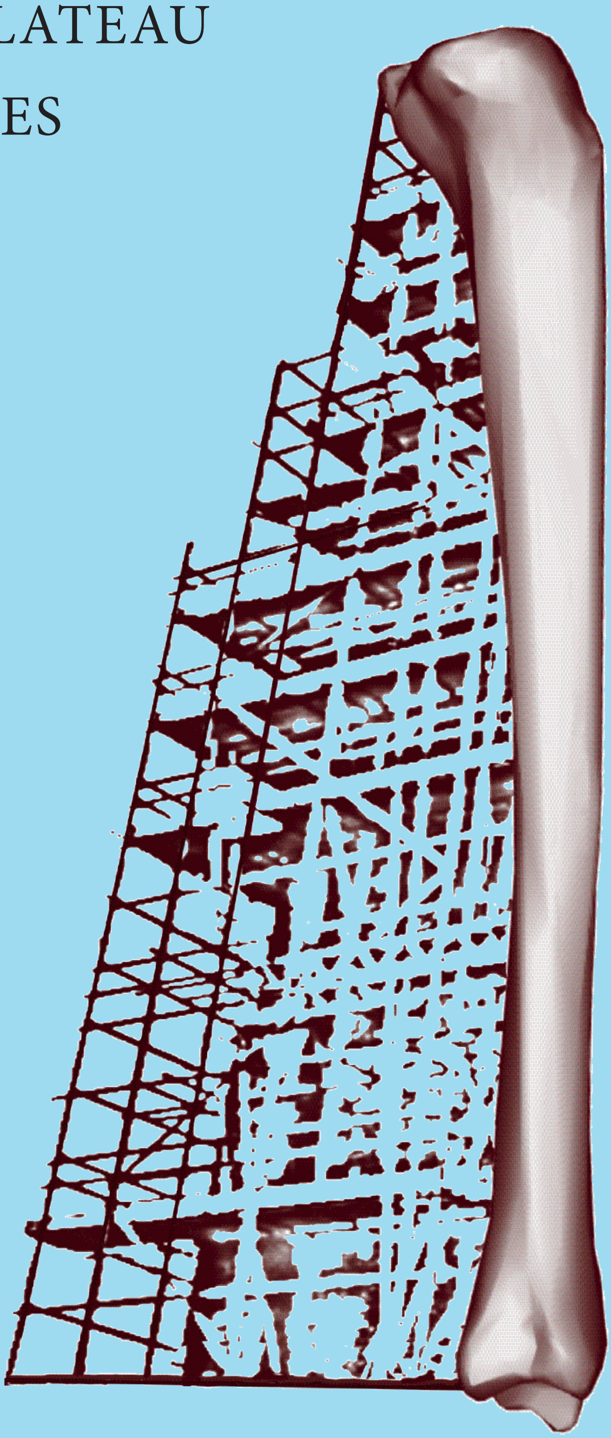
Strategies on Improving the Outcome of Posterior Tibial Plateau Fractures



Juriaan David van den Berg

STRATEGIES ON IMPROVING THE OUTCOME OF POSTERIOR TIBIAL PLATEAU FRACTURES

Strategieën voor verbetering van de uitkomsten na posterieure tibiaplateaufracturen

Juriaan David van den Berg

This thesis was realized as a collaboration between the Trauma Research Unit, Department of Surgery, Erasmus MC, Rotterdam, The Netherlands and the Traumatology department, University Hospitals Leuven, Leuven, Belgium.

Printing of this thesis has been financially supported by Erasmus University Rotterdam.

ISBN: 978-94-6423-636-1

Cover design: Marti van den Bogert
Layout: Dennis Hendriks || ProefschriftMaken.nl
Printing: ProefschriftMaken.nl

STRATEGIES ON IMPROVING THE OUTCOME OF POSTERIOR TIBIAL PLATEAU FRACTURES

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Thesis

to obtain the degree of Doctor from the
Erasmus University Rotterdam
by command of the rector magnificus

Prof.dr. A.L. Bredenoord, Erasmus University Rotterdam
and
to obtain a doctorate in Biomedical Sciences from the University of KU Leuven
by command of the rector

Prof.dr. L. Sels, Katholieke Universiteit Leuven

and in accordance with the decision of both Doctorate Boards,

The public defence shall be held on
Wednesday 23rd February 2022 at 10h30
at Erasmus University Rotterdam
by

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CHAPTER 1

General introduction and outline of the thesis

General introduction

The tibial plateau refers to the articular surface of the proximal tibia. In weight-bearing the tibial plateau has a lateral and medial zone of articulation (Figure 1). The lateral tibial plateau has a more convex shape and weaker underlying bone strength compared to the medial tibial plateau with a more concave shape and a relatively greater underlying bone strength[1]. The medial tibia plateau accounts for approximately 60% of weight bearing in the knee. In normal knee motion, increased flexion of the knee induces more posterior axial loading of the tibial surface by the femur condyles[2].

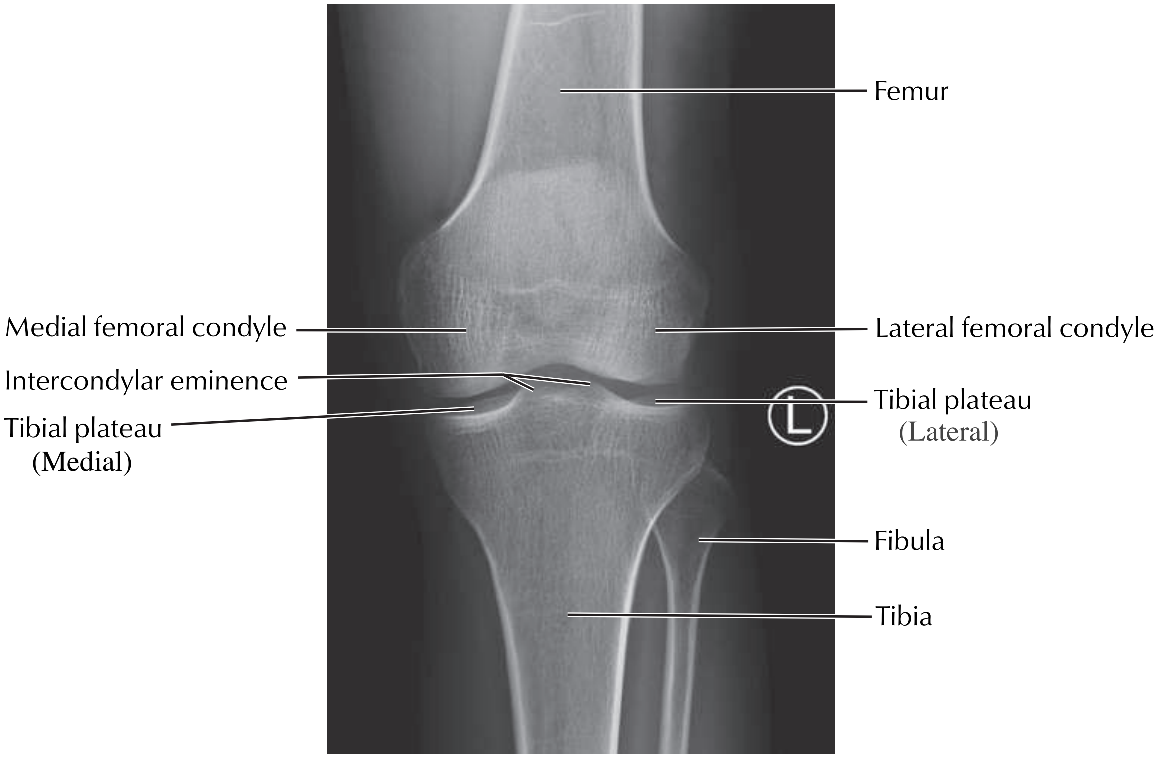

Figure 1. Anteroposterior x-ray of the (left) knee joint[3].

Fractures of the tibial plateau are generally considered to result from high energy trauma with axial compression forces combined with shear and rotational forces and lead to heterogeneous fracture morphology patterns. Over the years, numerous different classification systems have been provided. However, only few of these have been thoroughly validated[4]. The most widely used method of classification was proposed in 1979 by Schatzker et al., defining 6 different fracture types (Figure 2)[5].

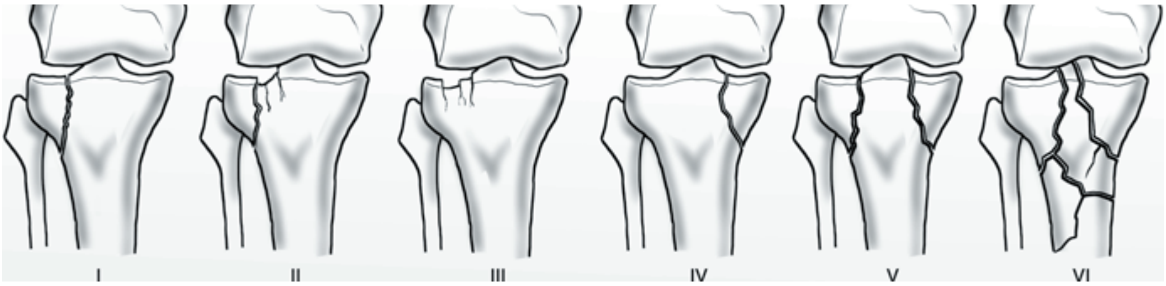

Figure 2. Schatzker classification of proximal tibia fractures[6].

Since it is based on anteroposterior x-ray imaging, fractures in the coronal plane are frequently underappreciated[7]. Today, CT imaging provides a better understanding of the fracture morphology and has become the gold standard in fracture evaluation over the last decade.

Tibial plateau fractures can have severe impact on knee function and long-term outcome[8, 9]. However, factors influencing the functional and general outcome in these patients were not clearly defined. Moreover, there has been growing interest in tibial plateau fractures with posterior involvement over the recent years. The reported incidence of these posterior tibial plateau fractures (PTPF) ranges from 28 to 70% but the possible impact on outcome has not been investigated sufficiently[10–12].

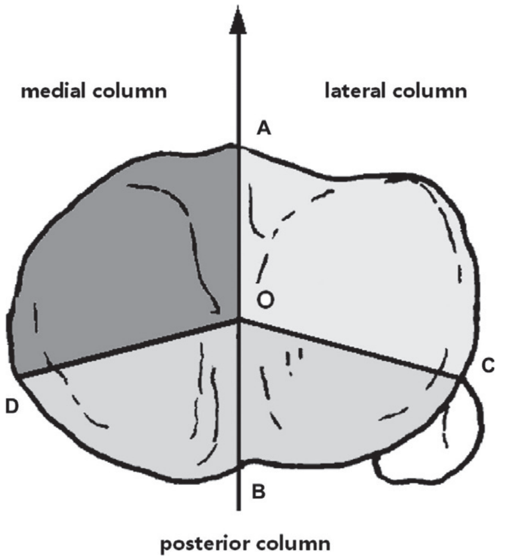

Figure 3. Three column classification[13].

In 2010 the three column classification (TCC) was introduced by Luo et al. allowing to depict posterior tibial plateau fractures (Figure 3)[13]. According to the TCC, tibial plateau fractures are classified as either one, two or three column fractures. Within the TCC approach, a column fracture is defined as a combined articular depression and cortical fracture and needs to be addressed successively. In case of (limited) articular depression without a cortical interruption (i.e. zero column fractures) minimally invasive or nonoperative treatment is justified[14]. The updated three-column concept (uTCC) was introduced in 2016 by Wang et al., supporting the surgical approach and implant placement in multiple column fractures based on mechanism of injury and fracture morphology. Importantly, the significance of tension and compression sides in the fracture and specific indications for posterior/posteromedial plate osteosynthesis are addressed[11]. The '10-segment classification' as presented by Krause et al. in 2016, highlights the frequent involvement of posterior segments[15]. Hoekstra et al. introduced the revised three-column classification approach, wherein lateral column fractures that extend into the posterolateral corner are defined as the so-called 'extended lateral column fractures' (Figure 4, striped area defined by 0CD) which can be treated from lateral solely[16]. As a consequence, the posterior column is reduced to the region of interest of PTPF described in this thesis (Figure 4, yellow area defined by 0BD).

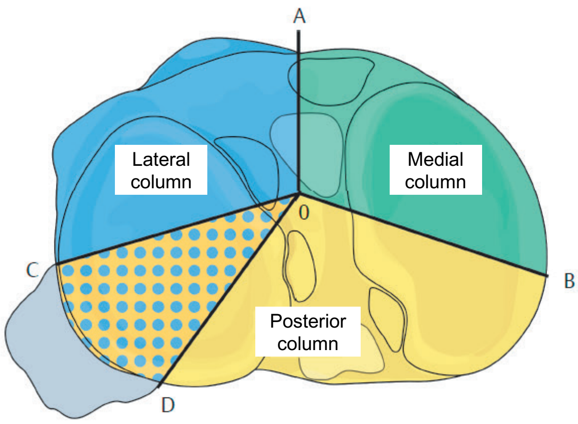

Figure 4. The revised three-column classification [16].

Aims of the thesis

in order to provide possible strategies on improving outcome of tibial plateau fractures, this thesis examines the following questions:

- What factors predict worse outcome in tibial plateau fractures?
- What is the incidence of posterior involvement in tibial plateau fractures and does it negatively affect outcome?
- Do patients with PTPF benefit from the 'updated three-column concept'?
- Does 3D-CT reconstruction alter preoperative surgical decision making?
- What is the impact of PTPF on sports activities and are patients satisfied with the results?
- Can differentiation of trauma mechanism help understand poor outcome?
- What is the (current) rationale for operative management of PTPF?
- Is the WAVE posterior proximal tibia plate a safe and feasible option in treatment of PTPF?

Outline of the thesis

In order to investigate the incidence of PTPF, a retrospective cohort of tibial plateau fractures between 2009 and 2014 was evaluated in **Chapter 2**. All included patients received preoperative CT-imaging to classify tibial plateau fractures according to the TCC and evaluate if uTCC principles were followed. Functional and general outcome was assessed with the knee injury and osteoarthritis outcome survey (KOOS) and compared to all available treatment and patient specific characteristics.

To further investigate the effect of operative fixation in posterior column fractures, in **Chapter 3** a retrospective cohort of tibial plateau fractures with posterior involvement was selected between 2009 and 2016. For all patients we evaluated in retrospect whether the treatment was according to uTCC principles or not, to determine a benefit in radiological and patient reported outcome (KOOS).

With the growing availability of CT imaging techniques, 3D-CT fracture reconstruction has been increasingly used. **Chapter 4** evaluates the possible added value of 3D-CT reconstruction in preoperative planning of PTPF.

Since functional and general outcome can be severely impacted in PTPF, we aim to further investigate the impact on daily life. Sports activities and sport-specific movements can put knee function under serious strain. Therefore, in **Chapter 5**, we assessed postoperative sporting abilities with special emphasis on type of sports before and after injury, time needed to resume sports, restricting factors in sports engagement and patient satisfaction.

Recent publications have underscored the possible role of trauma mechanism and associated soft-tissue injuries in tibial plateau fractures[11, 17]. In order to gain perspective on the outcome in PTPF, **Chapter 6** discusses a multicentric cohort classified by different trauma mechanism types. Varus-valgus and flexion-extension injury mechanism were assessed and evaluated against patient reported outcome.

Surgical management of PTPF has gained much interest in recent years. However, specific indications for posterior plate osteosynthesis remain under debate. In **Chapter 7**, we seek to answer the question for the rationale in surgical decision making for PTPF. This review of the current literature discusses the interplay between fracture morphology, trauma mechanism and soft-tissue injury. Moreover, surgical management using the reversed-L shaped concept for the posteromedial approach is described.

The treatment goal of operative management in all tibial plateau fractures is to restore alignment and articular congruence. Moreover, in PTPF restoration of the sagittal alignment and prevention of secondary displacement is adamant. To achieve these goals, sufficient buttress of posterior fracture components is necessary. In **Chapter 8,** the reversed L-shaped concept is utilized for evaluation of the newly developed WAVE posterior proximal tibia plate in PTPF. This prospective cohort study analyses the postoperative outcome at one year follow-up while also assessing the feasibility and safety of the implant.

The general discussion in **Chapter 9** debates all the findings of this thesis and future perspectives are outlined with regard to PTPF treatment of tomorrow.

Finally, a summary of the thesis in English and Dutch is provided in **Chapter 10** .

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CHAPTER 2

Functional outcome of intra-articular tibial plateau fractures: the impact of posterior column fractures

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Published in:

International Orthopaedics (2017)
doi: 10.1007/s00264-017-3566-3

Abstract

Introduction:
Although regularly ignored, there is growing evidence that posterior tibial plateau fractures affect the functional outcome. The goal of this study was to assess the incidence of posterior column fractures and its impact on functional outcome and general health status. We aimed to identify all clinical variables that influence the outcome and improve insights in the treatment strategies.

Methods:
A retrospective cohort study including 218 intra-articular tibial plateau fractures was conducted. All fractures were reclassified and applied treatment was assessed according to the updated three-column concept. Relevant demographic and clinical variables were studied. The patient reported outcome was assessed using the Knee injury and Osteoarthritis Outcome Score (KOOS).

Results:
Median follow-up was 45.5 (IQR 24.9-66.2) months. Significant outcome differences between operatively and nonoperatively treated patients were found for all KOOS subscales. The incidence of posterior column fractures was 61.9%. Posterior column fractures, sagittal malalignment and an increased complication rate were associated with poor outcome. Patients treated according to the updated three-column concept, showed significantly better outcome scores than those patients who were not. We could not demonstrate the advantage of posterior column fracture fixation, due to a limited patient size.

Conclusion:
Our data indicates that implementation of the updated three-column classification concept may improve the surgical outcome of tibial plateau fractures. Failure to recognize posterior column fractures may lead to inappropriate utilization of treatment techniques. The current concept allows us to further substantiate the importance of reduction and fixation of posterior column fractures with restoration of the sagittal alignment.

Introduction

The outcome of tibial plateau fractures is rather moderate [1-2]. Factors influencing functional outcome and general health status are not well defined in literature, due to heterogeneity in study populations, fracture types and osteosynthesis techniques. Moreover, variable follow-up time is reported and different measurement tools are used to assess outcome in tibial plateau fractures [1-4]. Recent studies suggest that involvement of the posterior surface of the tibial plateau has more impact on outcome than previously appreciated [5-6]. The reported incidence of posterior tibial plateau fractures ranges from 28.8% to 70.7% [6-8]. However, fractures of the posterior tibial plateau are not adequately depicted according to the widely used Schatzker and AO/OTA classification systems [7].

In contrast, the three-column classification (TCC) approach, introduced by Luo et al. in 2010 [9] has proven very useful and reliable for the preoperative planning and treatment of tibial plateau fractures, in particular posterior tibial fractures [8-10]. According to the TCC approach, tibial plateau fractures are classified as either one, two or three column fractures (combined articular depression and cortical fracture) and need to be stabilized successively. Subsequently, with the updated 3 column concept (uTCC) they support the surgical approach and implant choice for the treatment of multiple column fractures on the basis of the mechanism of injury and fracture pattern [8,11]. Limited articular depression without cortical fractures (i.e. zero column fractures) can be treated nonoperatively with rather good results [12].

In this study, we retrospectively assessed the incidence of posterior column fractures (PCF) and its impact on patient functional outcome and general health status in a large consecutive patient cohort with intra-articular tibial plateau fractures. Therefore, all intra-articular tibial plateau fractures were reclassified according to the TCC approach and the treatment type was assessed, subsequently. We aimed to identify all clinical variables that influence the patient reported outcome and improve insight in the treatment strategies of intra-articular tibial plateau fractures.

Patients and methods

Patients

Between January 2009 and December 2014, a total of 218 consecutive patients were included in this study. Patient selection method and exclusion criteria are displayed in Figure 1. All patients were treated in a single Level 1 trauma center for intra-articular tibial plateau fractures. Follow-up was until March 14th 2016, resulting in a minimal follow-up time of 14.5 months. This study was completed in compliance with national legislation and the guidelines of the ethics committee of the University Hospitals Leuven.

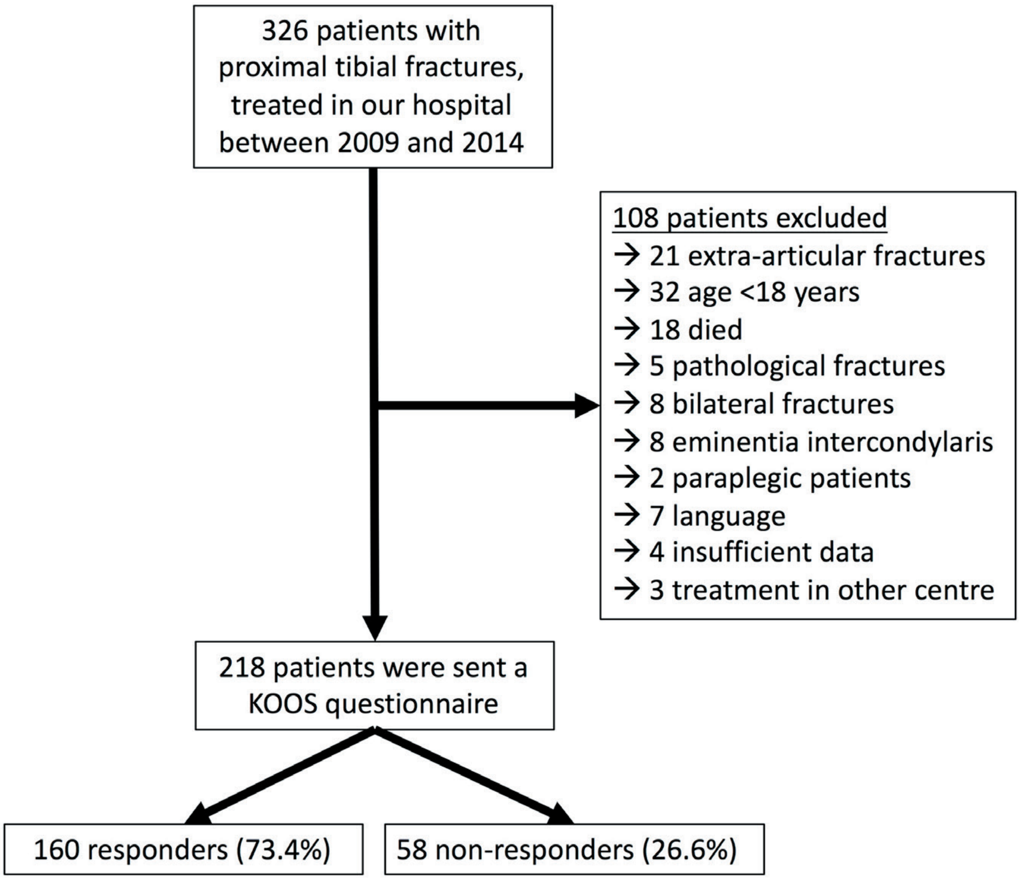


Figure 1: Patient inclusion and exclusion criteria.

