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Published in:
Orthopaedics & Traumatology: Surgery & Research

DOI (link to publication from Publisher):
10.1016/j.otsr.2023.103569

Publication date:
2023

Document Version
Publisher's PDF, also known as Version of record

Orthopaedics & Traumatology: Surgery & Research 109 (2023) 103569

Contents lists available at ScienceDirect

Orthopaedics & Traumatology: Surgery & Research

journal homepage: www.elsevier.com

Original article

Gait recovery is not associated with meniscus and/or knee ligament injuries following lateral tibial plateau fractures. A prospective 3-year cohort study of 56 patients

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INFO ARTICLE

Historique de l'article :
Reçu le 24 août 2022
Accepté le 10 janvier 2023

ABSTRACT

Introduction. – Though associated meniscus and/or knee ligament injuries following lateral tibial plateau fractures (TPF) are common, the importance of development in gait recovery is unknown. This study aim to report the 12- and 36-month gait recovery in patients with lateral TPF divided into two groups presenting with and without associated meniscus and/or knee ligament injuries. (Associated meniscus and/or knee ligament injuries were grouped as: 1) missing, 2) lateral or medial menisci, 2) posterior and anterior cruciate ligament (PCL/ACL), and 4) lateral or medial collateral ligament.)
Hypothesis. – Comparable results at the 12- and 36-month follow-up between groups presenting with and without soft tissue injuries.
Patients and methods. – Study design: cohort study. Included were patients admitted following a lateral TPF (AO-type 41 B) between December 1, 2013 and November 30, 2016. The primary outcome score was gait sample.
Results. – Fifty-six patients were included. The mean age of the patients at the time of fracture was 56 years (range from 22 to 86). Female gender represents 75%. MRI-verified associated meniscus and/or knee ligament injuries were observed in 28 patients (50%). The average gait speed at the 12- and 36-month follow-up were 125.7 (SD31.3) and 127.7 (SD16.6) cm/sec. for patients with associated meniscus and/or knee ligament injuries and 125.2 (SD31.1) and 130.1 (SD15.6) cm/sec. for patients without associated meniscus and/or knee ligament injuries ($p = 0.96$, $p = 0.17$). Regardless of soft tissue injuries, the development in percent of gait asymmetry for step-length and single-support decrease significantly between the 12- and the 36-month follow-up. ($p > 0.002$)
Discussion. – This study indicates that gait recovery following lateral TPFs were not associated with associated meniscus and/or knee ligament injuries at the 12- and 36-month follow-up. Between the 12- and 36-month follow-up asymmetry of the gait function decline significantly indicating a prolonged recovery period of gait function following TPFs.
Level of evidence. – II; prospective cohort study.

1. Introduction

The incidence of tibial plateau fractures (TPF) is recently published as 10.3 per 100,000 population per year, with sixty percent of all fractures involving isolated the lateral joint surface [1]. Associated soft tissue injuries to the knee joint (meniscal tears and rupture of the cruciate or collateral ligament), are reported to affect about 50% of patients [2].

The result of a lateral TPFs is known to influence patients long-term knee function. Limitations in knee function, knee pain, and development of posttraumatic osteoarthritis is frequently reported [3–9]. Although associated soft tissue injuries to the knee joint following lateral TPFs are common, the importance of development in gait patterns is unknown. Such information is highly needed because function and asymmetry in gait patterns are reported to significantly influence the patient-reported outcome following several fractures of the lower extremities [10].

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https://doi.org/10.1016/j.otsr.2023.103569

Asymmetry in gait patterns following TPFs is previously reported from small series[11–13]. However, the underlying variables of the gait cycle are still poorly understood. Investigating specific gait characteristics in patients with lateral TPFs and the importance of associated meniscus and/or knee ligament injuries may help clinicians to improved surgical protocols and rehabilitation programs.

