plantar pressure distribution

The left image shows the average plantar pressure distribution for the fractured side, the image in the middle shows the average plantar pressure distribution for the contralateral or control side. The right image shows the average difference in plantar pressure distribution between the two sides. A positive value indicates a higher pressure for the fractured leg in that square, a negative value indicates a lower pressure. The squares framed in bold indicate those sensors with significantly different changes in plantar pressure between the legs ($P<0.05$).

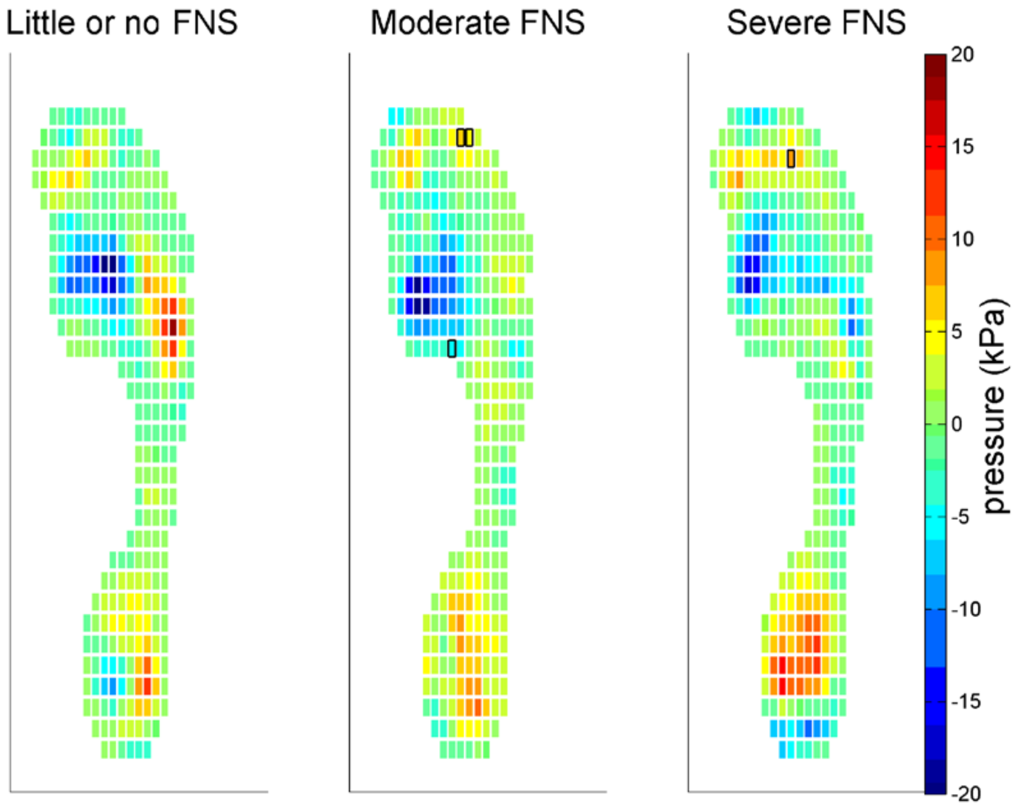

Figure 3. Differences in plantar pressure distribution between the fractured and contralateral leg for patients with various amounts of femoral neck shortening (FNS)

The left image shows the differences in plantar pressure distribution in the patients with little or no femoral neck shortening (<0.75 cm). The image in the middle shows the differences in plantar pressure distribution in the patients with moderate femoral neck shortening (0.75-1.50 cm). The right image shows the differences in plantar pressure distribution in the patients with severe femoral neck shortening (>1.50 cm). A positive value indicates a higher pressure for the fractured leg in that square, a negative value indicates a lower pressure. The squares framed in bold indicate those sensors with significantly different changes in plantar pressure between the legs (P<0.008; six groups of positive and negative sensors were compared, therefore threshold for significance = 0.05 / 6 = 0.008).

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