Demographics and clinical characteristics

A total of 18 demographic and clinical variables were studied. All data was retrieved from the University Hospitals Leuven electronic medical file database. Cardiovascular risk factors include current cardiovascular diseases (e.g., CVA, MI, peripheral artery disease), diabetes, obesity, smoking, dyslipidemia, hypercholesterolemia, hypertension, alcohol use and rheumatoid arthritis. Medication associated with impaired wound healing (e.g. corticosteroids, adrenergic beta-agonists and chemotherapeutic agents) was recorded. All fractures were classified according to the Schatzker and AO/OTA classification systems using X-rays and CT-images if available. In addition, all fractures and applied treatment were CT based reclassified according to the TCC approach and uTCC, respectively [8-9]. Type of treatment represents either a surgical or nonoperative approach. External fixation includes all fractures treated with an external fixator in a staged surgical protocol or as definite treatment. Complications were categorized as surgical site infection, nonunion and other tibia related complications (i.e. wound related problems, implant related complaints, compartment syndrome, excessive pain, drop foot, quadriceps muscle atrophy and deep vein thrombosis). In turn, surgical site infection was classified as either superficial or deep infection according to Center for Disease Control guidelines for surgical site infections. Furthermore, nonunion was assessed using follow-up radiographs and defined according to the US Food and Drug Administration guidelines as a not completely healed fracture within 9 months of injury and without progression towards healing over the past 3 consecutive months. The reintervention rate was defined as either implant removal or revision for screw loosening, loss of reduction, intra-articular hardware and total knee arthroplasty (TKA).

Outcome measures

Functional outcome and general health status were evaluated using the standardized and validated version of the Knee injury and Osteoarthritis Outcome Scale (KOOS) questionnaire for the Dutch language [13]. All eligible patients were sent questionnaires and contacted by telephone if no response was obtained after one month. The KOOS consists of five subscales; pain, symptoms, activities of daily living (ADL), function in sport and recreation (sport), and knee related quality of life (QoL). A normalized score (100 indicating no symptoms and 0 indicating extreme symptoms) was calculated for each subscale. A summarized scale of the KOOS score can not be calculated due to heterogeneity of the subscales.

The radiological outcome was evaluated by a single specialized emergency radiologist (E.G.) based on RX-alignment and location and grade of intra-articular congruence. Moreover, available images were evaluated to assess for coronal alignment (medial proximal tibial angle 87±5°) and sagittal alignment (posterior proximal tibial angle 9±5°) and condylar width (0-5 mm, inclusive). Furthermore, postoperative reduction was assessed and marked as failed reduction in the presence of articular incongruence (gap and/or step >2mm) [14-15].

Statistical analysis

Statistical evaluation of all data was performed using IBM SPSS 23.0 (SPSS Inc. Chicago, IL). Nominal variables were compared using Chi-Square statistics and nonparametric variables using the Mann-Whitney U test. For correlation testing the Pearson correlation test was used for continuous variables and the Spearman correlation test for nominal variables. A significance level of <0.05 was accepted for all tests. A multivariate analysis was conducted on all significant variables using a linear logistic regression analysis with a stepwise approach.

Results

Descriptives

Patient demography, fracture classification, and operative characteristics are displayed in Table 1-2 respectively. The median follow-up in the study was 45.5 months (IQR 24.9–66.2). 160/218 patients returned the questionnaire resulting in a response rate of 73.4%. Age was not distributed equally between responders (median 53.8, IQR 42.2-64.9) and nonresponders (median 41.0, IQR 29.4-60.2). Moreover, responding patients were more likely female (58.1%), nonsmoking (73.8%) and more often received operative treatment (73.8%). Besides infection and nonunion, 36 operatively treated patients suffered from other tibia related complications (11 wound related problems, 8 implant related complaints, 5 compartment syndrome, 5 excessive pain, 4 drop foot, 2 quadriceps muscle atrophy and 1 deep vein thrombosis). One superficial infection was recorded in an open tibial plateau fracture after nonoperative treatment. During the follow-up period 9 patients (4.1%) received a TKA, all after osteosynthesis as primary treatment, representing 6.1% of all operatively treated patients (n=148). The median time to TKA was 17 months (IQR 16-34). The incidence of patients with medial column fracures, lateral column fractures, and PCF was 29.8%, 64.2% and 61.9%, respectively.

Table 1: Demography and fracture classification.

	Total (n= 218)	Operative (n=148)	Nonoperative (n=70)
Age (years)	51.4 (36.5 – 63.7)	52.3 (41.0 – 63.3)	46.2 (31.7 – 66.6)
Gender			
Male	103 (47.2%)	67 (45.3%)	36 (51.4%)
Female	115 (52.8%)	81 (54.7%)	34 (48.6%)
ASA-score			
1	71 (32.6%)	59 (39.9%)	12 (17.1%)
2	96 (44.0%)	73 (49.3%)	23 (32.9%)
3	19 (8.7%)	14 (9.5%)	5 (7.1%)
4	1 (0.5%)	1 (0.7%)	0
Unknown	31 (14.2%)	1 (0.7%)	30 (42.9%)
BMI (kg/m^2)	25.3 (22.3 – 28.5)	25.5 (22.5 – 28.8)	24.4 (21.1 – 27.0)
Smoking	50 (22.9%)	37 (25.0%)	13 (18.6%)
Medication	37 (17.0%)	30 (20.2%)	7 (10.0%)
DM	16 (7.3%)	11 (7.4%)	5 (7.1%)
Other CVRF	102 (46.8%)	72 (48.6%)	30 (42.9%)
Side			
Left	131 (60.1%)	89 (60.1%)	42 (60.0%)
Right	87 (39.9%)	59 (39.9%)	28 (40.0%)
Open fracture	9 (4.1%)	8 (5.4%)	1 (1.4%)

Table 1: Continued.

	Total (n= 218)	Operative (n=148)	Nonoperative (n=70)
Fracture classification			
AO/OTA type 41			
B1	17 (7.8%)	9 (6.1%)	8 (11.4%)
B2	55 (25.2%)	16 (10.8%)	39 (55.7%)
B3	78 (35.8%)	61 (41.2%)	17 (24.3%)
C1	6 (2.8%)	5 (3.4%)	1 (1.4%)
C2	2 (0.9%)	1 (0.7%)	1 (1.4%)
C3	60 (27.5%)	56 (37.8%)	4 (5.7%)
Schatzker			
1	4 (1.8%)	3 (2.0%)	1 (1.4%)
2	57 (26.1%)	51 (34.5%)	6 (8.6%)
3	82 (37.6%)	27 (18.2%)	55 (78.6)
4	68 (31.2%)	60 (40.5%)	8 (11.4%)
5	1 (0.5%)	1 (0.7%)	0
6	6 (2.8%)	6 (4.1%)	0
TCC			
0 column	13 (6.0%)	0	13 (18.6%)
1 column	56 (25.7%)	28 (18.9%)	28 (40.0%)
2 column	79 (36.2%)	68 (45.9%)	11 (15.7%)
3 column	42 (19.3%)	41 (27.7%)	1 (1.4%)
missing CT	28 (12.8%)	11 (7.4%)	17 (24.3%)

Continuous parameters are expressed as median values with their respective interquartile range. *Abbreviations:* CVRF, Cardiovascular Risk Factors; BMI, Body Mass Index; DM, Diabetes Mellitus; ASA, American Society of Anesthesiologists; AO/OTA, Arbeitsgemeinschaft fur Osteosynthesefragen/ Orthopedic Trauma Association; TCC, three column classification; CT, computer tomography.

Table 2: Operative characteristics (n=148).

External fixation	14 (9.4%)
Delayed (-staged) surgery	
Direct (<24 hrs)	31 (20.9%)
Delayed (>24 hrs)	117 (79.1%)
Time to surgery (days)	3 (2 – 6)
Complication rate	40 (27.0%)
Superficial infection	3 (2.0%)
Deep infection	6 (4.1%)
Nonunion	3 (2.0%)
Other complications	36 (24.3%)
Reintervention rate	55 (37.2%)
Implant removal	48 (32.4%)
Revision	18 (12.2%)
TKA	9 (6.1%)
Treatment according to uTCC	
Medial column (n=65)	39 (60.0%)
Lateral column (n=140)	100 (71.4%)
Posterior column (n=135)	14 (10.4%)

Continuous parameters are expressed as median values with their respective interquartile range. Percentage displayed is according to total operatively treated fractures unless otherwise stated. *Abbreviations:* DVT, Deep Vein Thrombosis; TKA, Total Knee Arthroplasty; uTCC, updated three column classification.

Outcome

Reference values for the KOOS questionnaire were compared to the study population and presented in Figure 2 with regard to both operatively and nonoperatively treated patients [16]. Fifteen (10.1%) operatively patients lost their ability to participate in sporst activities. Regarding pain perception, 41 (27.7%) operatively treated patients reported experiencing pain on a daily basis. Nine (4.7%) patients were identified with continuous pain perception. The radiological failure rate was 42.2% (n=92), including 44 patients (20.2%) with coronal malalignment, 47 patients (21.6%) with sagittal malalignment, 35 patients (16.1%) with abnormal condylar width and 35 patients (16.1%) with postoperative articular incongruence. Good, moderate and poor functional outcome cases are illustrated in Figures 3-5, respectively.

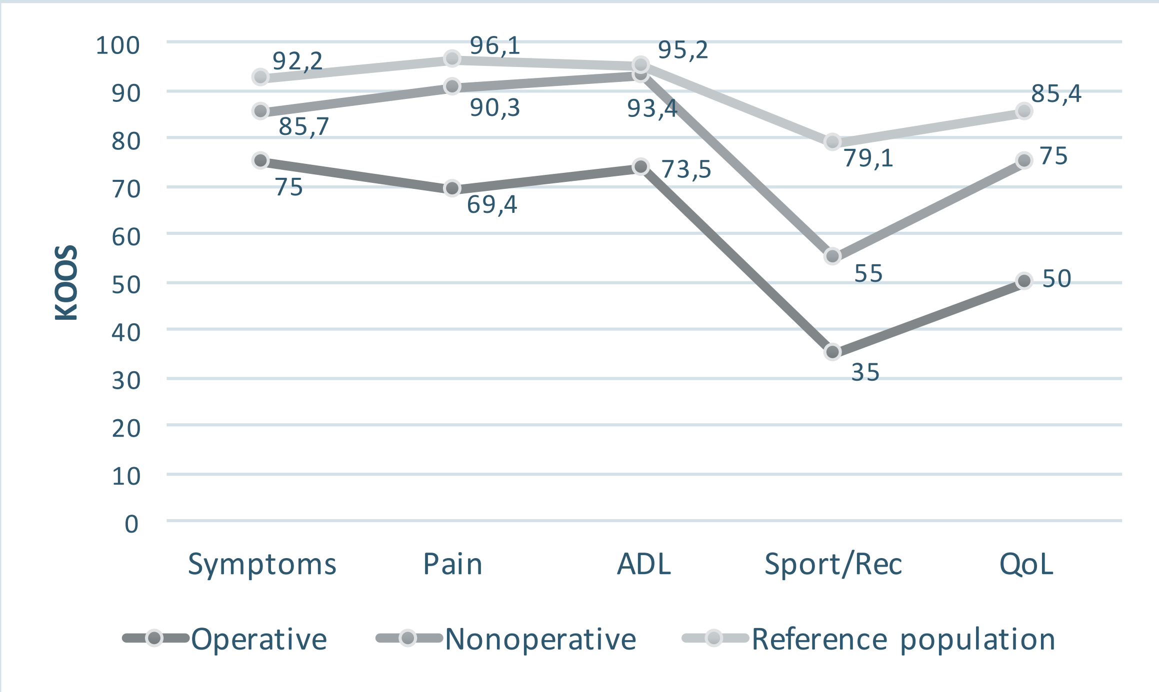


Figure 2: KOOS subscale results.
The KOOS subscales are displayed for 118 (73,8%) operatively treated patients, 42 (26.2%) nonoperatively treated patients, and a general population [16]. Abbreviations: KOOS, Knee injury and Osteoarthritis Outcome Score; ADL, activities of daily living; Sport/Rec, function in sport and recreation; QoL, knee related quality of life.

Which factors influence the outcome?

Bivariate analysis on the KOOS subscales was performed in regard to all demographic variables, fracture classifications, treatment parameters and radiological outcome. All results are presented in Table 3. Further investigation into influencing factors on KOOS subscales was achieved by analyzing bivariate significant results in a linear logistic regression model. Regarding the 'symptoms' subscale, PCF ($p=0.030$), sagittal malalignment ($p=0.039$) and an increased complication ratio ($p<0.001$) were all associated with worse outcome scores. Regarding the 'pain' subscale, PCF (p=0.035) and an increased complication ratio (p=0.002) were associated with more pain. For the 'ADL' subscale, PCF (p=0.004), sagittal malalignment (p=0.029) and an increased complication ratio were also identified as significant influencing factors. Poorer scores on the 'sport' subscale were associated with multiple column fractures (p=0.013), the need for external fixation (p=0.037) and an increased complication ratio (p=0.006). Regarding the 'QoL' subscale, PCF (p=0.018), sagittal malalignment (p=0.001) and an increased complication ratio (p<0.001) were associated with poorer outcome scores.

Table 3: Correlation analysis.

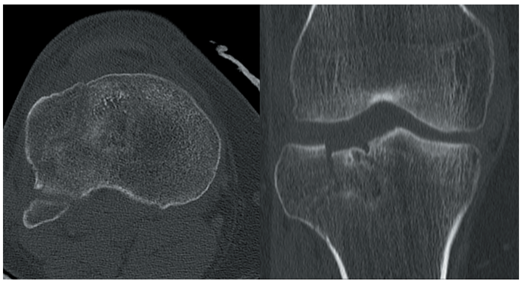
	Symptoms	Pain	ADL	Sport/Rec	QoL
Demographics					
Age[a]	.778	.961	.076	.061	.550
Gender	.917	.677	.474	.218	.604
ASA Score	.663	.768	.653	.645	.668
BMI[a]	.202	.394	.481	.702	.720
Smoking	.815	.878	.991	.816	.489
Medication	.424	.380	.488	.571	.880
DM	.106	.341	.896	.769	.197
Other CVRF	.183	.314	.873	.680	.465
Follow-up time[a]	.643	.948	.272	.062	.952
Side	.218	.650	.732	.403	.620
Open fracture	.012*	.032*	.038*	.201	.078
Fracture classification					
AO/OTA	.002*	.004*	.001*	.002*	<.001*
Schatzker	.038*	.013*	.010*	.026*	.031*
Three-column	.001*	<.001*	<.001*	<.001*	<.001*
Medial column	.100	.039*	.028*	.195	.076
Lateral column	.399	.882	.216	.025*	.116
Posterior column	.005*	<.001*	<.001*	.001*	<.001*
Treatment parameters					
Type of treatment	.007*	.008*	.014*	.004*	<.001*
External fixation	.019*	.055	.024*	.002*	.030*
Delayed (-staged) surgery	.595	.218	.371	.967	.096
Time to definite surgery[a]	.367	.699	.852	.348	.482
Complication rate	<.001*	<.001*	<.001*	<.001*	<.001*
Superficial infection	.062	.442	.243	.659	.180
Deep infection	.073	.185	.115	.061	.181
Nonunion	.087	.439	.502	.314	.344
Other complications	.213	.570	.566	.771	.991
Reintervention rate	.097	.197	.138	.015*	.109
Implant removal	.165	.309	.291	.046*	.499
Revision	.024*	.168	.107	.048*	.052
TKA	.414	.083	.045*	.162	.233
Radiological outcome					
Failure rate	060	057	025*	.093	.010*
Coronal malalignment	.670	.988	.879	.208	.582
Sagittal malalignment	.042*	.073	.033*	.076	.004*
Condylar width	.046*	.035*	.020*	.166	.096
Gap/Step	.240	.066	.068	.091	.137

Bivariate analysis was performed using Mann-Whitney U test and Pearson correlation. Results are displayed as p-value and marked (*) if p < 0.05. Continuous variables are marked with [a].
Abbreviations: ASA, American Society of Anesthesiologists; BMI, Body Mass Index; DM, diabetes mellitus; CVRF, cardiovascular risk factor; AO/OTA, Arbeitsgemeinschaft fur Osteosynthesefragen/ Orthopedic Trauma Association; TKA, total knee arthroplasty; ADL, activities in daily living; Sport/ rec, function in sport and recreation; QoL, knee related quality of life.

Relation between the uTCC, PCF fixation, and outcome

187/340 Column fractures (55.0%) were not treated according to the uTCC (Table 2); it concerned mainly PCF (n=121). In order to determine the value of the uTCC and importance of PCF fixation, a comparison between uTCC-based patient clusters was peformed. 147/218 Patients (67.4%) were not treated according to uTCC; it concerned 109/160 responding patients (68.1%), which showed significantly lower outcome scores on every subscale except for 'symptoms', as compared to patients treated according to uTCC ('symptoms' p= 0.061, 'pain' p= 0.012, 'ADL' p= 0.002, 'sport' p< 0.001, 'QoL' p= 0.001). Subanalysis for PCF however, revealed no significant differences for any KOOS subscale between those patients with (n=9, 8.8%) and without fixation of PCF (n=93, 91.2%).

a



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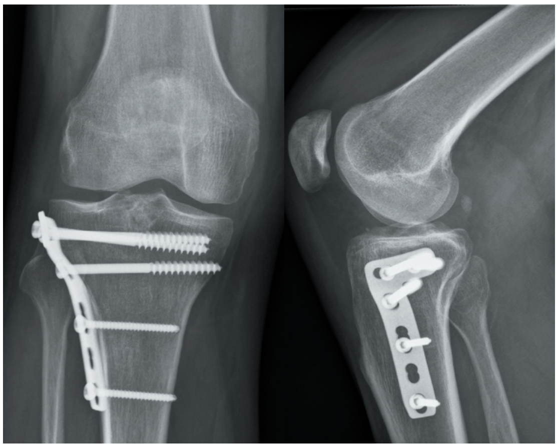

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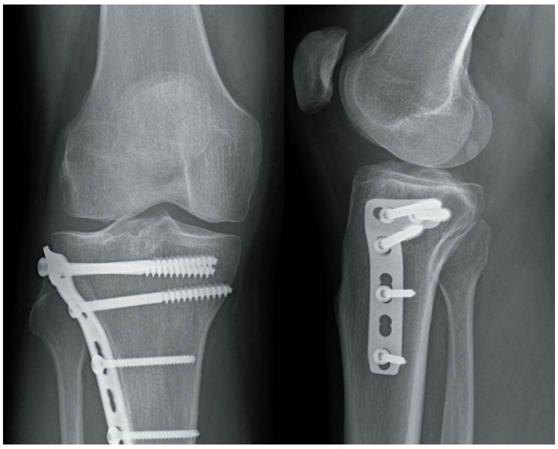

Figure 3: Demonstrative case with good functional outcome.
a Pre-operative CT-images showing a lateral column fracture with a depressed central fragment.
b Post-operative coronal and sagittal X-rays after anterolateral plating.
c Coronal and sagittal X-rays at 2 years follow-up.

Discussion

The primary aim of this study was to determine the incidence and impact of PCF on functional outcome and general health status. For that purpose, both operatively and nonoperatively treated intra-articular tibial plateau fractures were reclassified and the treatment modalities were assessed according to the (u)TCC. In order to improve the insight in treatment strategies, all variables affecting the patient reported outcome were identified.

Although comparing outcome between different studies is difficult due to differences in demographics, fracture patterns and study design, our patient reported outcome scores were markedly lower compared to the general population, with operatively treated patients scoring significantly lower (Figure 2) [16]. Our operatively treated patients also reported notable lower KOOS as compared to a recent retrospective study including 96 patients by Van Dreumel et al. [1], whereas our findings were rather in line with Timmers et al. [2]. Since differences between operative and nonoperative treatment are inherently biased by fracture severity, demonstrated by less complications and a lower response rate in nonoperatively treated patients, further comparison between the two groups was not conducted. On the contrary, all fractures were reclassified and the treatment modalities were assessed according to the (u)TCC. Both PCF and sagittal malalignment were found to negatively influence the functional outcome of intra-articular tibial plateau fractures. In addition, the occurence of postoperative complications was associated with poor outcome as well.