This study aimed to address the following questions:

- is the 12- and 36-month gait recovery associated to meniscus and/or knee ligament injuries in patients treated surgically following a lateral TPF?
- what is the association of asymmetry in gait function and patient-reported outcome?

The working hypothesis was that comparable results at the 12- and 36-month follow-up between groups presenting with and without soft tissue injuries will be obtained.

2. Methods

2.1. Design of the study

The design of the study was a consecutive cohort study. Patients managed surgically after a lateral TPF (AO-type 41B) were included. Patients admitted at Aalborg University Hospital, Denmark from December 1, 2013 to November 30, 2016 were requested for participation.

Patients admitted with pathological fractures, multi-trauma and other fractures to the lower extremities were excluded. Pregnant patients, patients not able for magnetic resonance imaging, and patients with mental impairment were also excluded. Due to ethical acceptance patients younger than 18 years were prohibited.

Basic data including age, sex, height and body weight, mode of trauma, and fracture classification (A.O. classification) were collected. Associated meniscus and/or knee ligament injuries were examined with magnetic resonance imaging preperatively. Gait analysis was performed for all patients at 6, 12- and 36-months following surgery.

The measurement for primary outcome was gait sample at the 12- and 36-month follw-up.

The study was approved by the Danish Agency of Data Protection (Journal number: 2008-58-0028 id 2013-123). The committee of ethics stated that this study does not require confirmation. Reporting of this observational study adherence to the: "strengthening the reporting of observational studies in epidemiology (STROBE)" statement [14].

2.2. GAITRite System

The (GAITRite System®) was used to measure walking ability and percentage of gait asymmetry [15]. The GAITRite collected speed of the gait, cadence, and temporal and spatial outcome of the gait. The used pressure-sensitive mat was 6 meter long. The test was performed at 12 meter. All patients walked with a self-selected walking speed (Fig. 1).

Several studies have used and validated the *GAITRite System* method, including orthopaedic injuries [15–17].

2.3. Gait outcome

The speed and the cadence of the gait cycle were obtained. Gait measurements of the fractured and the non-fractured leg were obtained for single support and step length. Asymmetry of the specific gait measurements expressed as the difference between the fractured and the non-fractures leg was calculated ($100 \times \text{Ln}(\text{injured/non-injured})$) [18]. The coefficient of variance (CV) was calculated to express the variability of the gait cycle for stance time ($100 \times \text{SD/mean}$).

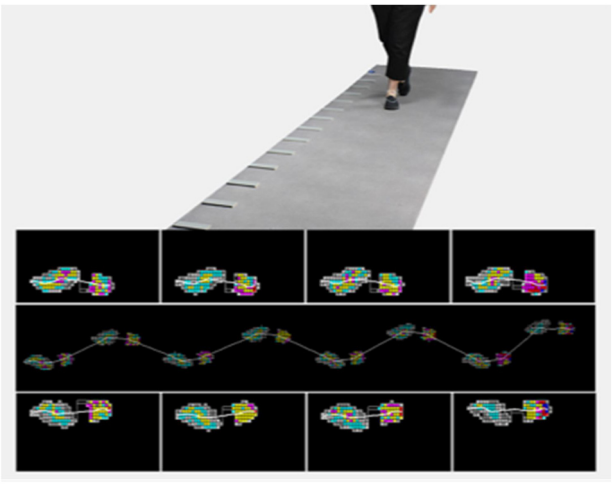

Figure 1. The GAITRite System in use.

2.4. Patient-reported outcome

Eq5D-5L is a validated and patient-reported measurement to evaluated health outcomes [19]. The questionnaire includes the following subscales: self-care, mobility, anxiety/depression, usual activities, and pain/discomfort. The index of the Eq5D-5L was calculated and 1.0 indicated the best health. Danish reference data of the Eq5D is published [20].

2.5. Radiological outcomes

Preoperatively obtained CT scans were used for fracture classification, AO classification [21]. At 12-month follow-up lateral condyle depression was examined on a standing AP and lateral X-ray.

