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Asymmetry in gait pattern following bicondylar tibial plateau fractures—A prospective one-year cohort study☆,☆☆

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ABSTRACT

Introduction: Despite the high number of studies evaluating outcomes following tibial plateau fractures, the literature lacks studies including the objective assessment of gait pattern. The purpose of the present study was to evaluate asymmetry in gait patterns at 12 months after frame removal following ring fixation of a tibial plateau fracture.
Patients and methods: The study design was a prospective cohort study. The primary outcome measurement was the gait patterns 12 months after frame removal measured with a pressure-sensitive mat. The mat registers footprints and present gait speed, cadence, as well as temporal and spatial parameters of the gait cycle. Gait patterns were compared to a healthy reference population.
Results: Twenty-three patients were included with a mean age of 54.4 years (32–78 years). Patients presented with a shorter step-length of the injured leg compared to the non-injured leg (asymmetry of 11.3%). Analysis of single-support showed shorter support time of the injured leg compared to the non-injured leg (asymmetry of 8.7%). Moreover, analysis of swing-time showed increased swing-time of the injured leg (asymmetry of 8.9%). Compared to a healthy reference population, increased asymmetry in all gait patterns was observed. The association between asymmetry and health-related quality of life (HRQOL) showed moderate associations (single-support: $R = 0.50$, $P = 0.03$; step-length: $R = 0.43$, $P = 0.07$; swing-time: $R = 0.46$, $P = 0.05$).
Conclusion: Compared to a healthy reference population, gait asymmetry is common 12 months after frame removal in patients treated with external ring fixation following a tibial plateau fracture of the tibia.

Introduction

Fractures of the tibial plateau have been recently reported with an incidence of 10.3/100,000/year [1]. The operative treatment of complex tibial plateau fractures is challenging due to comminution of the joint surface, resulting in difficulties obtaining anatomic reduction as well as axial alignment, often complicated by soft tissue damage [2–6].

The outcomes following complex tibial plateau fractures have been described in several studies as a high risk of joint pain, malalignment, intraarticular soft tissue injuries, posttraumatic osteoarthritis and limitations in activity of daily living and health-related quality of life (HRQOL) [3–13].

Despite a large number of studies evaluating the outcomes following tibial plateau fractures, the literature lacks studies including objective assessment of patient's recovery regarding functional ability and gait pattern. A single study by Warschawski et al. [14] reported the long-term functional outcome, including objective measurements of gait patterns, in a patient group of complex tibial plateau fractures treated by plates. The reported altered spatiotemporal gait patterns were compared to a healthy control group. The gait patterns were found to be significantly correlated to worse HRQOL. Moreover, the LEAP study group [15,16] reported significant gait abnormalities following severe lower extremity injuries; patient satisfaction was highly correlated to physical function.

The recovery of gait function following fractures of the tibial plateau and the underlying gait variables are poorly understood. The literature lacks studies reporting on the development in gait

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patterns from the time of surgery and onwards. Prospective studies evaluating specific gait variables (pace, rhythm, variability, injured/non-injured asymmetry, cadence and walking speed) in patients treated by a ring fixator following a tibial plateau fracture have not been previously reported. Increased knowledge on specific gait characteristics may contribute to improve surgical as well as rehabilitation programmes and increase the quality of patient information.

The purpose of the present study was to evaluate asymmetry in gait patterns at 12 months after frame removal following a bicondylar tibial plateau fracture treated with a ring fixator. The explorative aim was to report the association between asymmetry in gait patterns and patient-reported HRQOL.

The hypothesis was that patients treated by ring fixation following a bicondylar tibial plateau fracture would show gait asymmetry at 12 months after frame removal compared with a healthy reference population.

Patients and methods

Study design

The study design was a prospective follow-up study including all patients treated with a ring fixator following a bicondylar fracture of the tibial plateau. This study reports the outcomes 12 months after frame removal. The primary outcome measurement was the gait patterns at 12 months after frame removal. The Danish Data Protection Agency (J. nr. 2008-58-0028) approved the study, which was performed according to the principles of the Declaration of Helsinki. The reporting of the study complies with the Strengthening the Reporting of Observational studies in Epidemiology (STROBE) statement [17].

All patients treated with a ring fixator following a bicondylar fracture of the tibial plateau between December 2012 and May 2014 at Aalborg University Hospital, Denmark, were included. Patients with bicondylar tibial plateau fractures treated without a ring fixator, who were unable to participate in gait analysis due to physical or mental disabilities, who were unable to walk 2×6 m without walking aids or who were treated with total knee replacement (TKR) were excluded.

Basic characteristics regarding age, gender, fracture classification and co-morbidities were registered. Fracture classification was performed according to the AO classification [18] and was conducted on preoperatively obtained CT-scan.