Patients who were treated according to the uTCC compared to those who were not, showed significantly better outcome scores on all subscales except for 'symptoms'. The 'symptoms' subscale showed a clear tendency towards significance though. In parallel, the presence of PCF was significantly associated with lower scores on 'symptoms', 'pain', 'ADL' and 'QoL'. This indicates that implementation of the (u)TCC may improve the outcome. Of all patients with a PCF, only 10.4% were treated according to the uTCC. Therefore, failure to recognize PCF may lead to inappropriate utilization of treatment techniques resulting in worse outcome as also shown by other authors in recent years [11,17]. Nevertheless, no significant differences were observed for any KOOS subscale between those patients with and without fixation of PCF. The limited number of responding patients, with PCF treated according to uTCC (n=9), may explain this.

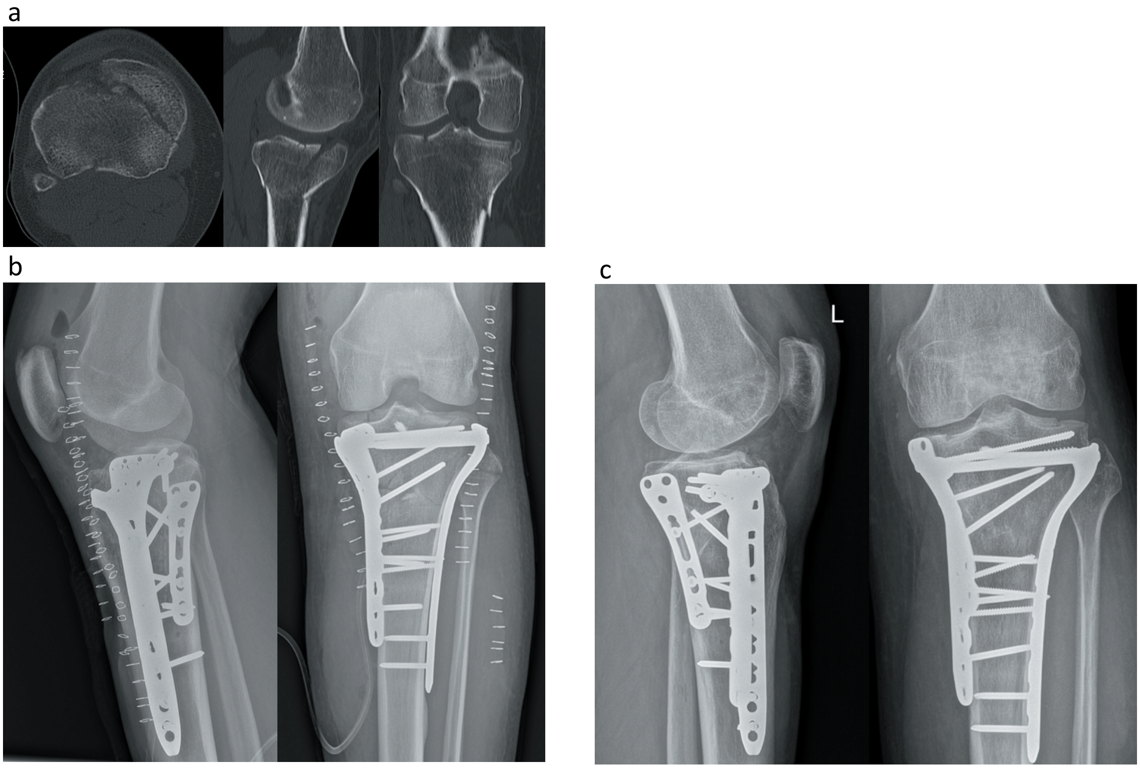

Figure 4: Demonstrative case with moderate functional outcome.
a Pre-operative CT-images showing a three-column tibial plateau fracture.
b Post-operative coronal and sagittal X-rays after combined lateral, anteromedial and posteromedial plating.
c Coronal and sagittal X-rays at 1 year follow-up.

Sagittal malalignment was found to have a negative impact on 'symptoms', 'ADL' and 'QoL', whereas coronal malalignment did not have consequential impact on the outcome. Sagittal malalignment can lead to biomechanical and functional problems [18]. Various authors have already demonstrated the importance of reduction and fixation of posterior tibial plateau fractures and prevention of malalignment [5,19-20]. These observations, together with our findings regarding the outcome, underscore the need for reduction of PCF and restoration of the posterior proximal tibial angle within reasonable limits. Using buttress techniques in an adequate manner as described before [8,10-11], may help to choose the optimal approaches and reduction methods. In contrast, articular incongruence does not necessarily have negative impact on the functional outcome as previously reported by different authors [14,21]. Furthermore, according to concurrent studies by Van Dreumel et al. [1] and Siegler et al. [22], the radiological characteristics of OA are not related with lower functional outcomes in the mid- to long-term. These findings are consistent with our data on postoperative articular incongruence. Neither the AO/OTA nor Schatzker classification was significantly associated with the outcome, probably due to its heterogeneity. In contrasts, multiple column fractures (TCC approach) negatively influenced function in sports and recreation.

For all KOOS subscales, an increased complication ratio was a predictor for worse outcome. Although the category of complications was heterogeneous (e.g. infections, compartment syndrome, implant related), the occurrence of any of these complications seems to have a relevant impact on outcome. Except for one superficial infection in an open fracture, all complications were registered in operatively treated patients. Compared to the literature our overall observed complication rate in the operatively treated group was relatively low (27.0%). Jansen et al. [23] reported an overall complication rate of up to 39.1% with high infection rates and local wound problems. In contrast, our total infection rate was remarkably lower (4.6%) than in most other studies [15,24]. Secondary OA is a late complication of tibial plateau fractures often resulting in the need for an TKA, but the incidence rates of both OA and TKA vary in the literature [21,25]. For TKA, incidence ranges from 4% after a mean follow-up of 20 months to 22% after a mean follow-up of 6 years. [1-2]. Wasserstein et al. defined the risk for TKA in a large cohort at 5.3% and 7.3% after five and ten years respectively [25]. Since our study has a median follow-up of 45.5 months, the incidence rate for TKA of 6.1% was in line with the literature.

This study has some limitations. Firstly, the limitations inherent to any retrospective study. Secondly, the fact that outcome was reported at a single point in time rather than at a certain point in follow-up time may limits the strength of the evidence. Furthermore, concurrent soft tissue injury was not evaluated in this study which could potentially influence outcome results.

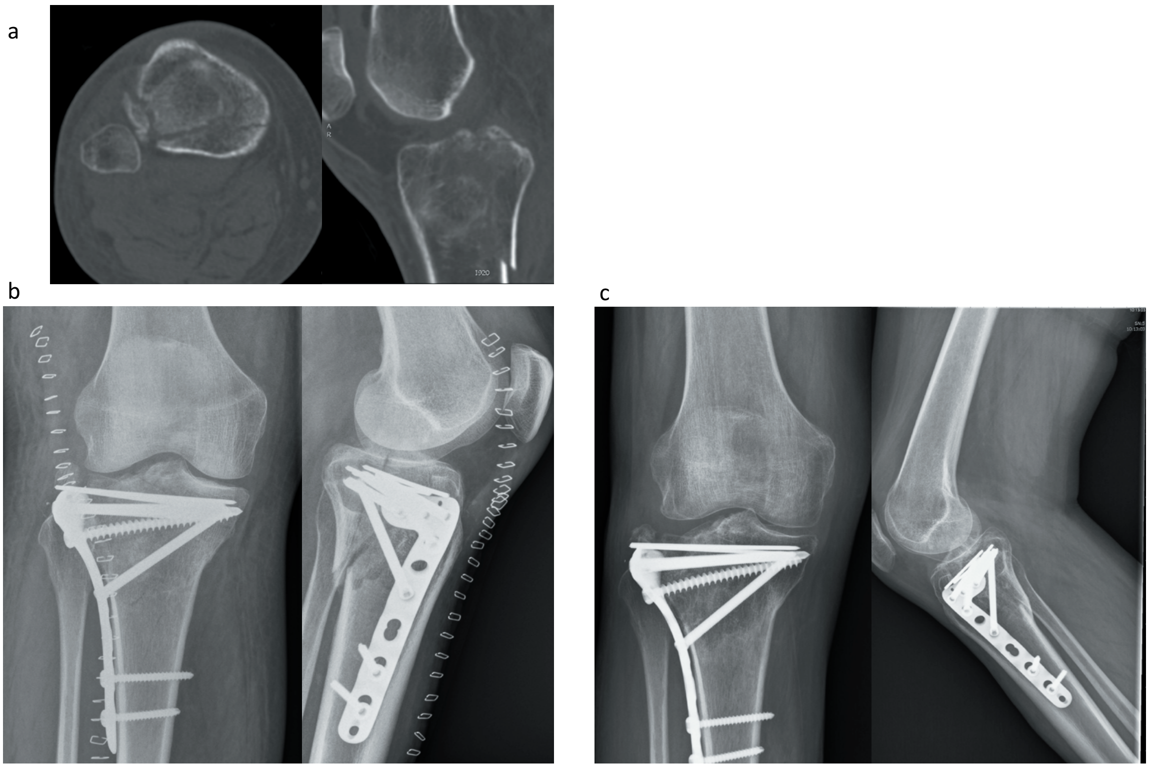

Figure 5: Demonstrative case with poor functional outcome.
a Pre-operative CT-images showing a three-column tibial plateau fracture.
b Post-operative coronal and sagittal X-rays after anterolateral plating and the use of additional K-wires.
c Coronal and sagittal X-rays at 10 months follow-up.

In conclusion, our outcome scores after both operative and nonoperative treatment of intra-articular tibial plateau fractures were markedly lower compared to the reference population. The incidence of patients with PCF (61.9%) was rather high. This may be explained by the frequent involvement of the posterolateral corner in lateral column fractures, the so-called extended lateral column fractures [10]. Subsequently, PCF and associated sagittal malalignment were identified as negative prognostic factors towards the outcome; patients treated according to the uTCC showed significantly higher outcome scores than patients who were not. This indicates that implementation of the uTCC may improve the outcome. Failure to recognize and treat PCF and sagittal malalignment may lead to inappropriate utilization of treatment techniques resulting in worse outcome (Figure 5). Nevertheless, we could not demonstrate the benefit of PCF fixation compared to non PCF fixation due to limited patient numbers. Moreover, the occurrence of complications of various etiology in operatively treated patients had significant effects on the overall outcome as well. This retrospective comparative study was only possible by the fact that posterior tibial plateau fractures were often ignored in our clinical practice. However, since 2014 all tibial plateau fractures in our center are treated according to the (u)TCC principles. Therefore, consistent treatment allows us in the future to further substantiate the importance of reduction and fixation of PCF with restoration of the sagittal alignment.

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CHAPTER 3

Limited value of the column concept in operative management of posterior column tibial plateau fractures

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Published in:

European Journal of Trauma and Emergency Surgery (2019)
doi: 10.1007/s00068-019-01078-5

Abstract

Introduction:

The three-column concept has been proposed as tool in surgical decision making for treating tibial plateau fractures. Recent studies have underscored the negative effect of posterior column tibial plateau fractures on clinical outcome. The purpose of this study was to assess the value of the three column concept and posterior plating in posterior column fractures. We hypothesized that treating patients according to the three-column concept improves functional outcome.

Methods:

111 consecutive tibial plateau fractures, treated between January 2009 and December 2016, with at least a posterior column fracture were included. Relevant demographic and treatment variables were studied. Applied treatment was retrospectively evaluated according to the three-column concept. Patient reported outcome was assessed using the Knee injury and Osteoarthritis Outcome Score (KOOS).

Results:

Median follow-up was 43.1 months (IQR 29.0-63.3) with a response rate of 80,2%. Outcome scores were markedly lower compared to the general population. 22.5% patients were treated according to the three-column concept and 27% was treated with posterior plating. Predominantly combined fractures of posterior and lateral columns were treated without fixation of the posterior column. Neither treatment according to the three-column concept and/or with posterior plating were found to significantly influence outcome.

Conclusions:

The outcome of posterior column fractures was equal, regardless of whether these fractures were treated or not. This indicates that the three-column concept seems insufficient and gives rise to further debate on surgical strategies of posterior column fractures. The implementation of trauma mechanism based fracture morphology in the three-column concept might be important in order to consummate the three-column concept as guiding tool.

Introduction

The reported incidence of posterior involvement in proximal tibial plateau fractures ranges from 28.8% to 70.7% [1-3]. Outcome in these posterior column fractures (PCF) is not widely described in the literature but recent studies suggest that involvement of the posterior surface of the tibial plateau has more impact on outcome than previously appreciated [2-5]. Sagittal malalignment has been shown to have a negative impact on knee kinematics and functional outcome as well [5,6].

As previously shown, the functional outcome of tibial plateau fractures is markedly better if patients are treated according to the three-column concept (TCC) [3,5]. The TCC guides the surgical approach and implant choice for the treatment of multiple column fractures on the basis of the mechanism of injury and fracture pattern [3]. However, in the past PCF were frequently ignored and therefore we could not determine the benefit of separate PCF fixation. Between 2009 and 2014 only approximately 10% of all PCF were treated according to TCC principles and fixed in our center [5].

Since 2014 we have been treating patients more often according to the principles of the TCC wherein particularly PCF were managed operatively, assuming that this ultimately will benefit the functional outcome of the patient. This allows us now to assess the importance of open reposition and internal fixation (ORIF) of PCF. To this end, all consecutive tibial plateau fractures involving the posterior column were assessed and evaluated with regard to functional outcome. We hypothesized that ORIF of PCF improves patient reported outcome.

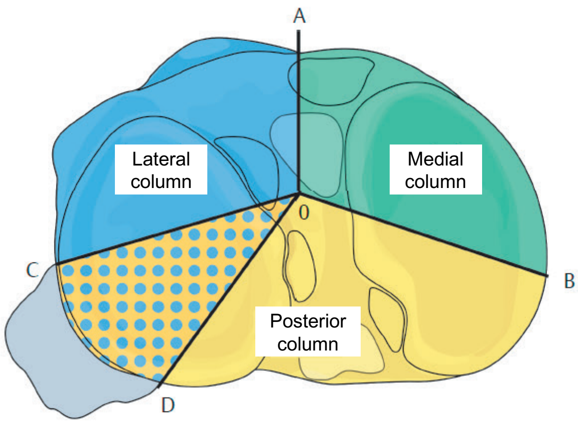

Figure 1. Revised three-column classification.
The revised three-column classification (rTCC) according to Hoekstra et al. [7], depicting the posterior column (0BC) which should be treated via a posterior approach. Lateral column (0AC) fractures that extent into the posterolateral corner (dotted area) are defined as extended lateral column fractures (0AD) and can sufficiently be treated via a single lateral approach using VA-LCPs [11].

Patients and methods

Patients

All adult patients treated operatively for a tibial plateau fracture between January 2009 and December 2016 were assessed and classified according to the revised three-column classification approach (Figure 1), retrospectively [7]. All patients sustaining a PCF were selected and evaluated for eligibility according to the exclusion criteria. A total of 87 patients were excluded (Figure 2). Pre-existing osteoarthritis was not evaluated. Polytraumatized patients were included, except in cases of bilateral fracture. In addition, treatment strategy in all selected patients was evaluated according to updated TCC principles [3]. This study was completed in compliance with national legislation and the guidelines of the ethics committee of the University Hospitals Leuven.

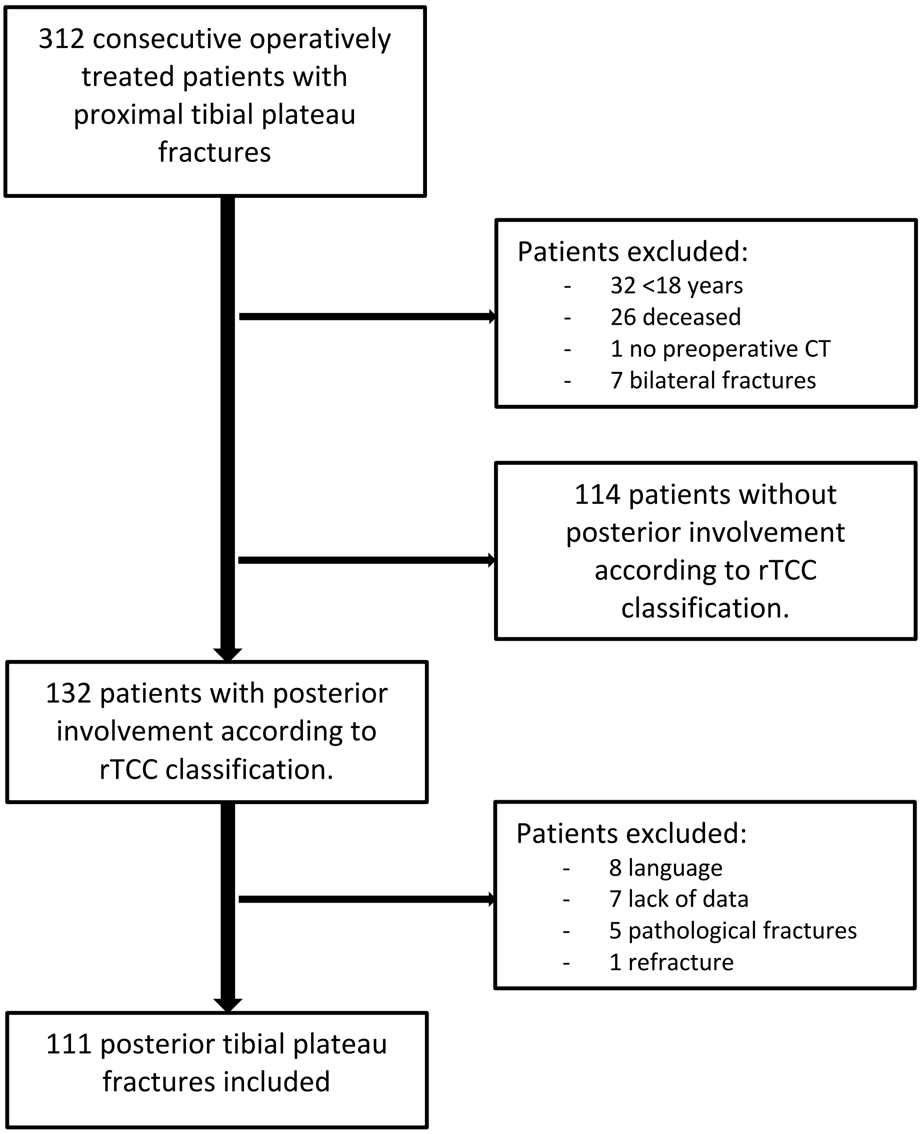

Figure 2: Patient selection.

Study variables

All patient data was retrieved from the University Hospitals Leuven electronic medical file database KWS. A total of 17 demographic and clinical variables were assessed. Cardiovascular risk factors include current cardiovascular diseases (e.g., CVA, MI, peripheral artery disease), diabetes, obesity, smoking, dyslipidemia, hypercholesterolemia, hypertension, alcohol use, and rheumatoid arthritis. Medication associated with impaired wound healing (e.g., corticosteroids, adrenergic beta-agonists, and chemotherapeutic agents) was recorded. External fixation included all fractures treated using an external fixator in a staged surgical protocol. No patients were treated with an external fixation as definite treatment. Complications were categorized as fracture related infection, nonunion and other tibia related complications (i.e., wound related problems, implant related complaints, compartment syndrome, excessive pain, drop foot, quadriceps muscle atrophy, deep vein thrombosis and neuropraxia). In turn, fracture related infection was defined according to the recent consensus definition [8]. Furthermore, nonunion was assessed using follow-up radiographs and defined according to the US Food and Drug Administration guidelines as a not completely healed fracture within 9 months of injury and without progression toward healing over the past three consecutive months. The quality of the fracture reduction was assessed using CT if available. The reintervention rate was defined as either implant removal, revision or total knee arthroplasty. Revision was defined as any intervention for loss of reduction, hardware failure or intra-articular hardware.

Outcome measures

Functional outcome and general health status were assessed using the standardized Knee injury and Osteoarthritis Outcome Score (KOOS) [10]. The KOOS questionnaire is validated for the Dutch language and consists of five subscales; symptoms, pain, activities of daily living, function in sport and recreation and knee related quality of life. Each subscale is presented as a normalized score (100 indicating no symptoms, 0 indicating extremely severe symptoms) and no summarized KOOS score can be constructed due to heterogeneity of the subscales [9]. All eligible patients were sent questionnaires and contacted by telephone if no response was obtained after four weeks.

Statistical analysis

Statistical evaluation of all data was performed using IBM SPSS 25.0 (SPSS Inc. Chicago, IL). Nominal variables were compared using Chi-Square statistics and nonparametric variables using the Mann-Whitney U test. For correlation testing the Pearson correlation test was used for continuous variables and the Spearman correlation test for nominal variables. A significance level of <0.05 was accepted for all tests. A multivariate analysis was conducted on all significant variables using a linear logistic regression analysis with a stepwise approach.

Results

Descriptives

Between January **2009** and December 2016, all 312 consecutive patients presenting with a tibial plateau fracture in our institution were reviewed. After exclusion, a cohort of 111 patients was included in our study (Figure 2). The median follow-up in the study was 43.1 months (IQR 29.0-63.3). A total of 89 patients responded to the questionnaires, leading to a response rate of 80.2%. In contrast to the responding patients, the nonresponders where more likely to be male (p=0.010), young (p=0.005) and smoking (p=0.005). No other significant demographic or clinical differences between responders and nonresponders were found. The patient, fracture and operative characteristics are summarized in Table 1.