Magnetic resonance imaging was completed preoperatively to examine associated meniscus and knee ligament injuries. Associated meniscus and/or knee ligament injuries were reported as:

- lateral or medial menisci
- posterior and anterior cruciate ligament (PCL/ACL)
- lateral or medial collateral ligament.

2.6. Surgical procedure

All patients were surgically managed with fixation with screws of the TPF and conservative treatment of associated meniscus and knee ligament injuries. Bone tamps were used to reduce the fracture through a 11 mm intramedullary canal from the anterolateral part of the tibia. Fracture stabilisation was performed from the lateral side of the tibial plateau with two or more percutaneous 7.3 mm cannulated titanium screws [22]. Split fractures (AO-B1) were treated without bone tamping.

Following the surgical procedure all patients were immobilised for six weeks in an adjustable angle knee brace. Patients were recommended 6 weeks of non-weight bearing. After the first six weeks, all patients were referred to physiotherapy.

All surgical procedures were performed by senior specialised trauma surgeons.

Table 1
Baseline characteristics of the patients.

	Without soft tissue injury	Soft tissue injuries
Number of patients	28	28
Age	52.6	60.8
Female, N (%)	14 (50%)	19 (68%)
Heigt, mean (SD)	174.2 (10.0)	169.8 (7.7)
Weight, mena(SD)	79.4 (14.8)	77.4 (17.4)
High energy trauma, N (%)	7 (25%)	6 (21%)
AO classfication, N (%)		
41-B1	2 (7%)	5 (18%)
41-B2	7 (25%)	1 (3%)
41-B3	19 (68%)	22 (79%)
Gustilo classification, N (%)		
I	1 (4%)	
II		1 (4%)
Closed fractures, N (%)	27 (96%)	27 (96%)
Soft tissue injuries, N (%)		
ACL		1 (4%)
PCL		1 (4%)
Medial collateral ligament		3 (11%)
Lateral collateral ligament		3 (11%)
Medial meniscus		11 (39%)
Lateral meniscus		18 (64%)
Maximal articuklar depression mm(SD)		
Peroperatively	6.3 (3.3)	9.0 (5.1)
12 months follow-up	0.6 (1.0)	2.6 (4.0)
Complication/re-operation, N(%)		
Infection	0	0
Joint stiffness	0	0
Removal of screws between 12 and 36 months	2 (7%)	1 (4%)

N: number; SD: standard deviation; ACL: anterior cruciate ligament; PCL: posterior cruciate ligament; mm: millimeter.

2.7. Statistics

Inspection of QQ plots were used to investigate the assumption of data distribution. Continuous variables are reported by mean and standard deviation (SD) and categorical variables by frequencies. Asymmetry between fractured and non-fractured legs was expressed as percentage of asymmetry ($100 \times \mathrm{Ln}(\mathrm{injured/non\text{-}injured})$ [18] To compare gait patterns between patients with and without associated meniscus and knee ligament injuries T-tests were used. To express the association between Eq5D and asymmetry of the gait cycle Pearson's test was used. p-values of <0.05 were considered significant.

The authors of the present study have recently reported the one-year development in patient-reported HRQOL for this patient group divided by associated meniscus and knee ligament injuries and found comparable outcomes regardless of soft tissue injuries. [23] This study includes a sub-population of this study.

3. Results

A total of 56 patients were included. At the time of fracture, the mean age was 56 years, ranging from 22 to 86 years of age. Three out of five patients were female gender. Basic characteristics of the patients are shown in Table 1.

Fifty-one patients complete the 6-month gait analyses, 50 patients the 12-month gait analyses and 38 patients the 36-month gait analyses, respectively, 91%, 89% and 68% follow-up.

MRI-verified associated meniscus and/or knee ligament injuries was present in 28 patients (50%). The distribution of associated soft tissue injuries was: one patient with anterior cruciate ligament (ACL) rupture, one patient with posterior cruciate ligament (PCL) rupture, three patients with medial collateral ligament rupture, three patients with lateral collateral ligament rupture, 18 patients with a lateral meniscus tear, and 11 patients with a medial meniscus tear. Seven patients presented with more than one soft tissue injury (Table 1).