Gait assessment

Walking ability and gait asymmetries were measured while walking on a pressure-sensitive mat (GAITRite System®) [19]. The mat registers footprints, gait speed and cadence, as well as temporal and spatial parameters of the gait cycle. The method is thoroughly described and validated in a number of studies also including orthopaedic injuries [19–22].

The patients were asked to walk on the (6-m-long) pressure-sensitive mat. The test was performed twice (12-m test). The values from each trial were averaged. The patients walked with a self-selected walking speed from a starting position approximately 2 m outside the measuring area, continuing to 2 m past the end of the pressure-sensitive mat.

The outcome of the GAITRite system consisted of 21 different gait variables. The mean temporal (step-time, stance time, single- and double-support time, swing-time, cadence and speed) and spatial values (step length, foot angle) were calculated during the 12-m test.

Selection of gait variables for outcome analysis

Gait speed and cadence represented the general characteristics of the gait pattern. Gait characteristics for the injured and the non-injured leg were evaluated with respect to: single-support, step-length and foot rotational characteristics. The asymmetry between the injured and the non-injured leg was reported as percentage asymmetry ($100 \times \text{Ln}(\text{injured}/\text{non-injured})$) [23]. Furthermore, the variability of the gait cycles was reported as the coefficient of variance (CV) of stance-time ($100 \times \text{SD}/\text{mean}$). Gait patterns from the outcome analysis were compared to a healthy reference population [24,25].

Patient-reported HRQOL

Eq5D-5L is a standardised and validated instrument to assess health outcomes [26]. It consists of five dimensions: mobility, self-care, usual activities, pain/discomfort and anxiety/depression, and a self-rated health scale on a 20 cm vertical, visual analogue scale with endpoints labelled 'the best health you can imagine' and 'the worst health you can imagine'. An Eq5D-5L index at 1.0 indicated full health, and 0 denoted death. Eq5D reference data from a general population-based sample in Denmark is available [27].

The authors have previously reported the one-year development in patient-reported HRQOL in patients treated with ring fixation following a bicondylar tibial plateau fractures and found generally lower HRQOL scores compared to an established reference group [36]. The present study includes a subgroup of this study population including Eq5D-5L scores to evaluate the association between HRQOL and asymmetry in patients' gait patterns.

Surgical treatment

All fractures were treated by external ring fixator. The authors preferred to manage proximal tibial plateau fractures with initial screw fixation of articular bone fragments and, if necessary, with exposure of the joint surface. Both autogeneous and allogeneous bone grafting were used. The frame was attached to the bone by both hydroxyapatite-coated half pins and k-wires with olives. After applying the ring fixator, alignments were assessed and corrected. Amendments such as proximal fixation to the femur were used when deemed appropriate (Fig. 1).

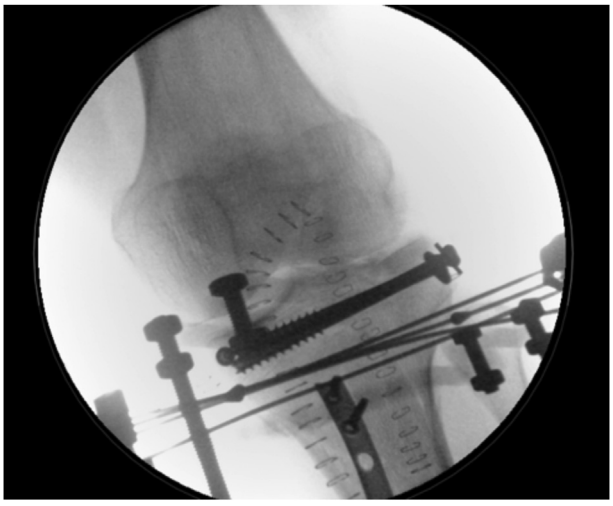

Fig. 1. Treatment of proximal tibial fracture with internal screw fixation and ring fixation.

Statistics

The assumption of normal distribution of variables was checked visually by QQ-plots. Continuous data were expressed with mean and standard deviation (SD). Categorical data were expressed as frequencies. Asymmetry between injured and non-injured legs is expressed as % asymmetry ($100 \times \text{Ln}(\text{injured/non-injured})$ [23]. At 12 months after frame removal, the Pearson's-test was used to analyse the correlation between Eq5D-5L and % asymmetry between the injured and non-injured leg. A P-value of <0.05 was considered significant. The statistical analysis was performed by SPSS V.22 and STATA V.13.