Outcome

Median KOOS scores for the five subscales are 64.3 (IQR 46.4 – 85.7) for 'symptoms', 62.5 (IQR 44.4 – 88.9) for 'pain', 66.2 (IQR 51.5 – 89.7) for 'activities of daily life', 25.0 (IQR 5.0 – 50.0) for 'sports and recreation' and 39.6 (IQR 25.0 – 57.8) for 'knee related quality of life'. With 23 (20.5%) patients stating full flexion and/or extension as impossible. With regard to pain perception, 34 (30.6%) patients reported experiencing pain on a daily basis and 10 (9.0%) patients were suffering pain continuously. The median KOOS scores are displayed in Figure 3 in comparison to the general population [10].

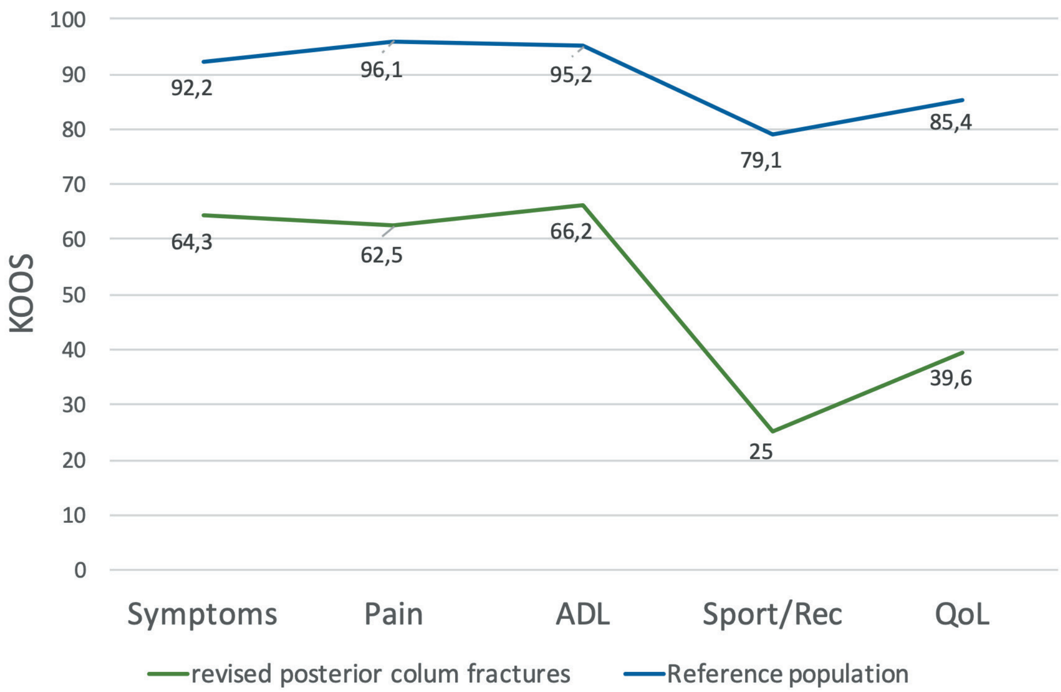

Figure 3: KOOS subscale results.
KOOS subscale outcome scores of study cohort, compared to a reference population [13]. Abbreviations: KOOS, Knee injury and Osteoarthritis Outcome Score; ADL, activities of daily living; Sport/Rec, function in sport and recreation; QoL, knee related quality of life.

Table 1: Descriptives (n = 111).

Age (years)	52.6, 51.6 (42.7 – 61.1, 15.3, 21.2 – 91.0)
Gender	
Male	44 (39.6%)
Female	67 (60.4%)
ASA-score	
1	36 (32.4%)
2	65 (58.6%)
3	9 (8.1%)
4	1 (0.9%)
CVRF	
BMI (kg/m²)	26.3, 26.8 (22.9 – 29.3, 4.9, 18.3 – 42.1)
Smoking	29 (26.1%)
Medication	27 (24.3%)
DM	9 (8.1%)
Other CVRF	44 (39.6%)
Side	71 (64.0%)
Left	40 (36.0%)
Right	8 (7.2%)
Open fracture	8 (7.2%)
rTCC classification	
1 column	6 (5.8%)
2 columns	52 (46.8%)
posterior + medial	10
posterior + lateral	42
3 columns	53 (47.7%)
External fixation	18 (16.2%)
Delayed (-staged) surgery	
Direct (<24 hrs)	17 (15.3%)
Delayed (>24 hrs)	94 (84.7%)
Time to surgery (days)	4, 5.15 (2 – 7, 4.6, 0 - 24)
Complication rate	43 (38.7%)
Fracture related infection	13 (11.7%)
Nonunion	5 (4.5%)
Other complications	34 (30.6%)
Reintervention rate	49 (44.1%)
Implant removal	40 (36.0%)
Revision	17 (15.3%)
TKA	8 (7.2%)

Continuous parameters are expressed as median and mean values with their respective interquartile range, standard deviation and range. Categorical variables are expressed as numbers and percentages of the total number of included patients (n=111).
Abbreviations: ASA, American Society of Anesthesiologists; CVRF, cardiovascular risk; BMI, body mass index; DM, diabetes mellitus; rTCC, revised three-column classification; TKA, total knee arthroplasty.

TCC, posterior plating and outcome

Treatment of all patients was assessed for compliance according to the TCC principles. A comparison between demographics and fracture characteristics of patients treated according to the three-column concept and those who were not is displayed in Table 2.

Table 2: Treatment according to three-column concept and not (n = 111).

	TCC (n=25)	no TCC (n=86)	P-value
Age (years)	53.9, 52.8 (42.5 – 62.9, 14.7, 24.0 – 81.4)	51.7, 51.3 (42.3 – 60.7, 15.5, 21.2 – 91.0)	0.525
Gender			0.984
Male	10 (22.7%)	34 (77.3%)	
Female	15 (22.4%)	52 (77.6%)	
ASA-score			0.944
1	9 (25.0%)	27 (75.0%)	
2	13 (20.0%)	52 (80.0%)	
3	3 (33.3%)	6 (66.7%)	
4	0	1 (100%)	
CVRF			0.031*
BMI (kg/m^2)	27.4, 28.5 (25.2 – 32.2, 4.9, 18.8 – 40.4)	25.7, 26.3 (22.6 – 29.0, 4.7, 18.3 – 42.1)	
Smoking	5 (17.2%)	24 (82.8%)	0.445
Medication	7 (25.9%)	20 (74.1%)	0.717
DM	4 (44.4%)	5 (55.6%)	0.097
Other CVRF	10 (22.7%)	34 (77.3%)	0.950
Side			0.612
Left	15 (21.1%)	56 (78.9%)	
Right	10 (25.0%)	30 (75.0%)	
Open fracture	1 (12.5%)	x 7 (87.5%)	0.481
rTCC classification			0.038*
1 column (posterior)	2 (33.3%)	4 (66.7%)	
2 columns	5 (9.6%)	47 (90.4%)	
posterior + medial	2 (20.0%)	8 (80.0%)	
posterior + lateral	3 (7.1%)	39 (92.9%)	
3 columns	18 (34.0%)	35 (66.0%)	

Comparison between demographics and fracture characteristics of patients treated according to the three-column concept and those who were not. Continuous parameters are expressed as median and mean values with their respective interquartile range, standard deviation and range. Percentage displayed is according to the respective treatment category. The respective P-values for all variables are calculated between treatment groups using Chi-Square testing for binominal, ANOVA for multinominal and Mann-Whitney U test for continuous variables.
Abbreviations: TCC, three-column concept; ASA, American Society of Anesthesiologists; CVRF, Cardiovascular Risk Factors; BMI, Body Mass Index; DM, Diabetes Mellitus; rTCC, revised three-column classification.

In total, 25/111 (22.5%) patients were treated according to the TCC principles with a disproportionate time distribution (p=0.002): 7/61 (11.5%) before and 18/50 (36.0%) after implementation of the TCC in 2014. No significant relation between TCC (or no TCC) and any of the KOOS subscales was found in our cohort (symptoms p=0.218, pain p=0.400, activities of daily life p=0.960, sports and recreation p=0.853 and knee related quality of life p=0.587, respectively). Furthermore, patients treated between 2014 and 2016 showed also no significant differences in outcome if treated according to TCC principles or not (symptoms p=0.091, pain p=0.370, activities of daily life p=0.159, sports and recreation p=0.489 and knee related quality of life p=0.113).

In contrast, 30/111 (27.0%) of all patients were treated with a posterior plate, including 5 patients who were not fully treated according to the TCC principles (Figure 4): 2/6 (33.3%)

patient with a single (posterior) column fracture, 16/52 (30.8%) patients with 2 column fractures, and 12/53 patients with 3 column fractures. After implementation of the TCC in 2014 the number of patients treated with a posterior plate doubled: 11/61 (18.0%) before and 19/50 (38.0%) after implementation, respectively. No significant relation between posterior plate (or not) and any of the KOOS subscales was found (symptoms p=0.452, pain p=0.113, activities of daily life p=0.934, sports and recreation p=0.789 and knee related quality of life p=0.456, respectively). There was also no significant difference is KOOS scales in the patients treated with a posterior plate between 2014 and 2016: symptoms p=0.888; pain p=0.681; activities of daily life p=0.778; sports and recreation p=0.961; knee related quality of life p=0.707). Moreover, the quality of fracture reduction was routinely assessed from 2014 onwards and postoperative CT showed articular incongruence in 46% (23/50) of these patients.

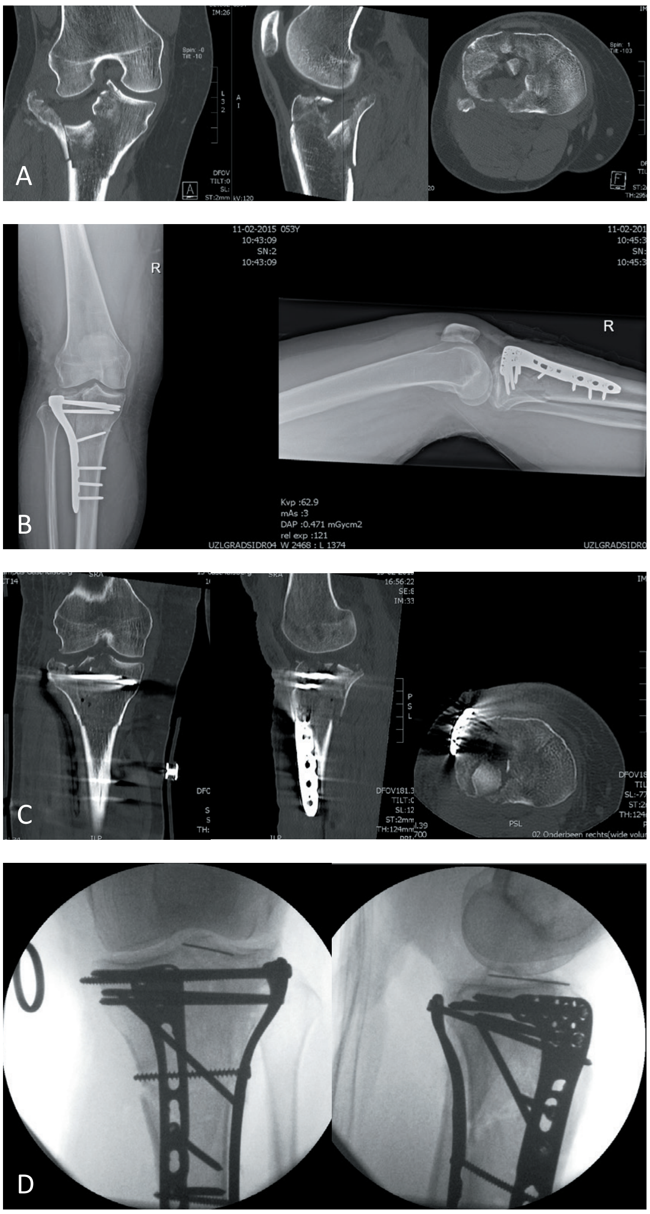

Figure 4:
53-year-old female who sustained a three-column tibial plateau fracture. A, preoperative CT including respectively coronal, sagittal and axial view. B, initial treatment consisted of a single VA-LCP osteosynthesis. C, postoperative CT revealed coronal and sagittal malalignment due to a collapsed lateral tibial plateau and an unstable posterior column fracture (respectively coronal, sagittal and axial view). D, reosteosynthesis with posterior buttress of the posterior column fracture and ORIF of the extended lateral column using a VA-LCP and a K-wire. The combined (antero-) lateral and posteromedial reversed L-shaped approach provide here an extensive exposure of both the joint (whole extended lateral column) as well as the posterior aspect of the proximal tibia. After arthrotomy and tibia condyle osteotomy, the exposure of the joint can be increased by inserting a small retractor behind the posterior wall just medially of the fibular head.

Discussion

The aim of this study was to investigate the value of the TCC in the treatment of tibial plateau fractures, including posterior column fractures and determine whether or not there is benefit of posterior fixation. We hypothesized that ORIF of PCF might improve patient reported outcome. Therefore, we examined all operatively treated tibial plateau fractures with a PCF between 2009 and 2016 in our center, and assessed whether or not the operative management was according to the TCC principles with adequate fixation of the PCF. Surprisingly, we could not reveal a significant benefit of TCC with regard to the functional outcome. Although the TCC was implemented as early as 2014, only well over a third of the patients were treated according to the TCC and did not show significant differences in KOOS subscales. Apart from whether patients were treated according to the TCC, also patients treated with posterior plating did not show better outcome scores.

The 2 column fractures mainly concerned combined posterior and lateral column fractures (Table 1), which were treated using single lateral plate fixation predominantly. Using variable angle - locking compression plates (VA-LCP) with a 30 degrees' cone allows us to diverge the VA-LCP locking (rafting) screws posteriorly through the fracture and ensure adequate fixation and articular support of extended lateral column fractures. Nevertheless, lateral ORIF does not always provide sufficient support of posterolateral (and posteromedial) column fractures (Figure 1) [11-13]. Surely enough, only 3/42 patients (7.1%) with a combined lateral and posterior column fracture were treated according to the TCC (i.e. lateral and posterior ORIF). No statistically significant difference in outcome was noted, although these numbers are insufficient to draw conclusions from.

A frequently observed fracture pattern was a lateral tibial plateau fracture with an anteroposterior fracture configuration, and depression or sagittal malalignment or depression. Strict evaluation of these fractures according to the TCC indicates a combined lateral and posterior column fracture. As shown by Molenaars et al. such lateral split fracture pattern are frequent and can occur in up to 75% of all tibial plateau fractures [2]. Although optimal treatment strategy for this type of fracture can further be debated (i.e. fracture morphology, degree of articular depression), a lateral split (depressed) fracture should sufficiently be treated via a single lateral approach. On the contrary, if a fracture of the posterior wall is present in a more lateromedial direction (shear fracture), additional posterior fixation with adequate buttressing according to the TCC seems necessary [2-3]. This shows that there is a flaw in the TCC and might also be an explanation for the fact that we have not been able to show any added value of the TCC in patients sustaining a PCF.

Fracture morphology is indeed important in the choice whether or not to treat posterior column fractures. The implementation of trauma mechanism based fracture morphology can be an important link in order to consummate the TCC and guide future surgical decision making with regard to the fixation of the posterior column [14]. The 10-segment classification proposed by Krause et al., being more exhaustive towards recognizing articular fracture patterns and associated ligamentous injury, is not likely to offer added value towards prediction of secondary displacement or surgical planning [15]. Therefore, further investigation into current techniques and hardware to assess for efficacy in the treatment of these fractures is needed.

We are aware that the current study has some limitations. Firstly, the retrospective design has to some degree an inherent selection bias. Secondly, to a certain extent surgical decision making causes an inherent heterogeneity due to treatment selection bias. In other words, a severe fracture with comminution potentially could have a higher probability of receiving posterior fixation. Furthermore, the long inclusion period encompasses different implemented treatment strategies over time. Lastly, the cross-sectional design leads to a variable follow-up time of the measured outcome. Nevertheless, this study represents a relatively large cohort of consecutive patients in a single large level 1 trauma center, with a structured management, rehabilitation and follow-up protocol. Furthermore, the relatively high response rate and diverse patient characteristics make this cohort representable for study purposes.

In conclusion, the outcome scores of patients after sustaining a PCF were markedly lower than values in the reference population. Although the current revised three-column classification approach is very helpful toward surgical planning, in particular of extended lateral column fractures [11], there are still multiple issues that need to be addressed. Fracture patterns of multiple column fractures seem to be more comprehensive than can be adequately expressed by the TCC. Fracture morphology and the risk for secondary displacement are case specific and although thoroughly investigated with CT-images, no current classification seems to fully satisfy. Case selection for posterior fixation is still highly debated and our current findings can't sufficiently direct our decision making. Further investigation into fracture morphology in relation to trauma mechanisms and surgical decision making needs to be performed in order to adequately treat the diversity of fracture patterns. 3D-classification is a relatively new concept that could be investigated towards predicting outcome and give direction to surgical planning of these complicated fractures. Furthermore, prospective study protocols with adequate fixation of selected posterior column fractures and extensive review of the outcome are needed.

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CHAPTER 4

Value of 3D-CT reconstruction in the treatment of posterior tibial plateau fractures

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Published in:

The Knee (2019)
doi: 10.1016/j.knee.2019.11.001

Abstract

Background:
Indication for surgical treatment of posterior tibial plateau fractures (TPF) remains up for debate. 3 Dimensional-CT (3D-CT) reconstruction can provide insight into fracture morphology and could improve treatment strategy and surgical planning.

Objectives:
In this study we investigate the value of 3D-CT reconstruction in the treatment of posterior TPF and evaluate the influence on surgical decision making.

Design and Methods:
CT images of 34 cases with a TPF involving the posterior column were included and digitally presented to a panel of five international observers at 2 intervals. At the first evaluation, only coronal, axial and sagittal images were shown. After an interval of at least 3 weeks 3D-CT reconstruction images were added. During both surveys, observers were asked to classify the TPF according to the revised three-column classification (rTCC), as well as to define operative strategy.

Results:
When using 2D images, overall multirated kappa value was 0.48, with an average pairwise agreement of 68%. After adding 3D images, overall multirated kappa value was 0.43, with average pairwise agreement of 67%. Hierarchical logistic regression of decision to operate on image condition (3D *vs.* 2D) shows an odds ratio of 2.01 (95% CI, 1.11 to 3.67), p=0.022. Increase of operative indication was seen mainly in posterolateral fractures.

Conclusion:
This study investigated the value of 3D classification in the treatment of posterior column TPF. Contrary to expectations, the addition of 3D images to the assessment does not reduce but rather appeared to increase operative indications, especially in fractures involving the posterolateral region.

Introduction

To date, the outcome of tibial plateau fractures (TPF) remains uncertain. Recently, fractures of the posterior surface of the tibial plateau have been identified as an important prognostic factor on clinical outcome [1]. In contrast to commonly used classification systems (Schatzker, AO/OTA), posterior TPF are better depicted according to the 3-column concept [1-6]. According to the three-column concept, every column fracture (articular depression in combination with a cortical interruption) should be treated surgically [7]. TPF that were treated in accordance with this concept reported a better functional outcome [1,7].

However, there seems to be a flaw in the 3-column concept. Fracture patterns of multiple column fractures are more comprehensive than can be adequately expressed by three-column classification [1, 5, 8-9]. Fracture morphology and the risk for secondary displacement are case specific and although thoroughly investigated with CT-images, no current classification seems to fully satisfy. Case selection for posterior fixation is still highly debated and our current evidence can't sufficiently direct our decision making.

Recently, 3 dimensional (3D) classification for calcaneal fractures has been shown to be a reliable tool to gain more insight into fracture morphology and thus to improve treatment strategy [10]. According to the literature, additional 3D images provide insights in several other orthopedic domains as well [11-12]. In 2009, Hu et al. suggested 3D-CT images to be a more reliable radiographic modality than 2 dimensional-CT (2D CT) in evaluation of fracture patterns in tibial plateau fractures [13]. CT-imaging in these fractures is widely accepted as the gold standard in preoperative investigation and planning and recently 3D reconstruction is more widely available. However, the impact of adding 3D-reconstruction on preoperative planning and decision making has not been thoroughly evaluated.

Therefore, the goal of the present study was to determine the value of 3D reconstruction in classification and treatment of tibial plateau fractures with posterior involvement. We assessed the intra-observer and interobserver variability between 2D and 3D imaging and evaluated the influence of 3D images on surgical decision making and clinical practice.

Patients and methods

This study was completed in compliance with national legislation and the guidelines of the ethics committee of the University Hospitals Leuven. CT images of 34 patients with a TPF involving the posterior column treated between July 24, 2014 and May 29, 2018 were included. Selection of cases was based on quality of imaging series providing high quality 3D reconstruction. All CT images were recorded using the Aquilion One Volume CT scanner (Toshiba, Tokyo, Japan), with a table pitch of 0.641, collimation of 0.5×64, slice thickness of 0.5 mm, slice increment of 0.5 mm, and rotation time of 0.5 second. All images were anonymized and digitally presented to a panel of five international observers to classify the tibial plateau fractures (all posterior column fractures, possibly combined with a medial and / or lateral column fracture). The questionnaire and the images were presented on a secure, custom-made website (*https://rtcc.lifehost.org*). The reference drawing of the rTCC (revised three column classification) was presented during the survey. At the first evaluation, the 2-dimensional (2D-CT) images (coronal, axial and sagittal) were shown. After a minimum interval of 3 weeks, in addition, 3D reconstructed images were presented to the observers. During both surveys, the observers were asked to classify the tibial plateau fractures according to the rTCC, as well as to define the operative strategy. In this study, both intra- and interobserver reliability were examined.