3.1. Radiological outcomes

At the 12-month follow-up all patients have united. Peroperative and 12 months postoperative maximal articular depression divided by patients with and without associated meniscus and/or knee ligament injuries are outlined in Table 1, indicating a higher degree of articular depression in the patient group presenting with associated meniscus and/or knee ligament injuries.

3.2. Gait outcome

Twelve months postoperatively, basic gait characteristics show an average gait speed of 125.7 (SD31.3) cm/sec. for patients with associated meniscus and/or knee ligament injuries and 125.2 (SD31.1) cm/sec. for patients without associated meniscus and/or knee ligament injuries ($p = 0.96$).

At the 36-month follow-up the average gait speed for patients presenting with and without associated meniscus and/or knee ligament injuries were 127.7 (SD16.6) and 130.1 (SD15.6), respectively ($p = 0.17$).

At the 12-month follow-up the mean cadence of patients with associated meniscus and/or knee ligament injuries was 118.8 (SD13.5) steps/min. and 113.5 (SD12.7) steps/min. for patients without associated meniscus and/or knee ligament injuries ($p = 0.16$).

At the 36-month follow-up the mean cadence of patients presenting with and without associated meniscus and/or knee ligament injuries were 118.8 (SD9.9) and 117.8 (SD8.1), respectively ($p = 0.72$).

Gait assessment of speed and cadence at the six-month follow-up did not show a significant difference between groups with and without associated meniscus and/or knee ligament injuries ($p > 0.16$).

Comparing results from the 12- and 36-month follow-up to a reference population [24], the participants did not significantly differ in the speed of the gait, expressed as 95% confidence intervals non overlapping.

3.3. Primary outcome

The primary analysis of gait asymmetry grouped by patients with and without associated meniscus and/or knee ligament injuries are presented in Table 2. At the 12- and 36-month follow-up, patients with and without associated meniscus and/or knee ligament injuries show non-significant difference in percentage asymmetry of the gait function, indicating that associated meniscus and/or knee ligament injuries 12 and 36 months after a lateral TPF did not influence gait recovery.

Regardless of associated soft tissue injuries, the development in percent of gait asymmetry decrease significantly between the 12- and 36-month follow-up. ($p > 0.002$).

3.4. Gait pattern - specific outcomes

At the 12- and 36-month follow-up, patients with associated meniscus and/or knee ligament injuries did not show a significant difference in step length, single support and stance variability (CV) (of both the fractured and non-fractures leg) compared to patients without associated meniscus and/or knee ligament injuries ($p > 0.13$).

An intrapersonal comparison of step length, single support, and stance variability (CV) between the fractured and non-fractures leg

Table 2
Gait patterns divided by soft tissue injury.

	Soft tissue injury						Without soft tissue injury						
	6 months		12 months		36 months		6 months		12 months		36 months		*p* value at
	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	6/12/36 months
Single support injured (sec)	0.4	0.04	0.4	0.03	0.4	0.03	0.41	0.03	0.41	0.04	0.40	0.02	
Single support non-injured	0.44	0.07	0.42	0.05	0.40	0.04	0.43	0.04	0.43	0.04	0.41	0.04	
Single support asymmetry (%)	8.02%	14.99	6.36%	7.29	3.86%	3.74	6.99%	9.35	6.39%	8.81	4.26%	4.4	0.61/0.50/0.77
Step length injured (cm)	59.64	12.99	61.74	12.17	64.79	5.98	62.67	11.25	65.01	13.06	68.85	7.39	
Step length non-injured	63.32	12.03	63.86	11.22	64.47	4.43	64.62	9.91	65.53	11.36	69.72	7.67	
Step length asymmetry (%)	9.24%	15.39	6.64%	10.18	4.21%	3.47	6.80%	7.84	6.06%	8.44	3.92%	4.09	0.76/0.59/0.80
Variance of stance time injured (CV)	3.43	3.63	2.6	2.3	1.87	1.23	3.81	5.65	3.08	2.09	2.33	2.29	
Variance of stance time non-injured	2.97	2.91	2.2	1.34	2.38	1.59	3.29	3.57	2.76	1.72	3.68	6.67	
Variance of stance time asymmetry (%)	2.59%	64.45	6.25%	137.91	4.71%	36.7	10.86%	65.74	11.93%	56.81	8.91%	77.72	0.25/0.28/0.06