Results

A total of 29 patients with a tibial plateau fracture all treated with an external ring fixator were included during the study period. Three patients did not wish to participate in the evaluation 12 months after frame removal. During the study period, 1 patient was excluded from the study as he was unable to walk 2×6 m without walking aids, and another patient was excluded due to treatment with TKR. Thus, the study population consisted of 23 patients, 11 females and 12 males. The mean age at the time of fracture was 54.4 (SD12.7) years, ranging from 32 to 78 years. Baseline characteristics of all patients are presented in Table 1.

Radiological outcomes

All patients united during the study period. Five of the 23 patients presented with either malalignment >3°, condylar widening >5 mm and/or articular depression >5 mm 12 months after frame removal. A detailed overview is presented in Table 2. The radiological outcomes of knee osteoarthritis evaluated by Kellgren & Lawrence score [28] show 3 patients with no or doubtful signs of osteoarthritis (Type 0 and 1), 13 patients with minimal signs of osteoarthritis (Type 2) and 6 patients with moderate signs of osteoarthritis (Type 3). One patient did not participate in the final radiological examination.

Gait outcomes

Twelve months after frame removal, the basic characteristics of gait show a mean gait speed of 110.3 (SD31.9) cm/s and a mean cadence of 107.6 (SD13.3) steps/min. Compared to a healthy reference population [24], the study population showed no significant difference in gait speed, revealed by non-overlapping 95% confidence intervals (Table 3).

The primary analysis of gait asymmetry is presented in Table 4. At the 12 month follow-up, patients presented with a shorter step-length of the injured leg compared to the non-injured leg, representing an asymmetry of 11.3%. Analysis of single-support shows a shorter support time on the injured leg compared to the non-injured leg, representing an asymmetry of 8.7%. Moreover, analysis of swing-time shows a longer swing-time of the injured leg, representing an asymmetry of 8.9%. The analysis of variability in swing-time shows a coefficient of variance (CV) asymmetry of 8.0% between the injured and non-injured leg. The evaluation of functional rotation during walking showed an asymmetry of 35.9% between the injured and non-injured leg.

Correlations between HRQOL, speed and gait asymmetry

Analysis of the association between gait speed and HRQOL showed a weak and non-significant association (Pearson's test: R = 0.19, P = 0.45).

The association between (%) asymmetry of: single-support, step-length and swing-time and HRQOL showed moderate associations (Pearson's test: single-support: R = 0.50, P = 0.03; step-length: R = 0.43, P = 0.07; swing-time: R = 0.46, P = 0.05).

Discussion

Although several studies have evaluated the clinical and functional outcomes following fractures of the tibial plateau [3–13], the literature lacks studies evaluating the objective assessment of functional ability, including specific gait patterns following injury. The present study assesses the gait function 12 months after frame removal in a group of patients all treated with an external ring fixator following a complex tibial plateau fracture and showed that gait asymmetry was common.

Gait patterns in healthy individuals are considered almost symmetrical [25]. Patterson et al. [25] reported a degree of asymmetry in healthy individuals for step-length of 3.0% compared to 11.3% in the present study, swing-time of 2.4% compared to 8.9% in the present study and support-time of 1.7% compared to 8.7% in the present study. A recent study by Warschawski et al. [14]

Table 1
Baseline characteristics of the 23 patients.

Age at time of fracture, mean (range)	54.4(32–78)
Gender Male/Female	12/11
BMI, mean (SD)	25.7(4.5)
Smoker Yes/No	14/9
Side of injury, Right/Left/Bilateral	11/11/1
High/low energy trauma	8/15
Open/closed fracture	2/21
Co-morbidities	
ASA-score, mean (SD)	1.56(0.67)
Charlston co-mobidity score, mean (SD)	2.4(1.5)
Diabetes mellitus, N	3
Fracture classification	
AO-41	23
A	1
B	0
C	22

Table 2
12 months after frame removal, the radiological assessments were made on AP and side X-rays.

Proximal (41-):	
Malalignment >3°	2
Condylar widening >5 mm	2
Depression >5 mm	3
Number of affected patients	5

Fractures were evaluated concerning alignment and depression of the articular surface and condylar widening as described by Rasmussen [30].

Table 3
Gait speed compared to an established reference population.

	mean	95% CI
Study group speed men (cm/s)	111.4	92.0–130.8
Reference group men, mean, (95%CI)	125.2 (115.6–134.8)	
Study group speed women (cm/s)	109.2	85.7–132.6
Reference group women, mean, (95%CI)	110.5 (105.2–115.8)	

Reference group: Öberg et al. [24]. Basic gait parameters: Reference data for normal subjects, 10–79 years of age.

Table 4
Asymmetry of gait pattern.