The 3-column concept and rTCC

According to the three-column concept as proposed by Luo et al. in 2010 an independent column fracture is defined as an articular depression with a fracture of the column wall [2]. Subsequently, column fractures should be fixated accordingly [7]. According to rTCC classification, lateral column fractures that extend into the posterolateral corner (dotted area - OCD), are defined as extended lateral column fractures (OAD). Posterolateral corner fractures extending medially of the fibular head are referred to as posterolateral column fractures (OCB) and should be treated as posterior column fractures (ODB). The posterior column can be divided on the midline in a posterolateral (ODE) and posteromedial part (OEB). (Figure 1)

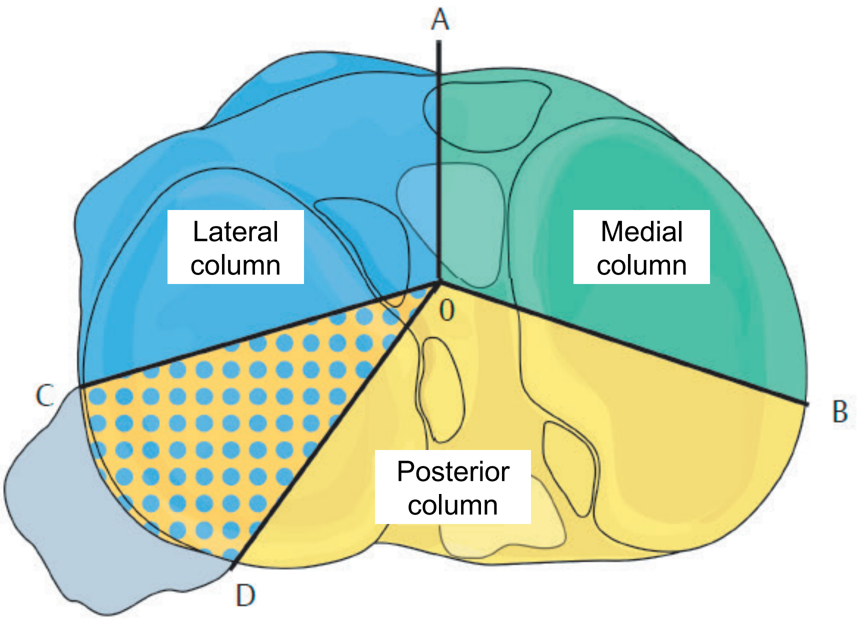

Figure 1. The revised three column classification.
Lateral column fractures that extend into the posterolateral corner (dotted area - OCD), are defined as extended lateral column fractures (OAD). Posterolateral corner fractures extending medially of the fibular head are referred to as posterolateral column fractures.

Using the kappa statistic, the reliability of the fracture classification made by the same observer on separate occasions (intraobserver reliability) or by different observers on the same occasion (interobserver reliability) was measured. The reliability guidelines were scored using the Landis and Koch guidelines [15]. The distribution of the rTCC classification scores was compared between the 2D-CT images and the 3D-CT images. First, we recorded the percentage of agreement, which equals the probability that 2 observers would give the same score. Second, the Fleiss kappa (κ) for multiple observer was recorded. The Fleiss κ is a measure of the degree of interobserver agreement beyond the level of chance. Next, an analysis of decision to operate based on 3D-CT versus 2D-CT images using hierarchical logistic regression was done. The analyses were performed using SPSS Statistics for Windows, version 25.0 (SPSS Inc., Chicago, Ill., USA).

RESULTS

A total of 34 multislice CT-scans of patients with a tibial plateau fractures with posterior involvement according to rTCC classification were assessed by a panel of five international observers. The average interval between surveys was 7.5 weeks (range; 3.1-10.3).

The intra-observer agreement and reliability between 2D and 3D classification was, on average, 72.4% (range; 56%-91%) with an average Kappa of 0.53 (range; 0.17-0,85) (Table 1). A hierarchical logistic regression of the decision to operate on image condition (3D versus 2D): OR of image condition was 2.01 (95% CI, 1.11 to 3.67), p=0.022 (Table 2).

The average pairwise interobserver agreement was 68% with an overall multirated kappa value of 0.48 when using 2D images. Adding the 3D-CT images during the second survey resulted in an overall multirated kappa value of 0.43, with an average pairwise agreement of 67% (Table 3).

All 13 cases where an increase in operative indication was observed were separately assessed for fracture morphology. In one case there was a posteromedial fracture, and in twelve cases both the posterior and lateral column were involved. Of these 12 cases, 10 cases involved the posterolateral column exclusively (Figure 1, ODE).

Table 1: Intraobserver agreement and reliability between 2D and 3D classification.

	Agreement 2D-3D classification	Kappa (intraobserver)
Observer 1	23 (68%)	0.52
Observer 2	31 (91%)	0.85
Observer 3	27 (79%)	0.65
Observer 4	23 (68%)	0.46
Observer 5	19 (56%)	0.17

Table 2: Analysis of decision to operate based on 3D vs 2D images.

	2D operate, N (%)	3D operate, N (%)	Difference (95% CI)
Observer 1	20 (59%)	22 (65%)	6 (-13, 24)
Observer 2	19 (56%)	21 (62%)	6 (-7, 18)
Observer 3	19 (56%)	20 (59%)	3 (-5, 11)
Observer 4	16 (47%)	21 (62%)	15 (-1, 29)
Observer 5	25 (74%)	29 (85%)	12 (-3, 27)

Table 3: Interobserver agreement and reliability when using 2D or 3D images.

2D/3D	Observer 1	Observer 2	Observer 3	Observer 4
Observer 1				
Observer 2	28 (82%) / 21 (62%)			
Observer 3	27 (79%) / 26 (76%)	29 (85%) / 28 (82%)		
Observer 4	25 (74%) / 21 (62%)	29 (85%) / 26 (76%)	24 (71%) / 24 (71%)	
Observer 5	15 (44%) / 17 (50%)	19 (56%) / 20 (59%)	14 (41%) / 23 (68%)	22 (65%) / 22 (65%)

Discussion

Since no current comprehensive classification system for the treatment of posterior TPF is available, the goal of this study was to determine the added value of 3D reconstruction in surgical decision making and treatment of tibial plateau fractures with posterior involvement. Firstly, we assessed the intra- and interobserver variability of rTCC classification between 2D and 3D imaging. Secondly, we evaluated the influence of added 3D imaging on surgical decision making and clinical practice.

On average intra-observer agreement was moderate on classification with and without 3D imaging available [14]. Although, a wide range in intra-observer agreement was found between observers (0.17 – 0.85). The interobserver agreement on classification decreased slightly when 3D was added with kappa values of 0.48 and 0.43 respectively. The pairwise average interobserver agreement before 3D and after, was 68% and 67% respectively. Regarding decision to operate, we found an increase of 8.2% in favor of fixation of posterior column fixation when assessing 3D reconstructed images with an odds ratio of 2.01 (p=0,022). This is in contrast with the findings of other studies, reporting an overestimation of comminution based on 2D images in fractures of the foot, and therefore less need for surgery [10, 15]. Although all observers show an increase in operative indication, the results are highly influenced by observer 4 and 5 as shown by their low intra-observer agreement (0.46 and 0.17 respectively).

In current literature, conflicting evidence exists concerning the added value of 3D-CT images in fracture management. Recently, Misselyn et al. demonstrated an improved interobserver agreement in fracture classification when adding 3D-CT images regarding calcaneal fractures [10]. Specifically, in proximal tibia fractures, CT-based classifications have been shown to be a reliable tool to gain more insight into fracture morphology and thus improve treatment strategy [4,8]. In a recent systematic review, Millar et al. demonstrated an interobserver kappa value ranging from 0.37 to 0.73 when using the Schatzker classification [16]. Castiglia et al. reported an interobserver reliability of 0.64 for the Schatzker classification with the use of 3D-CT images, and, they showed that the use of CT (compared to a radiograph) also had an impact on the surgical approach. Furthermore, they reported an improvement in the interobserver reliability with added CT imaging. However, during each assessment the observers were shown all imaging techniques sequentially. Although a decisive impact in surgical decision was shown in tibial plateau fractures with added CT imaging, no differences were reported after adding 3D imaging [17]. Nevertheless, the results of the comparison between the assessments at different times, are not reported. In our current study, the 3D imaging was only presented to the observers after the time interval of minimum 3 weeks.

In the series presented by Zhu et al., there was a "substantial interobserver agreement" with the use of the Three-Column Classification (TCC) based on 2D-CT images [4]. Our current study showed only moderate interobserver agreement. However, this may partially be explained by the classification system, as the TCC only has four categories (including zero column fractures), while the rTCC has an additional class [6]. In 2015, Mellema demonstrated the addition of 3D-CT reconstructions did not improve the interobserver reliability of CT-based evaluation of tibial plateau fractures when using the Schatzker or Luo's three column classification [3]. Although our results on interobserver agreement for the rTCC are in line with Mellema et al., the current findings show an increase in surgical management of posterior tibial plateau fractures (OR 2.01, p=0.022). This suggests an inherent failure of current 2D-CT classification on guiding surgical treatment. A recent study by Pätzold et al. suggests a new classification scheme based on the 3D geometry of bicondylar proximal tibial fractures guided by the direction of fracture lines. They report a kappa value of 0.936 for the 3D classification scheme compared to 0.720 and 0.785 for the AO/OTA and the Schatzker classification respectively [18].

Optimal treatment strategies for PTF with posterior involvement are not well established and decision making is mostly based on degree of articular depression, fracture morphology and patient characterization. Recently, there has been increased interest in the direction of fracture lines towards treatment planning. 3D-CT visualization can improve understanding of fracture patterns. Moreover, visualization of posterior involvement with specific coronal fracture lines may improve surgical decision making [5, 18]. Current literature, including frequently referenced Luo et al. and Wang et al. does not provide absolute criteria or values for posterior plate osteosynthesis. The finding of increased operative indication in this study after review of 3D reconstruction suggests a limitation of current classification schemes. As previously shown by different authors, fracture patterns in proximal tibia fractures are not always well presented by three column classification [8,18,19]. Furthermore, we have shown that decision making in fractures of both the posterolateral (ODE) and extended lateral (OAD) is influenced by 3D-CT reconstruction (Figure 1). In Figure 2 we present an illustrative case wherein the opinion of the observer panel changed to posterior operative indication. This further substantiates the hiatus of current classifications and the ongoing discussion regarding treatment strategies of posterolateral tibial plateau fractures.

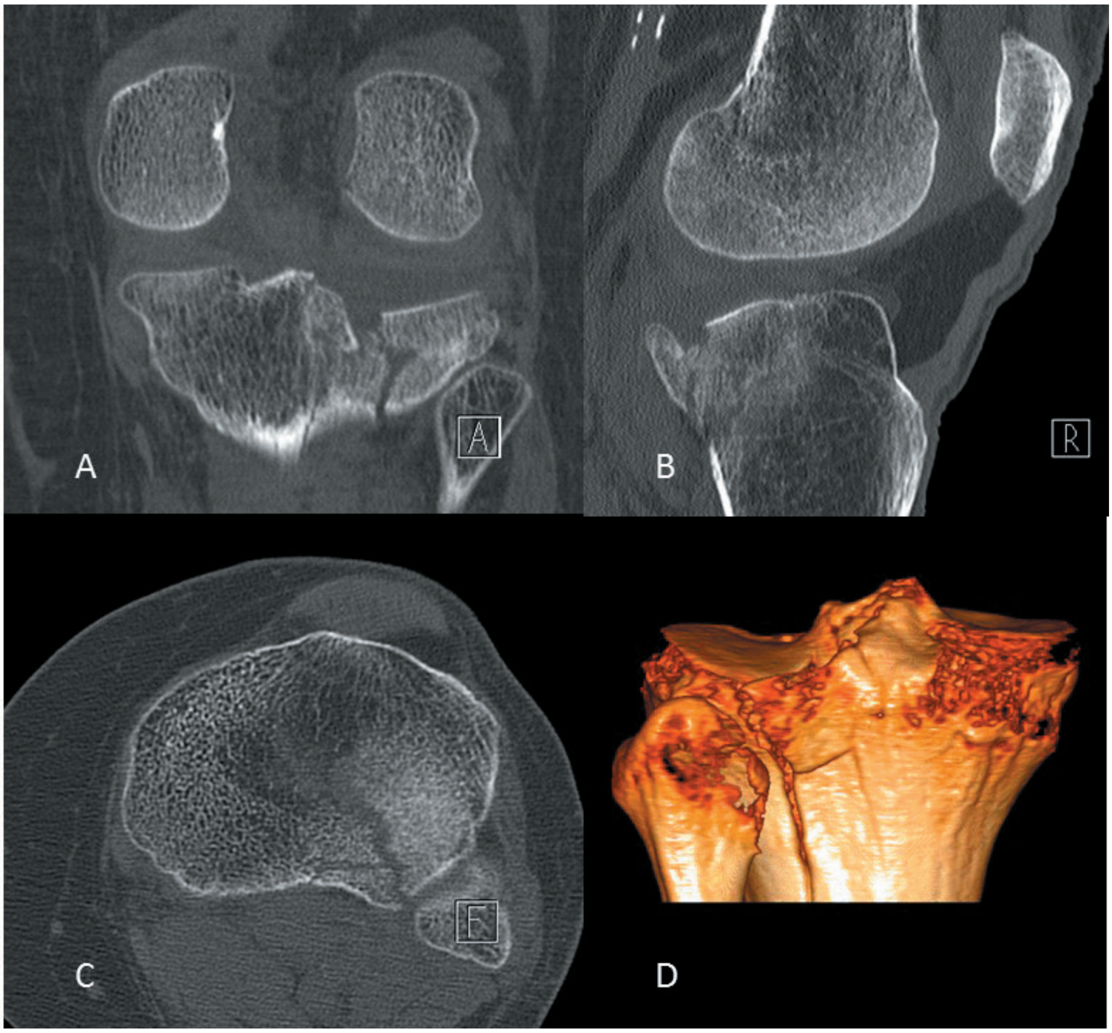

Figure 2. Illustrative case
Illustrative case of a 65 year old women, who sustained a tibial plateau fracture after a fall in a hole at road works. Coronal view (A), Sagittal view (B), Axial view (C) and 3D-CT reconstruction are presented. Preoperative imaging shows a lateral column fracture combined with posterior column fracture (posterolateral segment, OEC). The coronal and axial view show the fracture line oriented in the sagittal plane, which can be treated via lateral approach (A, C). Axial and sagittal view show a separate fracture component with fracture line in the coronal plane (B, C). 3D-CT reconstruction shows the posterior aspect of the proximal tibia with both the sagittal fracture line and the posterior fragment in view.

In this study we did not investigate the correlation between the increased operative indication and functional outcome. Therefore, no definite conclusions can be drawn towards future guiding of surgical planning and management of posterior tibial plateau fractures. An increase of operative indications could potentially harm patient outcome. Therefore, more research will be needed to verify optimal indication for posterior fixation of these fractures. Another weakness of this study was the limited number of experienced knee trauma surgeons involved, as only 5 observers were included. Therefore, the largest impact on the operative indication is based on the observers with the lowest intra-observer reliability.

Conclusion

The current findings indicate that utilization of 3D-CT images in preoperative planning might increase surgical intervention on posterior column tibial plateau fractures, especially in fractures involving the posterolateral column. To our knowledge, the current study is the first to assess the added value of 3D-reconstruction in rTCC classification and towards surgical decision making in posterior fractures. Further investigation is necessary with focus on specific fracture patterns and morphology towards guidance in surgical decision making.

Acknowledgements

We acknowledge Walter Coudyzer (Department of Radiology, University Hospitals Leuven, Leuven, Belgium) and all the observers who participated in the present study.

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CHAPTER 5

Poor sporting abilities after tibial plateau fractures involving the posterior column - How can we do better?

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Published in:

European Journal of Trauma and Emergency Surgery (2019)
doi: 10.1007/s00068-019-01220-3

Abstract

Purpose:

Tibial plateau fractures with involvement of the posterior column are an important prognostic factor towards poor functional outcome. We aimed to assess the sporting abilities postoperatively with special emphasis on type of sports and sport specific movements, as well as time needed to resume sports, restricting factors in sports engagement, and patient satisfaction. We aimed to provide prognostic information on return to sports.

Methods:

Demographic, clinical and radiological variables were retrospectively collected from 82 multicentric patients between 2014 and 2016. Prospectively, sporting abilities before and after surgery were determined using questionnaires at a mean follow-up of 33 months postoperatively.

Results:

Involvement in sports significantly decreased, with only 68.4% of patients resuming sports ($p<0.001$). The mean time needed to partially or fully resume sports was 6-9 and 9-12 months, respectively. The ability to resume at the pre-injury level of effort and performance were 22% and 12%, respectively. Restricting factors were pain (66%), fear of re-injury (37%), limited range of motion (26%), and instability (21%). The majority (59%) of patients were unsatisfied with their physical abilities. Significantly worse outcomes were observed in patients playing high impact sports, experiencing knee-pain during physical activity, suffering from extension/valgus or flexion/varus trauma.

Conclusions:

Tibial plateau fractures with involvement of the posterior column significantly hamper the patients' sporting abilities, leaving the majority of patients unsatisfied. Preoperative counseling about prognosis, setting realistic expectations, optimizing rehabilitation and pain management postoperatively, and advising low impact sports, might improve engagement in physical activities and emotional impact on patients.

Introduction

Tibial plateau fractures account for 1% of all fractures and are typically sustained by high-energy traumas [1]. The consequences of tibial plateau fractures can be far-reaching, especially for those who suffered from a more severe type, requiring extensive surgery [2-4]. Tibial plateau fractures with involvement of the posterior column have been identified as an important prognostic factor towards poor outcome [5].

Assessing functional outcome after a tibial plateau fracture, patients reported significantly lower scores on the sports and recreation subscales of the Knee injury and Osteoarthritis Outcome Score (KOOS)[3-5]. Since the majority of patients sustaining these injuries are relatively young and active, this can have devastating consequences for their leisure or competitive involvement in sports. Adequate physical activity is important among all ages, and its health benefits for both physical and emotional wellbeing have been well established [6-9]. While clinical and radiological outcomes of tibial plateau fractures are elaborately studied, there has been very little appreciation for the impact of these injuries on the patient's physical lifestyle, in particular their ability to participate in sports. In studies using validated functional outcome scores, return to sports is often only a secondary outcome measure. Therefore, detailed description of physical limitations is lacking.

The handful of studies that do elaborate on the sequelae after tibial plateau fractures with regard to return to sports seem to agree that the majority of patients are not able to return to their previous level of activity. For patients playing competitive sports this injury can be a career ender [10-12]. The complexity of the fracture and the age at the time of the injury seem to be an important prognostic factor for the final sporting abilities [11-12]. A recent study demonstrated a weak correlation between the physical abilities after these injuries and the range of knee motion and postoperative infection rates [11]. However, comprehensive information on return rates, detailing the type of sports and sport specific movements that are mostly affected by the injury, is not available. Moreover, insight into the time it takes to return to both training and full-level sports, and the emotional impact on the patients is lacking. And lastly, to our knowledge, no research has been performed into the causes of these physical limitations, which is crucial information for setting up early interventions and an adequate rehabilitation program.

Therefore, we aimed to provide comprehensive information on these four aspects, as well as provide prognostic information on return to sports after these fractures.

Methods

Patients

This multicenter study has been conducted throughout three level 1 trauma centers. After identification of all consecutive patients operatively treated for a tibial plateau fracture between 2014 and 2016, only those with (1) involvement of the posterior column according to the revised three-column concept (rTCC) classification [13] and (2) a closed epiphysis were included. Exclusion criteria were non-articular fractures, bilateral fractures, patients with accompanying injuries in the same extremity, pathologic fractures, deceased patients, and patients missing CT-scan preoperatively. According to these criteria, a total of 82 patients were available. Informed consent was obtained from all individual participants included in the study, comprising a total of 51 patients. The study protocol was approved by all local medical research ethics committees (Ethische Commissie Onderzoek UZ/KU Leuven, Commissie Medische Ethiek and Medische Ethische Toetsings Commissie Erasmus MC) and the rights of the subjects were protected.

Demographics and clinical characteristics

A total of 26 demographic, clinical and radiological variables were retrieved from the hospitals electronic medical file databases. The demographic characteristics recorded were age, gender, ASA-score, BMI, smoking status, medication status, diabetes status and other cardiovascular risk factors. Trauma and treatment variables that were recorded included trauma mechanism, open vs. closed fractures, time to surgery, external fixation use (either as definite treatment or in staged surgery) and period of non-full-weight bearing. All fractures were classified using the rTCC approach, in order to depict posterior column fractures and track the total number of fractured columns [13]. Recorded complications were categorized as fracture related infection, non-union and reintervention. Postoperatively, coronal alignment, sagittal alignment, condylar width and articular congruence were measured.

Outcome measures

Prospectively, sporting abilities before and after surgery were determined using questionnaires. The questionnaires included the standardized and validated versions of the KOOS questionnaire for the Dutch [14] or French [15] language, as well as 23 sport-related questions. These sport-related questions assessed sporting frequency and level in the year before the injury and at the time of the survey. In addition, questions were included regarding the specific sports played, the ability to perform specific movements according to the Activity Rating Scale (ARS) for disorders of the knee [16-18], the perceived limitations in effort and performance, the time needed to resume physical activities, the perceived reasons for limitations, and the satisfaction with ones sporting abilities. Concerning the ARS, ‘running’ is interpreted as running while playing a sport or jogging, ‘cutting’ is interpreted as changing directions while running, 'decelerating' is interpreted as coming to a quick stop while running, and 'pivoting' is interpreted as turning your body with your foot planted while playing a sport. To compare our KOOS scores with an average adult population, the population-based cohort of Paradowski et al. was used as a reference [19].