SD: standard deviation; sec: seconds; CV: coefficience of variance

at the 12- and 36-month follow-up showed no significant difference between the fractures and non-fractures leg for both patient groups. ($p > 0.11$).

3.5. Gait speed, percentage asymmetry, and patient-reported outcome

The 12- and 36-month analyses of the correlation between gait speed and patient-reported outcome (Eq5D) divided by associated soft tissue injuries shows weak and non-significant correlations. (Patients with associated meniscus and/or knee ligament injuries: 12 months: R = 0.35, $p = 0.91$, 36 months: R = 0.21, $p = 0.41$. Patients without associated meniscus and/or knee ligament injuries: 12 months: R = 0.22, $p = 0.72$, 36 months: R = 0.09, $p = 0.75$).

The association between asymmetry of single-support, step-length and patient-reported outcome divided by associated meniscus and/or knee ligament injuries shows weak (moderate) and non-significant correlations. (Single-support: patients with associated meniscus and/or knee ligament injuries: 12 months: R = 0.38, $p = 0.89$, 36 months: R = 0.28, $p = 0.26$ – patients without associated meniscus and/or knee ligament injuries: 12 months: R = 0.17, $p = 0.61$, 36 months: R = 0.02, $p = 0.93$; Step-length: Patients with associated meniscus and/or knee ligament injuries: 12 months: R = 0.17, $p = 0.58$, 36 months: R = 0,31, $p = 0.24$ – Patients without associated meniscus and/or knee ligament injuries 12 months: R = 0.06, $p = 0.24$, 36 months: R = 0.02, $p = 0.94$).

Two patients from the study population presenting with major intraarticular injuries. One patient with an anterior cruciate ligament (ACL) and lateral meniscus injury and one patient with a posterior cruciate ligament (PCL) and medial, lateral collateral ligament injury. Individual results are presented in supplemental materials Table 3.

4. Discussion

Though associated meniscus and/or knee ligament injuries following lateral TPFs are common, the importance of development in gait recovery is unknown. This study aimed to assess the question: Is 12- and 36-month gait recovery associated to meniscus and/or knee ligament injuries in patients treated surgically following a lateral TPF? We found non-significant difference between patients with and without associated meniscus and/or knee ligament injuries at the 12- and 36-month recovery of gait function. Regardless of associated soft tissue injuries the development in percent of gait asymmetry decrease significantly between the 12- and 36-month follow-up indicating prolonged recovery of the gait function following TPFs.

4.1. Is the 12- and 36-month gait recovery associated to meniscus and/or knee ligament injuries in patients treated surgically following a lateral TPF?

Symmetrical gait function is reported in healthy individuals [25,26]. Patterson et al. [25] showed asymmetry in healthy individuals for a step-length of 3.0% compared to 6.0% at 12 month and 4% at 36 month in this study population. Support-time for healthy individuals was reported to 1.7% compared to 6.3% at 12 month and 4% at 36 month in this study population. These results are supported by other studies reporting limitations to gait function following TPFs [11,12]. Studies reporting on patients with meniscal injuries (no fracture) reported that spatial and temporal gait parameters changed significantly after a meniscus injury and returned to normal values within 12 months [27]. The decrease in percent of gait asymmetry between the 6, 12 and 36-month follow-up indicating prolonged recovery of the gait function following lateral TPFs. Such information is highly important in clinical practice to help guiding patients regarding the anticipated timeframe of rehabilitation.