	12 months after frame removal	
	mean	SD
Single support injured (s)	0.416	0.035
Single support non-injured	0.451	0.048
Single support asymmetry (%)	8.7%	9.2%
Step length injured (cm)	56.26	18.15
Step length non-injured	59.72	16.60
Step length asymmetry (%)	11.3%	11.9%
Swing time injured (s)	0.452	0.051
Swing time non-injured	0.416	0.037
Swing time asymmetry (%)	8.9%	9.6%
Rotational foot injured (°)	5.0	3.9
Rotational foot non-injured	7.3	4.4
Rotational foot asymmetry (%)	35.9%	93.9%
Variance of swing time injured (CV)	4.10	2.73
Variance of swing time non-injured	3.90	1.69
Variance of swing time asymmetry (%)	8.0%	94.9%

supported these findings, reporting altered spatiotemporal gait patterns in patients following tibial plateau fractures compared to a healthy control group. However, data on gait patterns between the studies are not directly comparable, as the study by Warschawski et al. [14] did not include logarithm of % asymmetry, as described by Yogev et al. [23].

The outcomes following complex tibial plateau fractures are commonly reported to be high risk of joint pain, malalignment, intraarticular soft tissue injuries and posttraumatic osteoarthritis [3–13]. These are all factors which may affect the post-injury gait function and asymmetry in gait patterns.

In general, several studies, of a broad variety of conditions, have reported strong associations between asymmetry in gait patterns and decreased function and HRQOL [14,22,29]. However, the association between asymmetry in gait patterns and HRQOL for patients with tibial plateau fractures has only been examined in a single study [14]. The present study showed a moderate correlation for single-support: $R = 0.50$, step-length: $R = 0.43$, and swing-time: $R = 0.46$, indicating that 18–25% of the decrease in HRQOL (Eq5d-5L) can be explained by asymmetry in gait patterns. These findings are supported by Warschawski et al. [14], reporting a stronger correlation ($R = 0.71$, $P < 0.001$) between single limb support of the injured leg and SF-12 in patients following a tibial plateau fracture at the 3-year follow-up.

The risk of posttraumatic osteoarthrosis (OA) following complex tibial plateau fractures is well known [7,30–32]. Furthermore, malalignment of the knee joint and altered gait function in OA patients have previously been described in the literature [33]. The present study evaluated the gait function at 12 months after frame removal compared to the study of Warschawski et al. [14], reporting outcomes with an average of 3 years post-injury. This time difference may be a contributing factor in the difference between studies. Moreover, radiological data regarding alignment, articular depression and development of OA are not provided in the study by Warschawski et al. [14], making comparisons to the present study difficult. Finally, all patients in the present study were treated with an external ring fixator compared to patients in the study by Warschawski et al. [14], who were all treated with plates. To the authors' knowledge, no randomised studies have investigated the effect on development in gait patterns between treatments with external circular frames vs. plates in patients with tibial plateau fractures. A randomised controlled trail (RCT) by the Canadian Orthopaedic Trauma Society reported on the development in of HRQOL, radiological outcome and the risk of complications between the two surgical methods, finding no significant differences [13].

Walking speed has been reported to influence functional performance and QOL [34,35]. Twelve months after frame removal, patients from the present study did not show any significant differences in gait speed compared to an age-matched healthy reference population [24]. The average gait speed of patients from the present study (110.3 cm/s) was faster compared to patients in the study by Warschawski et al. [14], reporting an average gait speed of 100.3 cm/s. The observed differences in gait speed may be due to the differences in follow-up time between the two studies and a possible difference in the frequency and severity of OA.

Moreover, gait speed was reported with a weak association to the patients HRQOL ($R = 0.19$, $P = 0.45$) in the present study. The lack of differences in gait speed between the study group and the age-matched reference group [24] may be an important driver in this observed weak association.

Findings from the present study indicated that regaining symmetrical gait patterns following a complex tibial plateau fracture is a prolonged process and may be difficult for many patients. This information is important for orthopaedic surgeons and physiotherapists when planning rehabilitation and informing patients on the expected outcome following the treatment of complex tibial plateau fractures.

The main limitation of the present study is the observational design, implying that no conclusions regarding causality can be drawn. Moreover, the sample size is limited, which may increase the risk of Type 1 error. However, this prospective study included a consecutive group of patients all treated with an external ring fixator, and provided novel findings regarding the development in gait patterns following a tibial plateau fracture. Finally, the use of standardised objective assessments of multiple gait patterns are a strength of the study.

Conclusion

Compared to a healthy reference population, gait asymmetry is common 12 months after frame removal in patients treated with external ring fixation following a tibial plateau fracture of the tibia.

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Conflict of interest

The authors declare that they have no conflict of interest to report. The authors did not receive benefits or grants in any form from a commercial part related directly or indirectly to the subject of this article.

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