Statistical analysis

Statistical analysis was performed using IBM SPSS 25.0. Normal distribution was tested in continuous data using a Shapiro-Wilk test. Continuous data are shown as mean with SD (if parametric) or as median with P25-P75 (if nonparametric). Normally distributed data were compared using t-tests, and for nonparametric variables a Mann-Whitney U test was used. Chi-square statistics were used to compare nominal variables. Nominal variables that did not comply with the assumptions for a chi-square test were compared using a fisher's exact test. Predictive analysis was performed using multiple logistic regression. A significance level of <0.05 was accepted for all tests.

Results

Descriptives

A total of 51 patients were included in this study. The average age of the cohort was 51 (± 14) years, comprising a total of 17 men and 34 women, with a mean follow-up time of 33 months and a minimal follow-up of 14 months. All demographic, clinical and radiographic variables are displayed in Table 1. These were compared with the variables of the patients that did not return a written informed consent. Only the BMI differed significantly between those that did and those that didn't return a written informed consent, 26.5 ± 4.8 and 24.6 ± 3.9 (p=0.036), respectively. The KOOS scores for the study population are displayed in Figure 1, and compared with reference values from an average adult population [19], and values from an average population of tibial plateau fractures treated with ORIF [3].

Table 1: Demographic and clinical characteristics.

	Mean (± SD), Median (P25-P75) or n (%)
Age (years)	51 (±13.7)
Gender	
Female	34 (67%)
ASA	
1	19 (37%)
2	29 (57%)
3	3 (6%)
BMI (kg/m^2)	26.2 (23.5-28.2)
Smoker	11 (22%)
Taking medication	13 (25%)
Diabetes	6 (12%)
Other CVRF	12 (24%)
Trauma mechanism	
Extension/Valgus	18 (35%)
Extension/Varus	6 (12%)
Flexion/Valgus	15 (29%)
Flexion/Varus	12 (24%)
Open fracture	
Yes	5 (10%)
rTCC	
1 column	3 (6%)
2 columns	21 (41%)
3 columns	27 (53%)
Lateral column	46 (90%)
Medial column	29 (57%)
Treatment parameters	
Delayed staged surgery	9 (18%)
Time to surgery (days)	4 (2-8)
Period of non-full-weight bearing (days)	12 (8-12)
Complications	
Any complication	19 (37%)
Infection	10 (20%)
Nonunion	2 (4%)
Other complication	7 (13%)
Re-intervention	24 (47%)
Implant removal	18 (35%)
Revision	9 (18%)
Radiology	
Radiologic failure	33 (65%)
Coronal malalignment (MPTA 87+/-5)	7 (14%)
Sagittal malalignment (PPTA 9+/-5)	7 (14%)
Condylar width (<0mm, >5mm)	7 (14%)
Articular incongruence (>2mm)	23 (45%)

Other complications are: deep venous thrombosis, neuralgia, soft tissue swelling with blisters, and dehiscence.

Abbreviations: ASA, American Society of Anesthesiologists; BMI, body mass index; CVRF, cardiovascular risk factors; rTCC, revised three-column classification; MPTA, Medial Proximal Tibia Angle; PPTA, posterior proximal tibial angle.

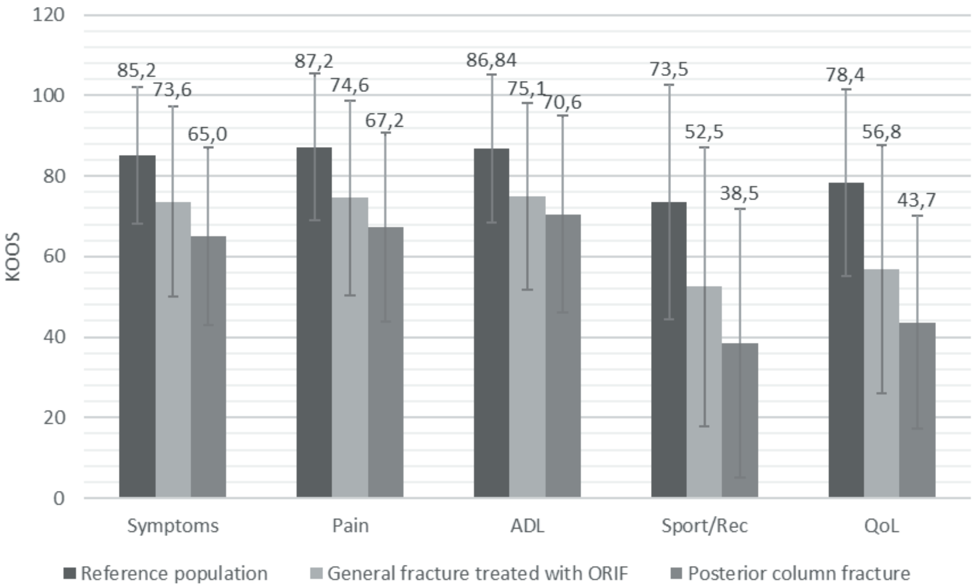

Figure 1:
The KOOS subscales, comparing a reference population [19], and an average population of tibial plateau fractures treated with ORIF (14), with our cohort of 51 patients who suffered an operatively treated tibial plateau fracture involving the posterior column. Abbreviations: KOOS, Knee injury and Osteoarthritis Outcome Score; ADL, activities of daily living; Sport/Rec, function in sport and recreation; QoL, knee related quality of life.

Sports and recreational activities

A total of 29 patients (57%) were engaged in sports throughout the year before the injury, either on recreational, competitive or professional level. Thirty-one percent of patients were active 2-3 times a week, 16% 4-5 times a week and 10% more than 5 times a week. Only 3 patients played on a competitive or professional level before the injury. According to the ARS, several specific movements stressing the knee were further analyzed. During their activities 44% of the physically active patients ran during their physical activities, 44% performed cutting movements and quick directional changes, 28% performed quick decelerations and 50% performed rotational movements pivoting on their knees.

At the end of the follow-up, only 39% of the patients were engaged in sports, indicating that that only 2 out of 3 patients playing sports before the injury are still able to do so after, illustrating a significant decrease ($p<0.001$). As much as 55% of all patients reduced their frequency of physical activity. The mean time needed to partially resume pre-injury activities was 6-9 months. Sixteen percent of the responding patients were not able to resume their activities. For those able to fully resume, the mean time needed to do so was 9-12 months. However, as much as 41% did not fully return to their pre-injury sports.

The decrease in knee stressing movements performed during physical activity was more pronounced than the decrease in patients engaged in sports. Only 16% still ran during their physical activities after the injury, 19% of the patients still performed cutting movements and quick directional changes, 13% still performed quick decelerations and 25% still performed rotational movements pivoting on their knee.

Self-reported ability to resume a sport at the pre-injury level of effort and performance was poor. 78% of patients reported not being able to fully engage and as much as 88% reported they were not able to reach the same level of performance.

Importance of type of sport

Forty-seven percent of the patients engaged in physical activity before their injury played at least one high impact sport (tennis, squash, horseback riding, snowboarding, skiing, waterskiing, running or dancing). Thirty-four percent of the patients engaged in physical activity were only engaged in low impact sports (cycling, swimming or hiking). Nineteen percent did not disclose their type of physical activity.

Patients who played only low impact sports were more likely to return to it than those engaged in high impact sports (9 out of 11 (82.8%) versus 6 out of 15 (40%); p=0.043) (Figure 2). The odds of being able to return to sports were 6.8 times higher. Of all patients, only 2 increased their frequency of activities. Both concerned elderly people, aged 60 and 75 years. Nevertheless, they did not disclose their type of physical activity and considering their age, it is most likely they participated in lower impact sports. Three patients who were not engaged in physical activity before their injury, stated to have picked up sports afterwards. All three picked up only low impact sports.

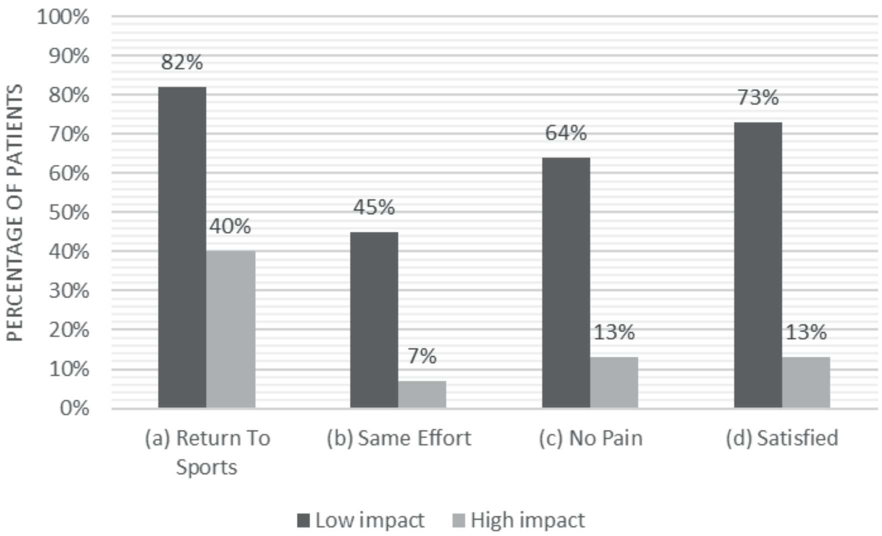

Figure 2:
Importance of the type of sports, comparison between high- and low-impact sports with (a) the percentage of patients able to return to sports, (b) the percentage of patients able to resume a sport at the pre-injury level of effort, (c) the percentage of patients not experiencing pain in the knee during physical activity, and (d) the percentage of patients satisfied with the physical abilities.

Being engaged in low impact sports was associated with a sooner partial, as well as full resumption of pre-injury sports, compared with high impact sports. At 6-9 months respectively 9-12 months after the injury, the mean time needed to partially respectively fully resume sport activities, patients playing low impact sports succeeded 7.0 times respectively 7.2 times more often to resume their pre-injury sports than those patients playing high impact sports (6 out of 11 (54.5%) versus 3 out of 15 (20%); p=0.031 resp. 7 out of 11 (63.6%) versus 3 out of 15 (20%); p=0.043 respectively).

Finally, a better outcome for self-reported ability to resume a sport at the pre-injury level of effort was associated with lower impact sports as well (5 out of 11 (45.5%) versus 1 out of 15 (6.7%); p=0.040) (Figure 2). Although a low percentage of patients were able to engage with the same level of effort, patients playing low impact sports were 11.7 times more likely to be able to do so than patients playing high impact sports. Self-reported ability to resume a sport at the pre-injury level of performance is not associated with the impact of the sports played (2 out of 11 (18.2%) versus 1 out of 15 (6.7%); p=0.382). Both patients engaged in low and high impact sports were very likely to not be able to do so.

Perceived causes for limitations in sport engagement

All patients, regardless of their ability to return to sports, were questioned about knee and non-knee related factors they felt were restricting them from fully engaging into physical activities. The most important knee related factors were pain in the knee, fear of either hurting or re-injuring the knee, limitations in the range of motion and instability of the knee (Figure 3). 16% of the patients experienced non-knee related factors. Patients suffering pain during sports were 11 times more likely to not return to sports than those who did not experience pain during physical activity (11 out of 21 (52.4%) versus 1 out of 11 (9.1%); p=0.035). No significant association between the other factors, nor the amount of factors, and the ability to return to sports was found.

Patients engaged in higher impact sports were 11.4 times more likely to suffer from pain related knee problems during physical activity than patients only engaged in low impact sports (13 out of 15 (86.7%) versus 4 out of 11 (36.4%); p=0.014) (Figure 2). The occurrence of the other knee and non-knee related limitations were not significantly associated with the impact of the sports played.

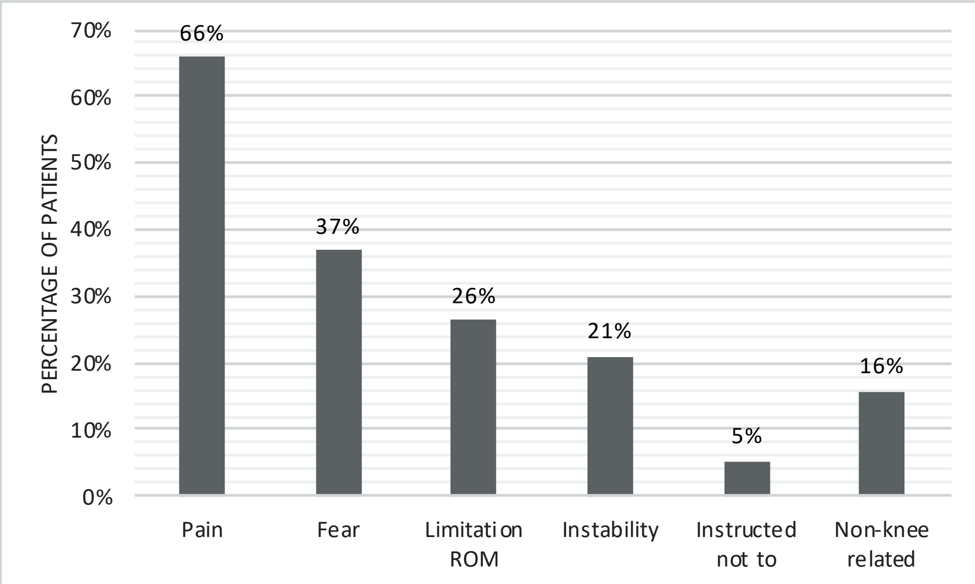

Figure 3:
Restricting factors in sports engagement. Abbreviations: ROM, range of motion.

Satisfaction

Thirty-one percent of the patients were very disappointed, 28% were slightly disappointed, 19% were satisfied, and 22% were very satisfied with the outcome. Patients were more likely to be unsatisfied with their physical abilities when not being able to resume sports (11 out of 12 (91.7%) compared to 8 out of 20 (40%); $p=0.014$) or play at pre-injury level of effort (19 out of 25 (76.0%) compared to 0 out of 7; $p<0.001$) or performance (19 out of 28 (67.9%) compared to 0 out of 4; $p<0.001$). Experiencing pain in the knee during physical activity, or experiencing 2 or more of above-mentioned causes for limitations, were also associated with a lower satisfaction rate (19 out of 21 (90.5%) compared to 0 out of 11. $p<0.001$ resp. 15 out of 17 (88.2%) compared to 4 out of 14 (28.6%); $p=0.002$). Playing a high impact sport was again associated with worse outcomes, as the odds of being unsatisfied for patients playing a high impact sport were 17.2 times higher compared to patients playing a low impact sport (13 out of 15 (86.7%) compared to 3 out of 11 (27.3%); $p=0.005$) (Figure 2).

Factors predicting sporting abilities

Bivariate analysis on ability to return to sports and the reduction in frequency of physical activity after the injury was performed in regard to all demographic, clinical and radiological parameters. All results are presented in Table 2. No predicting factors for return to sports could be established, since all bivariate significant results lost their significant p-value when considered in a multivariable model. For frequency of physical activity, trauma mechanism proved to be a predicting factor. A flexion/valgus trauma was associated with better outcomes than an extension/valgus trauma or a flexion/varus trauma (9 out of 10 (90%) versus 3 out of 10 (30%); $p=0.003$ resp. 9 out of 10 (90%) versus 5 out of 9 (55.6%); $p=0.023$).

Table 2: Correlation Analysis.

	Return to sports	Reduction in frequency of physical activity
Demographics		
Age (years)	0.087	0.200
Gender	0.999	0.999
ASA score	0.518	0.427
BMI	0.392	0.291
Smoking	0.999	0.484
Medication	0.372	0.394
Diabetes	0.516	0.484
Other CVRF	0.626	0.999
Trauma and Fracture		
Trauma mechanism	0.010*	<0.001*
Open fracture	0.620	0.999
Number of columns according to rTCC	0.458	0.225
Involvement lateral column	0.516	0.484
Involvement medial column	0.713	0.473
Treatment parameters		
Delayed staged surgery	0.620	0.101
Time to surgery (days)	0.243	0.223
Period of non-full-weight bearing (days)	0.390	0.183
Any complication	0.713	0.999
Infection	0.999	0.999
Nonunion	0.516	0.484
Re-intervention rate	0.726	0.479
Implant removal	0.288	0.716
Revision	0.683	0.394
Radiological outcome		
Radiological failure	0.724	0.716
Coronal malalignment (MPTA 87+/-5)	0.999	0.999
Sagittal malalignment (PPTA 9+/-5)	0.629	0.333
Condylar width (<0mm, >5mm)	0.338	0.999
Articular incongruence (>2mm)	0.726	0.479

Significant data are indicated with an *.
Abbreviations: ASA, American Society of Anesthesiologists; BMI, body mass index; CVRF, cardiovascular risk factors; rTCC, revised three-column classification; MPTA, Medial Proximal Tibia Angle; PPTA, posterior proximal tibial angle.

Discussion

While clinical and radiological outcomes of tibial plateau fractures have elaborately been studied, there has been very little appreciation for the impact of tibial plateau fractures on the patient's physical abilities. Therefore, the purpose of this study was to provide a more comprehensive description of the sequelae regarding sporting abilities after tibial plateau fractures involving the posterior column along with providing prognostic information on return to sports.

Our results indicate that tibial plateau fractures with involvement of the posterior column indeed significantly hamper the patients' sporting abilities, leaving the majority of patients unsatisfied. Despite moderate results with regard to the other KOOS subscales, patients scored indeed significantly lower on the sport and recreation subscale. Patients were likely to reduce their involvement in physical activity, scored significantly lower on the ARS, and a vast majority was not able to resume their sports at pre-injury level of effort nor performance. Worse outcome scores were observed in patients playing high impact sports and in patients experiencing pain in the knee during physical activity. Trauma mechanisms that proved to be associated with a reduction in frequency of physical activity were extension/valgus trauma and flexion/varus trauma.

Previously, Kraus et al. and Loibl et al. [10,12] reported 82% and 88% return to sport rates in a general cohort of tibial plateau fractures. We observed a return rate of only 68% after a mean follow-up of 33 months. Disparities in fracture types and treatment techniques are important to consider here, since more severe fractures are associated with poor outcome [10,12]. We included tibial plateau fractures with involvement of the posterior column, since posterior column fractures (and associated malalignment) has been identified as an important prognostic factor towards the poor outcome [5]. Kugelman et al. [11] reported even a lower return to sports rate of 52.4%. However, the mean follow-up in their study was only 15 months. Kraus et al. [10] demonstrated a significant increase in return to sports at a follow-up of 52.8 months after surgery, compared to the physical activity 1 year postoperatively ($p<0.001$). Furthermore, in our study, to our knowledge the first to report on the time needed to partially and fully return to sports, the mean time needed was 6-9 months and 9-12 months, respectively. This affirms the extensive rehabilitation needed for these fractures, with resumption of physical activity often outdating the standard follow-up for these injuries. Therefore, return to sports measured by Kugelman et al., and to a lesser extent in this study, is likely to further increase over time. Though these recent studies all demonstrated an overall good clinical result and rate of return to sports, patients were, in line with our results, very likely to give up ambitious sports activities [10-12]. In our cohort, 78% of patients reported they were not able to resume sport at the pre-injury level of effort and as much as 88% reported they were not able to reach the same level of performance.

Kraus et al.[10] were the first to point out a shift away from high towards lower impact activities. However, further analysis was lacking. We observed that patients playing high impact sports proved a high-risk group, being almost 7 times more likely to not return to sports, having a longer rehabilitation period, and being 11.7 times less likely to play at the pre-injury level of effort, 11.4 times more likely to suffer from pain related knee problems during physical activity and 17.2 times more likely to be unsatisfied with their surgical results. Counseling these patients about their post-injury prognosis, providing early interventions focusing on pain management and advising lower impact sports might therefore be beneficial for the functional outcome and the emotional impact on the patients. Moreover, it is known that the knee is a heavily stressed joint. Kuster et al.[20] described the peak loads in the knee joint being 1.2 times the body weight during cycling and 3 to 4 times the body weight during walking. Higher impact sports on the contrary showed much higher peak loads of 5 to 6 times the body weight during squatting, up to 10 times during downhill skiing and up to as much as 14 times during jogging and running [20]. Considering the degenerative articular changes and the fact that higher stresses might cause more pain, minimizing the peak loads on the knee during physical activity can be considered beneficial, and an extra argument to counsel the patients towards lower impact sports.

Crucial for setting up early interventions, is getting insight into why people are not able to resume their physical activities. To our knowledge, we are the first to investigate the perceived causes for these limitations. A range of reasons were pointed out, such as pain in the knee, fear of re-injury, limitations in range of motion, and instability of the knee. All of these are potentially adjustable, therefore important to focus on during rehabilitation. However, only pain in the knee during physical activities was significantly associated with the inability to return to sports. Patients experiencing pain during sports were as much as 11 times more likely to be unable to return to sports compared to patients without any pain, denoting adequate pain management an important issue to be addressed by the physician.