The present study lacks the power to include subgroup analyses of the severity of soft tissue injuries. However, the authors speculate that widespread knee damage involving major damage of several intraarticular soft tissue structures may likely affect the gait recovery. Most patients included in the present study presenting solely with meniscal tears and only two patients with major intraarticular ligament injuries. Results from the two patients indicated that major intraarticular injury may influence the gait recovery.

At the 12- and 36-month follow-up, patients without and with associated meniscus and/or knee ligament injuries showed no differences in gait speed compared to a healthy reference-population [24]. Furthermore, no difference in cadence between patients without and with associated meniscus and/or knee ligament injuries was observed. Between the 12- and 36-month follow-up an increase in gait speed was observed regardless of associated soft tissue injuries, underpinning the observation of a prolonged recovery in gait function following lateral TPFs. Compared to a few other

studies reporting on gait speed following lateral TPFs, patients included in the present study walk with higher speed [11,12]. This observation may be explained by more severe bi-condylar fractures and differences in observational time, thereby including more severe fractures and an increased risk of developing posttraumatic osteoarthritis.

4.2. What is the association of asymmetry in gait function and patient reported outcome?

The correlation between asymmetry of the gait cycle and drop in patient-reported outcome (PROM) is frequently reported in a broad range of medical conditions[11,17,28]. Regardless of associated meniscus and/or knee ligament injuries, the present study showed weak and non-significant correlations between walking speed, asymmetry in gait patterns, and PROM outcomes. Studies including bi-condylar TPFs and longer follow-up time reported a moderate to strong correlation between altered gait patterns and patient-reported outcomes. The differences in fracture location, the severity of the fracture, mode of injury, and follow-up time between studies makes comparison difficult. Furthermore, the decrease in asymmetry observed throughout the observational period and comparable gait speed between patients and the age-matched reference population may explain the observed weak correlations to PROM outcome.

Operative versus conservative treatment of associated meniscus and/or knee ligament injuries in patients following lateral TPFs is frequently discussed but lacks evidence[2,5,29–35]. Patients included in this study were all treated conservatively regarding all associated meniscus and/or knee ligament injuries. The present study reports on gait recovery following lateral TPFs with a primary endpoint at 36 months following surgery. Several studies have reported a long-term increased risk of posttraumatic osteoarthrosis (O.A.) in patients following TPFs [7,36,37]. Knee joint malalignment and limitations to the gait function in patients with severe osteoarthritis is also well known [38]. Consequently, more studies with long-term follow-up periods are essential to understand the impotence of associated meniscus and/or knee ligament injuries on gait recovery and surgical treatment strategies.

4.3. Limitations

This study has several limitations. The 36-months cohort design implies that no conclusions regarding causality can be drawn. Furthermore, the size of the included sample is limited and subgroup analyses regarding the severity of associated meniscus and/or knee ligament injuries are not possible. Furthermore, a limitation is the 36 months follow-up time. Associated meniscus and/or knee ligament injuries may increase the risk of posttraumatic osteoarthritis.

5. Conclusion

This study indicates that gait recovery following lateral TPFs were not associated with meniscus and/or knee ligament injuries at the 12- and 36-month follow-up. Between the 12-month follow-up and the 36-month follow-up asymmetry of the gait function decreased significantly indicating a prolonged recovery period of gait function following lateral TPFs.

Disclosure of interest

The authors declare that they have no competing interest.

Ethical approval

This is an observational study. The local Research Ethics Committee has confirmed that no ethical approval is required.

Consent to participate

Written informed consent was obtained.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Authors contributions

Both authors have made substantial contributions to all of the following: (1) the conception and design of the study, or acquisition of data, or analysis and interpretation of data, (2) drafting the article or revising it critically for important intellectual content, (3) final approval of the version to be submitted.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.otsr.2023.103569.

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