A wide variety of demographic, clinical and radiological variables were investigated for their predicting ability on return to sport. Loibl et al.[12], as well as Kugelman et al.[11], found that a higher age at the time of the injury was associated with a lower return to sports, arguing that an advancing age might be related to a reduced physiological reserve and healing potential. However, neither our study, nor Kraus et al.[10], found a significant difference between age groups. Furthermore, we found no other demographic variables that had a predicting ability on whether or not the patient was likely to return to sports. Considering the clinical variables, there is some evidence for a better outcome with the use of an external fixator combined with percutaneous large-fragment lag screws as definite treatment, compared to open reduction and internal fixation [21]. Return to sports was higher at 6 months (p=0.031) and 12 months (p=0.024) after the injury when external fixation was used to treat the fracture [21]. The authors argue that less soft tissue damage might be responsible for the better outcome. This difference, however, disappeared at 24 months after the fracture (p=0.128), and other long-term follow up studies could not conclude a significant difference [22]. This is in line with our results. Notwithstanding the fact that soft tissue injury was not scored in this retrospective study, delayed-staged surgery using a temporary external fixation device was performed in 9 cases. Moreover, delayed-staged surgery was not associated with less return to sports. The only clinical variable associated with reduction in frequency of physical activity was the trauma mechanism. Extension/valgus trauma and flexion/varus trauma were associated with worse outcome compared to a flexion/valgus trauma. Regarding the radiological variables finally, the importance of preventing postoperative knee malalignment is widely accepted [23-25].

However, we found no significant influence on the ability to return to sports.

The present study has a number of limitations. A first limitation is the retrospective design. As patients were asked about their physical activities in the year before the injury, raising the possibility of a recall bias since this, on average, dates back several years. Also, because the patients were several years older at the time of the follow-up, there might have been a decrease in engagement in physical activity independent of the injury, as patients tend to become less active with increasing age. Furthermore, 38% of patients did not return the questionnaire, which might cause a selection bias. However, apart from BMI, there were no other statistically significant differences in any of the other demographic, clinical or radiographic variables between responders and non-responders. Although this type of fractures was only treated by experienced orthopedic trauma surgeons in three level 1 trauma centers, there is a possible treatment bias involved. Finally, a subgroup analysis for the level of sports participation could not be performed, as only 3 patients played on a competitive or professional level. The strengths of the present study are the unique cohort, the detailed description of physical activities, the new prognostic insights and a long follow-up period.

CONCLUSION

In conclusion, tibial plateau fractures with involvement of the posterior column significantly hamper the patients' sporting abilities, leaving the majority of patients unsatisfied and unable to play at the pre-injury level of effort and performance. Patients, especially high risk groups such as patients playing high impact sports, should be counseled appropriate about the prognosis, setting realistic expectations. Moreover, early interventions and adequate rehabilitation programs focusing on pain management should be provided. Advising lower impact sports might also be beneficial for improving the engagement in physical activities and the emotional impact on the patients.

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CHAPTER 6

Trauma mechanism and patient reported outcome in tibial plateau fractures with posterior involvement

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Published in:

The Knee (2021)
doi: 10.1016/j.knee.2021.03.011

Abstract

Introduction:
Posterior tibial plateau fractures (PTPF) have a high impact on functional outcome and the optimal treatment strategy is not well established. The goal of this study was to assess the relationship between trauma mechanism, fracture morphology and functional outcome in a large multicenter cohort and define possible strategies to improve the outcome.

Methods:
An international retrospective cohort study was conducted in five level-1 trauma centers. All consecutive operatively treated PTPF were evaluated. Preoperative imaging was reviewed to determine the trauma mechanism. Patient reported outcome was scored using the Knee injury and Osteoarthritis Outcome Score (KOOS).

Results:
A total of 145 tibial plateau fractures with posterior involvement were selected with a median follow-up of 32.2 months (IQR 24.1 – 43.2). Nine patients (6%) sustained an isolated posterior fracture. Seventy-two patients (49%) sustained a two-column fracture and three-column fractures were diagnosed in 64 (44%) patients. Varus trauma was associated with poorer outcome on the 'symptoms' (p=0.004) and 'pain' subscales (p=0.039). Delayed-staged surgery was associated with worse outcome scores for all subscales except 'pain'. In total, 27 patients (18%) were treated with posterior plate osteosynthesis without any significant difference in outcome.

Conclusions:
Fracture morphology, varus trauma mechanism and delayed-staged surgery (i.e. extensive soft-tissue injury) were identified as important prognostic factors on postoperative outcome in PTPF. In order to assess possible improvement of outcome, future studies with routine preoperative MRI to assess associated ligamentous injury in tibial plateau fractures (especially for varus trauma) are needed.

Introduction

Posterior tibial plateau fractures (PTPF) account for 28 – 70% of all tibial plateau fractures [1-4]. PTPF and associated sagittal malalignment are important negative prognostic factors with severe impact on functional outcome [3-5]. However, the decision whether or not to perform a posterior surgical approach for open reduction and internal fixation (ORIF) of a PTPF is mainly based on individual morphology of the bone injury [1, 3, 7]. Although the three-column concept has been proven to be very helpful for the treatment of multiple column fractures and certainly helps to depict PTPF (3, 7), the patient reported outcome scores of PTPF are not necessary better when patients are treated according to the column concept (i.e. successive osteosynthesis of each column fracture) [7].

Fracture morphology is an important factor in the choice whether or not to treat PTPF [7-9]. Subsequently, the implementation of trauma mechanism-based fracture morphology seems to be an important link in order to adopt the column concept and guide surgical decision making with regard to PTPF fixation. Recently, Xie *et al.* clearly demonstrated six three-dimensional fracture patterns based on injury mechanism. The diagonal nature of these patterns are based on elemental fracture mechanics where a 'compression' side has an associated opposite 'tension' side. These models could help to predict concomitant soft-tissue injuries (i.e. ligamentous and meniscal injury) and forecast clinical outcome [10].

Reported incidence of ligamentous and meniscal injury in tibial plateau fractures using preoperative Magnetic Resonance Imaging (MRI) is rather high, ranging from 47% to 99% [11]. Nevertheless, the diagonal injury pattern of tibial plateau fractures and associated ligamentous injury is not always clear. Particularly with regard to PTPF, considering the trauma mechanism in the column concept to adequately assess associated ligamentous injury, could improve the outcome of these fractures.

The primary aim of this study was to assess trauma mechanism types in PTPF and correlate these with patient reported outcome in a large cohort of PTPF. This could further help to select those patients who may benefit from preoperative MRI investigation, in order to better guide surgical decision making on fracture and soft-tissue injury management, and improve the outcome. The secondary aim was to review the outcome of current posterior plate osteosynthesis in PTPF.

Patients and methods

Patients

A multicenter retrospective cohort study was conducted in five level 1 trauma centers (*names blinded for revision*). All consecutive operatively treated patients sustaining a tibial plateau fracture between January 2014 and December 2016 were evaluated for eligibility. Preoperative CT imaging was mandatory to classify all fractures according to the revised three-column classification [6]. All tibial plateau fractures involving at least a posterior column fracture (Figure 1, yellow marked zone) were selected. Exclusion criteria were: age < 18 years, deceased patients, no preoperative CT imaging available, bilateral fractures, pathological fractures, refractures and language incompatibility with the questionnaires. This study was completed in compliance with national legislation and the ethical guidelines of all separate institutions.

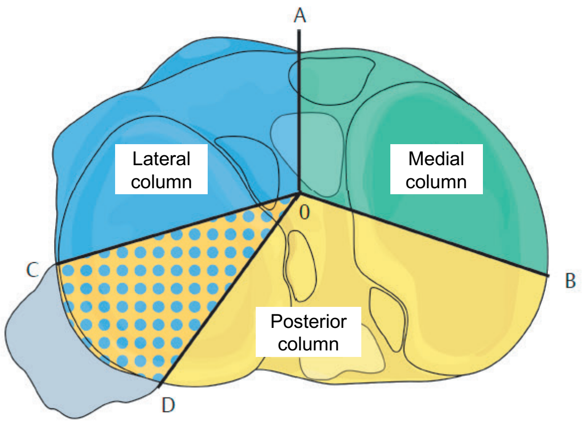

Figure 1: The revised three-column classification.
The revised three-column classification (rTCC) according to Hoekstra et al. [6], depicting the posterior column (0BC), which should be treated via a posterior approach. Lateral column (0AC) fractures that extend into the posterolateral corner (dotted area) are defined as extended lateral column fractures (0AD).

Study variables

All patient data was retrieved from the electronic medical file databases of the respective institutions. Relevant demographic and clinical variables were assessed. Cardiovascular risk factors include current cardiovascular diseases (e.g., cerebrovascular accident, myocardial infarction, peripheral artery disease), diabetes, obesity, smoking, dyslipidemia, hypercholesterolemia, hypertension, alcohol use, and rheumatoid arthritis). Medication associated with impaired wound healing (e.g., corticosteroids, adrenergic beta-agonists, and chemotherapeutic agents) was recorded. External fixation included all fractures treated by using an external fixator in a staged surgical protocol. No patients were treated with an external fixation as definite treatment. Complications were categorized as fracture-related infection, nonunion and other tibia related complications (i.e., wound related problems, implant related complaints, compartment syndrome, excessive pain, quadriceps muscle atrophy, deep vein thrombosis and neuropraxia). Fracture-related infection was defined according to the recent consensus definition [12]. Furthermore, nonunion was assessed by using follow-up radiographs and defined according to the US Food and Drug Administration guidelines as a not completely healed fracture within 9 months of injury and without progression toward healing over the past three consecutive months. Postoperative X-rays and CT-imaging were evaluated to assess the quality of the reduction. Medial proximal tibial angle (MPTA, coronal alignment, 87±5°), posterior proximal tibial angle (PPTA, sagittal alignment, 9±5°) and condylar width (0-5 mm, inclusive) were calculated (Figure 2). Furthermore, postoperative reduction was assessed and marked as failed if the articular congruence (gap and/or step) exceeded 2mm. The reintervention rate was defined as either implant removal, revision or total knee arthroplasty. Revision was defined as any intervention for loss of reduction, hardware failure or intra-articular hardware penetration.

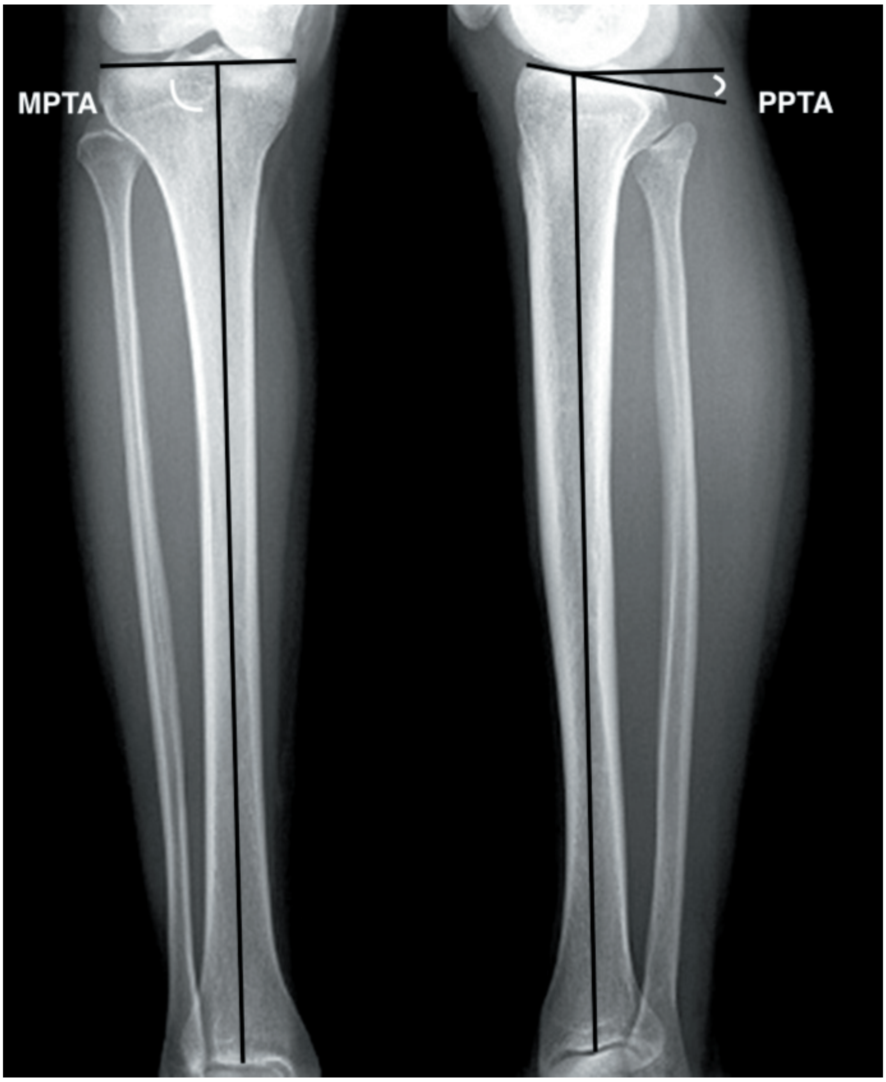

Figure 2: Measurement of MPTA and PPTA.
Measurement of MPTA and PPTA depicted on antero-posterior and lateral view, respectively.

Trauma mechanism

Preoperative X-rays and CT images were retrospectively reviewed to determine the trauma mechanism according to the updated Three-Column Concept. Varus trauma was defined as a decrease of MPTA on antero-posterior X-rays and coronal CT-imaging. Valgus trauma was defined as an increase of MPTA on antero-posterior X-rays and coronal CT-imaging. Extension trauma was defined as a decrease of PPTA on lateral X-rays and sagittal CT-imaging. Flexion trauma was defined as an increase of PPTA on lateral X-rays and sagittal CT-imaging. Furthermore, zones of greater comminution were taken into account in deciding on definitive trauma mechanism[3, 10]. Case examples are shown in Figure 3.

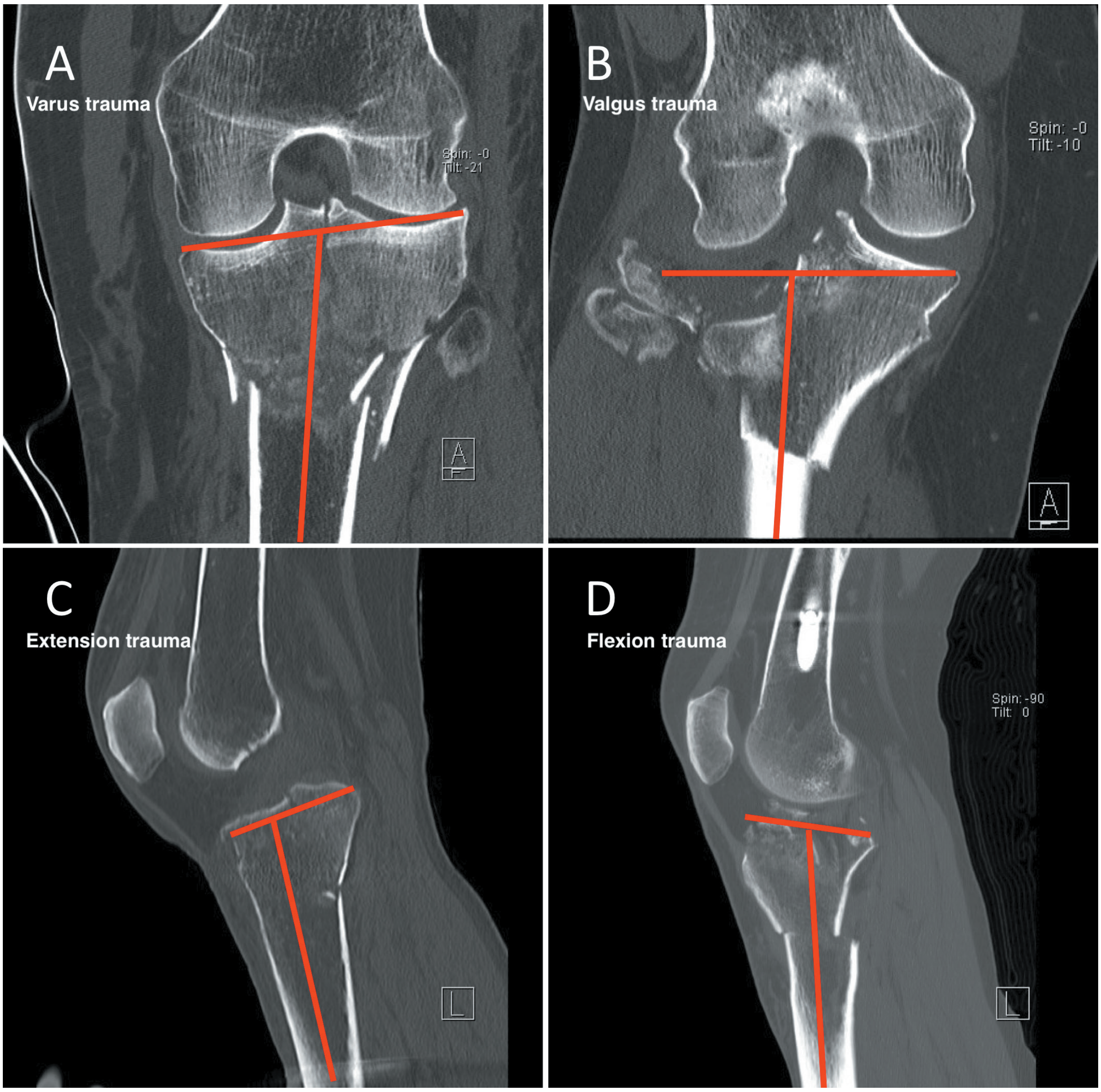

Figure 3: Radiological determination of trauma mechanism.
Varus or valgus trauma is determined by reviewing the respective decrease or increase of MPTA on antero-posterior X-rays and coronal CT-imaging (A, B). Extension and flexion trauma were determined by reviewing the respective decrease or increase of PPTA on lateral X-rays and sagittal CT-imaging (C, D).

Outcome measures

All selected patients received the standardized Knee injury and Osteoarthritis Outcome Score (KOOS) questionnaire to investigate functional outcome and general health status [13]. Patients were contacted by telephone if no response was obtained after four weeks. The KOOS questionnaire is validated for the Dutch, French and German language and consists of five subscales; symptoms, pain, activities of daily living (ADL), function in sport and recreation and knee related quality of life. Each subscale is presented as a normalized score (100 indicating no symptoms, 0 indicating extremely severe symptoms).

Statistical analysis

Statistical evaluation of all data was performed using IBM SPSS 25.0 (SPSS Inc. Chicago, IL). Nominal variables were compared using Chi-Square statistics (Fisher's Exact test) and nonparametric variables using the Mann-Whitney U test. For correlation testing the Pearson correlation test was used for continuous variables and the Spearman correlation test for nominal variables. A significance level of <0.05 was accepted for all tests. A multivariate analysis was conducted on all significant variables using a linear logistic regression analysis with a stepwise approach.

Results

Patient cohort

After exclusion, a total of 145 patients with a posterior tibial plateau fracture were included with a minimum of 14 months and a median of 32.2 months (IQR 24.1 – 43.2) of follow-up. A total of 92 patients (63%) responded to the questionnaires. Responders were compared to non-responders with regard to all demographic and treatment related variables. Non-responders were likely to have longer follow-up (38.9 months (IQR 26.4 – 50.5) versus 31.8 months (IQR 23.4 – 41.2), p=0.020) and have more cardiovascular risk factors (37.7% versus 19.6%, p=0.030). Descriptives are presented in Table 1. Open fractures were classified according to the Gustilo-Anderson classification, with 6 type I fractures, 5 type II fractures and 1 type IIIa fracture. Other complications were present in 24 (16%) patients. These included, 6 patients with wound dehiscence, 6 implant related complaints, 4 cases of compartment syndrome, 1 case with excessive clinical pain, 2 cases with deep venous thrombosis, and 5 cases with neurapraxia.

Table 1: Descriptives (n = 145).

Age (years)	50.8 (39.7 – 61.0)
Gender	
Male	53 (36.6%)
Female	92 (63.4%)
ASA-score	
1	64 (44.1%)
2	67 (46.2%)
3	14 (9.7%)
CVRF	
BMI (kg/m²)	25.1 (22.3 – 27.7)
Smoking	34 (23.4%)
Medication	32 (22.1%)
DM	10 (6.9%)
Other CVRF	38 (26.2%)
Side	
Left	85 (58.6%)
Right	60 (41.4%)
Open fracture	12 (8.3%)
External fixation	27 (18.6%)
Delayed(-staged) surgery	
Direct (<24 hrs)	37 (25.1%)
Delayed (>24hrs)	107 (73.8%)
Time to surgery (days)	4 (1 – 8.8)
Complication rate	
FRI	21 (14.5%)
Nonunion	4 (2.8%)
Other complications	24 (16.6%)
Reintervention rate	60 (41.4%)
Implant removal	38 (26.2%)
Revision	20 (13.8%)
TKA	5 (3.4%)

Continuous parameters are expressed as median values with their respective interquartile range. Categorical variables are expressed as numbers and percentages of the total number of included patients (n=145).
Abbreviations: ASA, American Society of Anesthesiologists; CVRF, cardiovascular risk factors; BMI, body mass index; DM, diabetes mellitus; FRI, fracture related infection; TKA, total knee arthroplasty.

Fracture classification and trauma mechanism

Classification according to the revised three-column classification resulted in 9 (6%) isolated posterior column fractures. Seventy-two patients (49%) sustained a two-column fracture, with 55 (37%) combined posterior and lateral column fractures and 17 (11%) combined posterior and medial column fractures. Three-column fractures were diagnosed in 64 (44%) patients, 27 patients sustaining a varus trauma, compared to 37 patients with valgus trauma. Considering all patients, valgus trauma was noted in 99 (68%) patients, either with extension or flexion in 42 (29%) and 57 (39) patients respectively. In 46 (31%) patients varus trauma was noted, combined with extension and flexion in 16 (11%) and 30 (20%) patients, respectively. Overall, varus trauma was associated with higher number of columns fractured (p=0.011).

Outcome

Median KOOS scores for the five subscales are 60.7 (IQR 35.7 – 82.1) for 'symptoms', 63.9 (IQR 47.2 – 83.3) for 'pain', 69.1 (IQR 51.5 – 89.7) for 'activities of daily life', 30.0 (IQR 10.0 – 62.5) for 'sports and recreation' and 37.5 (IQR 25.0 – 56.3) for 'knee related quality of life'. With 17 (18%) patients reporting frequent or continuous swelling of the knee. Inability to perform full extension and flexion was reported in 31 (33%) and 28 (30%) patients, respectively. Patients reported suffering from pain in the affected knee on a daily basis in 31 cases (33%) and continuous pain in 6 cases (6%). Median KOOS scores are displayed in Figure 4 in comparison to a population-based reference cohort and a cohort operatively treated tibial plateau fractures [7, 14]. Twenty-seven patients (18.6%) were treated with initial external fixation before definitive surgery, with 2-column and 3-column fractures in 8 and 19 patients respectively.

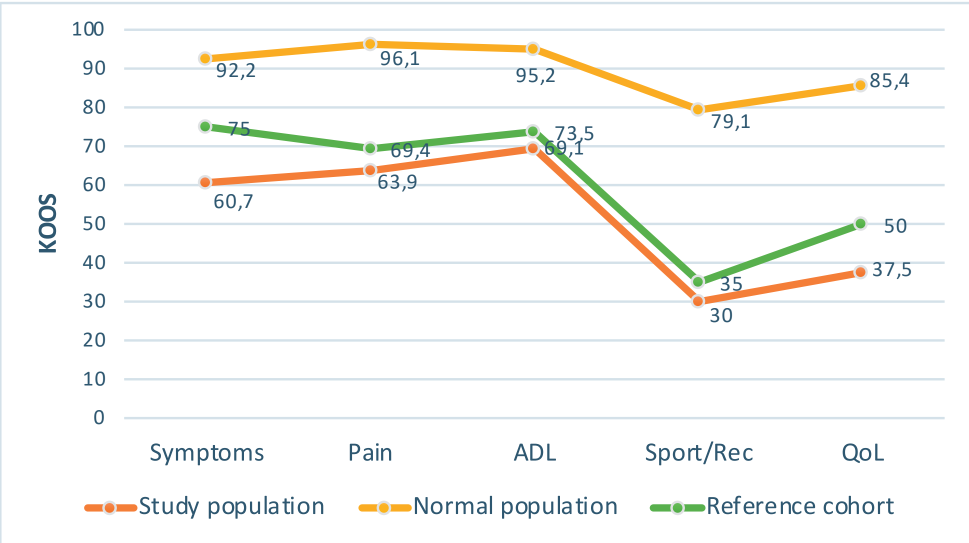

Figure 4: KOOS outcome scores.
KOOS subscale outcome scores of the study cohort, compared to a population-based reference cohort and a reference cohort of operatively treated tibial plateau fractures [7, 14].

Did posterior plate osteosynthesis improve the outcome?

In total, 27 patients (18%) were treated with posterior plate osteosynthesis. Eighteen of them returned the questionnaires (19% of all responders). Posterior plate osteosynthesis was performed in 4/9 patients (44%) with a single posterior column fracture, 9/72 patients (12%) with a two-column fracture and 14/64 patients (21%) with a three-column fracture. Comparing patients with and without posterior plate osteosynthesis did not show significant differences in any of the KOOS subscales ('Symptoms' p=0.510, 'Pain' p=0.076, 'ADL' p=0.746, 'Sports/Rec' p=0.947, 'QoL' p=0.869).

Which factors determined the outcome?

Bivariate analysis was performed on all KOOS subscales with regard to all demographic and treatment related variables, the results are presented in (**Table 2)**. All bivariate significant

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factors were evaluated for independence using a linear logistic regression analysis. Regarding the 'symptoms' subscale, varus trauma (p=0.004) and delayed-staged surgery (p=0.005) were associated with worse outcome. Varus trauma was also associated with higher 'pain' scores (p=0.039). Regarding the 'ADL' subscale, delayed-staged surgery (p=0.002) and number of columns fractured (p=0.026) were determining factors for worse outcome. Lower scores on the 'Sports and recreation' were seen in association with delayed-staged surgery (p=0.002). Regarding the 'quality of life' subscale, nonunion (p=0.033) and delayed-staged surgery (p=0.008) were associated with poorer outcome scores.

Table 2: Bivariate correlation analysis.

KOOS subscale	Symptoms	Pain	ADL	Sports/rec	QoL
Age[a]	0.061	0.152	0.576	0.557	0.142
Gender	0.249	0.903	0.244	0.920	0.863
ASA-score	0.513	0.948	0.102	0.210	0.277
BMI[a]	0.357	0.622	0.416	0.770	0.059
Smoking	0.507	0.463	0.409	0.707	0.764
Medication	0.714	0.523	0.541	0.883	0.195
DM	0.616	0.314	0.531	0.754	0.223
Other CVRF	0.134	0.342	0.881	0.422	0.952
Side	0.484	0.380	0.570	0.544	0.471
Open fracture	0.921	0.169	0.130	0.121	0.113
External fixation	0.005*	0.053	0.006*	0.002*	0.021*
Delayed (-staged) surgery	0.009*	0.529	0.196	0.380	0.163
Time to surgery[a]	0.093	0.633	0.360	0.493	0.958
Complication rate	0.361	0.299	0.373	0.845	0.092
FRI	0.652	0.813	0.633	0.400	0.682
Nonunion	0.083	0.129	0.047*	0.858	0.047*
Other complications	0.259	0.240	0.155	0.036*	0.036*
Reintervention rate	0.277	0.246	0.538	0.902	0.532
Implant removal	0.932	0.358	0.989	0.341	0.802
Revision	0.055	0.114	0.152	0.278	0.147
TKA	0.224	0.288	0.165	0.106	0.165
rTCC classification	0.038*	0.179	0.003*	0.028*	0.023*
Follow-up[a]	0.413	0.432	0.621	0.553	0.671
Radiological failure rate	0.253	0.031*	0.123	0.120	0.081
Coronal malalignment	0.774	0.682	0.464	0.667	0.460
Sagittal malalignment	0.544	0.940	0.557	0.704	0.413
Condylar width	0.207	0.040*	0.314	0.308	0.026*
Articular incongruence	0.184	0.088	0.070	0.309	0.141
Valgus/Varus	0.004*	0.040*	0.044*	0.102	0.052
Extension/Flexion	0.441	0.578	0.224	0.454	0.814

Bivariate analysis was performed using Mann-Whitney U test and Pearson correlation. Results are displayed as p-value and marked (*) if $p < 0.05$. Continuous variables are marked with[a]. Follow-up is the time interval between time of trauma and KOOS evaluation in months. Radiological failure rate was defined as presence of either malalignment, excessive condylar width or articular incongruence.
Abbreviations: KOOS, Knee injury and osteoarthritis outcome score; ADL, activities of daily living; Sports/Rec, Sports and recreation; QoL, quality of life, ASA, American Society of Anesthesiologists; BMI, body mass index; DM, diabetes mellitus; CVRF, cardiovascular risk factors; FRI, fracture related infection; TKA, total knee arthroplasty; rTCC, revised three-column classification.

Relation between trauma mechanism and outcome

A comparison between outcome in valgus and varus trauma is presented in **Table 3 & 4**. Subgroup analysis was performed for both groups respectively for flexion and extension. For all varus trauma patients, no statistical significant differences were observed in KOOS subscales between flexion and extension. Patients with valgus trauma reported lower outcome scores when associated with extension compared to flexion trauma for the 'ADL' (p=0.020) and 'Sports and recreation' (p=0.040) subscales.

Table 3: Trauma mechanism versus KOOS (n = 145).

	Valgus trauma (n=99)	Varus trauma (n=46)	P-value
KOOS			
Symptoms	67.9 (42.9 – 85.7)	46.4 (32.1 – 64.3)	0.004*
Pain	72.2 (50.0 – 94.4)	59.7 (44.4 – 75.0)	0.041*
ADL	73.5 (57.4 – 95.6)	61.8 (51.5 – 75.0)	0.045*
Sports/Rec	35.0 (10.0 – 67.5)	20.0 (5.0 – 43.8)	0.102
QoL	43.8 (31.3 – 62.5)	32.3 (12.5 – 50.0)	0.053

Continuous parameters are expressed as median values with their respective interquartile range. Percentage displayed is according to the respective trauma mechanism. The respective P-values are calculated between treatment groups using Mann-Whitney U test for continuous variables. *Abbreviations:* KOOS, Knee injury and osteoarthritis outcome score; ADL, activities of daily living; Sports/Rec, Sports and recreation; QoL, quality of life.

Table 4: Trauma mechanism (n=145).

	Valgus trauma (n=99)	Varus trauma (n=46)	P-value
Age (years)	53.0 (42.2 – 63.3)	47.6 (37.3 – 58.4)	0.196
Gender			0.418
Male	34 (34.3%)	19 (41.3%)	
Female	65 (65.7%)	27 (58.7%)	
ASA-score			0.684
1	43 (43.4%)	21 (45.7%)	
2	45 (45.5%)	22 (47.8%)	
3	11 (11.1%)	3 (6.5%)	
CVRF			
BMI (kg/m2)	24.8 (21.9 – 27.4)	26.1 (22.5 – 28.0)	0.188
Smoking	24 (24.2%)	10 (21.7%)	0.741
Medication	22 (22.2%)	10 (21.7%)	0.947
DM	8 (8.1%)	2 (4.3%)	0.409
Other CVRF	30 (30.3%)	8 (17.4%)	0.114
Side			0.012*
Left	65 (65.7%)	20 (43.5%)	
Right	34 (34.3%)	26 (56.5%)	
Open fracture	8 (8.1%)	4 (8.7%)	0.900
Delayed (-staged) surgery			0.081
Direct (<24 hrs)	21 (21.2%)	16 (34.8)	
Delayed (>24 hrs)	78 (78.8%)	30 (65.2)	
Time to surgery (days)	4 (2 – 9)	4 (1 – 7)	0.157
Complication rate	17 (17.2%)	20 (43.5%)	0.001*
FRI	11 (11.1%)	10 (21.7%)	0.096
Nonunion	1 (1.0%)	3 (6.5%)	0.059
Other complications	11 (11.1%)	13 (28.3%)	0.015*
Reintervention rate	40 (40.4%)	20 (43.5%)	0.726
Implant removal	28 (28.3%)	10 (21.7%)	0.404
Revision	10 (10.1%)	10 (21.7%)	0.059
TKA	4 (4.0%)	1 (2.2%)	0.566
Follow up (months)	31.9 (24.2 – 45.3)	33.4 (23.9 – 41.6)	0.827
Radiological failure rate	61 (61.6%)	33 (71.7%)	0.266
Coronal malalignment	11 (11.1%)	11 (23.9%)	0.080
Sagittal malalignment	21 (21.2%)	12 (26.1%)	0.527
Condylar width	18 (18.2%)	7 (15.2%)	0.814
Articular incongruence	40 (40.4%)	24 (52.2%)	0.211

Comparison between demographics treatment related variables of patients with valgus and varus trauma. Continuous parameters are expressed as median values with their respective interquartile range. Percentage displayed is according to the respective treatment category. The respective P-values for all variables are calculated between treatment groups using Chi-Square testing for binominal, ANOVA for multinominal and Mann-Whitney U test for continuous variables. *Abbreviations:* ASA, American Society of Anesthesiologists; CVRF, Cardiovascular Risk Factors; BMI, Body Mass Index; DM, Diabetes Mellitus; FRI, fracture related infection; TKA, total knee arthroplasty.

Discussion

The goal of this study was to assess the impact of trauma mechanism on patient reported outcome and to evaluate the outcome of current posterior plate osteosynthesis in a large multicenter cohort of PTPF. Since soft-tissue injuries are frequent in tibial plateau fractures, our results could potentially identify those patients who are at risk for poor outcome and require preoperative soft-tissue investigation using MRI [9-11, 15-16].

Our results showed that the majority of PTPF resulted from valgus trauma (68%), which is in line with previous studies showing frequent lateral column involvement in tibial plateau fractures [4, 10, 17]. In contrast, varus trauma, although less frequent, results in medial column fractures and is associated with posterolateral corner injury and other ligamentous injuries in the lateral compartment of the knee as shown by Porrino *et al*. [18] Patients who sustained a varus trauma showed significantly lower outcome scores for symptoms and pain compared to valgus trauma. However, no statistical significant differences in radiological postoperative outcome (gap/step, condylar width, MPTA and PPTA) between varus and valgus trauma were observed (Table 4). Although varus trauma more frequently resulted in three-column fractures, varus type trauma mechanism was multivariately found to be an independent factor for worse outcome. Moreover, a significantly higher complication rate was found after varus trauma. Varus trauma and medial column fractures have been associated with anterior cruciate ligament (ACL) ruptures, lateral collateral ligament (LCL) tears and posterolateral corner (PLC) injury [10-11, 19]. ACL tears combined with PLC injury can lead to rotational instability and subsequent osteoarthritis. The value of preoperative MRI and the implications of ligamentous injury and repair need to be further addressed. Routine assessment of soft-tissue injury and joint stability perioperatively as well as during the follow-up is essential to identify patients in need for secondary intervention. In the present study, meniscal injuries were not specifically investigated. However, in current literature regarding meniscal tears, surgical repair is advised during primary ORIF in all visualized lesions. Remarkably, Forman *et al*. showed that primary repair in lateral meniscal tears had similar outcome as patients without meniscal tears [15].

Secondary surgical treatment for soft-tissue injury in our cohort was reported in only 4 patients (n=1 medial collateral ligament repair and n=3 arthroscopic meniscal repair). Obviously, due to the retrospective nature of the study and possible loss to follow-up, these numbers could be an underestimation. Since both PTPF and ligamentous injury are associated with high-energy trauma, frequent involvement of these ligamentous and meniscal injuries is expected in this fracture type. Gardner *et al*. presented a prospective cohort of 103 consecutive patients sustaining a tibial plateau fracture, who all underwent a preoperative MRI. They showed that almost everyone (99% of patients) suffered from concomitant ligamentous injury, indicating not only the high frequency of these injuries but also implicating that not all diagnosed lesions need specific treatment [19]. Currently, studies presenting the incidence of ligamentous injury selectively for PTPF are lacking. Nevertheless, MRI is not routinely performed in the standard preoperative workup for tibial plateau fractures mainly due to lacking availability and costs. Thorough knee examination (under general anesthesia) after ORIF could contribute to early diagnosis of residual ligamentous instability. Since tension contralateral to the compression side of the fracture can lead to ligamentous injury, this might further substantiate the understanding of the trauma mechanism. Understanding the relation between position of the knee during trauma and the applied force vector (and rotation) ultimately leads to more precise understanding of associated ligamentous injury, similar to the Lauge-Hansen classification for ankle fractures, where this relation has undoubtedly proven helpful in guiding treatment and prognosis (i.e. a classification based on fracture morphology, ligamentous injury and trauma mechanism).

Delayed-staged surgery using an external fixation device was shown to be a significant indicator for worse outcome on all KOOS outcome subscales except for pain. A delayed-staged surgery protocol is primarily reserved for fracture dislocations and extensive soft-tissue injury[20-21]. Although delayed-staged surgery was associated with open fractures, the need for revision surgery and multiple column fractures, linear regression analysis clearly revealed that delayed-staged surgery is an independent factor influencing outcome. The authors conclude this substantiates the possible impact of soft-tissue injury on postoperative outcome in our cohort, meaning not only ligamentous and meniscal injury but all peri-articular tissue injury. However, grading of preoperative soft-tissue injury is highly influenced by the time of evaluation and was not standardized between participating centers.

Indication for posterior plate osteosynthesis remains a highly debated topic [1, 3, 7]. In our study, posterior plate osteosynthesis was performed in 18% of patients. Although differences in incidence were observed compared to one, two or three columns fractured (44%, 12% and 21% respectively), no statistical significant difference was found (p=0.932). No significant impact on any of the KOOS subscales was noted regarding application of posterior plate osteosynthesis. However, these results should be viewed with caution since only 18/92 responding patients were treated with posterior plating and due to heterogeneity in treatment protocols between participating centers. Recently, some authors have implicated posterior ORIF indications using the three-column concept, but this concept alone has shown insufficient to guide surgical decision making here [2-3, 7]. Hence, the question remains who will benefit from plate osteosynthesis of PTPF alone and who qualify for additional treatment.

The current study has some limitations. This study presents a large multicenter cohort of posterior tibial plateau fractures in which the relationships between fracture morphology, injury mechanisms and functional outcome have been assessed. Therefore, the inherent limitations of any retrospective cohort study apply. Information regarding ligamentous injury and clinical appreciation and decision-making can therefore not be completely ascertained. Secondly, possible selection bias as a result of difference in length of follow up between responders and non-responders cannot be excluded. Thirdly, due to heterogeneity in length of follow-up, no standardized scoring of radiological outcome and osteoarthritis could be performed.

In conclusion, the presence of PTPF have been shown to severely reduce patient reported outcome after surgical treatment of tibial plateau fractures. Besides fracture morphology, varus trauma mechanism and delayed-staged surgery (i.e. extensive soft-tissue injury) were identified as important prognostic factors on postoperative outcome. Future (prospective) studies with preoperative MRI are needed to investigate associated ligamentous injury patterns in PTPF and correlate with peri- and postoperative clinical findings to guide treatment protocols and improve outcome.

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CHAPTER 7

Why address posterior tibial plateau fractures?

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Published in:

Injury (2020)
doi: 10.1016/j.injury.2020.09.011

Abstract

Management of posterior tibial plateau fractures has gained much interest over the past few years. Fracture morphology, trauma mechanism, and soft-tissue injury have been identified as the key factors determining the treatment strategy and outcome. We provide a rationale for the operative management of posterior tibial plateau fractures by discussing the interplay between fracture morphology, trauma mechanism, and soft-tissue injury. The trauma mechanism has proven to be an important tool, not only to understand fracture morphology, but also to assess concomitant soft-tissue (i.e. ligamentous) injury. Subsequently, soft-tissue injury might play a role in future classification and diagnostic work-up of tibial plateau fractures, particularly in fractures with posterior involvement. Plate osteosynthesis using a posterior approach is safe and should be considered routinely in coronal fractures of the posterior tibial plateau, as illustrated.

Introduction

Tibial plateau fractures have significant impact on knee function [1, 2]. Posterior tibia plateau involvement has been increasingly recognized as a driver of poor functional outcome [3–5]. Incidence of these posterior tibial plateau fractures (PTPF) ranges from 28 - 70% [4,6–8]. Diagnosis and surgical planning are undoubtedly supported by CT-imaging and its three dimensional (3D) reconstructions [6, 9]. Furthermore, the use of MRI in the diagnostic work-up may provide further information on concomitant soft-tissue injury [10,11]. Although numerous different classification methods for tibial plateau fractures are available, only few have been thoroughly validated[12]. The most frequently used systems being Schatzker, AO/OTA and Luo's three-column classification. However, specific surgical guidance regarding PTPF is only minimally represented in few of these classifications. Moreover, soft-tissue injury is not taken into account by most of these classifications, while concomitant soft-tissue injuries do matter [11]. As for all tibial plateau fractures the main goal of treatment is to restore articular congruence, alignment, and achieve sufficient fracture stability that allows early mobilization. Therefore, choosing the right approach and fixation methods for the specific fracture type are crucial. However, this can be very challenging for the trauma surgeon, due to the large variability in fracture morphology.

The goal of this narrative review was to evaluate the current evidence regarding the surgical management of PTPF. Fracture morphology, trauma mechanism and soft-tissue injury have been identified as the key factors determining the treatment strategy and outcome [13]. We discuss their value guiding the operative treatment of PTPF, determine to what extent they may affect the outcome, and finally make a cautious statement about future treatment perspectives.

Fracture morphology

Early Classification Systems

Detailed understanding of fracture morphology is essential in order to optimize preoperative planning and surgical treatment. In 2016, Millar et al. reviewed all thirty-eight available classification methods for tibial plateau fractures [12]. Most of the older classification tools are intuitively focusing on the shape of the main fracture fragment, grouping fractures into split, depression or T- and Y-fractures. In fact, only three of the early classification systems appreciate PTPF (Duparc, Khan and Hohl & Moore) [14,15]. Nevertheless, besides acknowledging a posterior fragment, none of these three classifications pay attention to PTPF morphology. The most widely used Schatzker and AO/OTA classification systems were based on plain radiographs, giving insufficient information on fracture morphology, though they bear other merits on simplicity or documentation. The improved appreciation of fracture morphology using CT-imaging has been widely established, especially regarding PTPF [7,16,17].

3D Classification and Fracture mapping

3D classification systems such as the three column, four column or ten segments classification highlight the posterior aspect of tibial plateau and provide 3D understanding tibial plateau fractures. 3D classification approaches offer a more intuitive way to understand fracture morphology compared to 2D systems. Therefore, the widely used Schatzker classification was recently revisited 3D, dividing the tibia plateau into 4 quadrants in the axial plane, wherein the main fracture plane for each quadrant is identified. Subsequently, the main fracture plane is denoted by the two points of intersection at the tibia plateau rim, and by the exit point at the metaphyseal area [18].

The increased awareness of PTPF and importance to address these fractures, along with the improved imaging modalities such 3D CT-imaging, have boosted the search for more extensive classification methods. The CT-based three-column concept has gained much interest since the introduction by Luo et al. in 2010, and has proven beneficial in depicting PTPF [7,9]. In order to further differentiate specific fracture patterns, Krause et al. proposed the ten segment classification that provides more detailed information on fracture location at the level of the joint [19]. To better understand the frequency of fracture patterns, fracture mapping was introduced by Molenaars et al. in 2015 [6]. This innovative technique superimposes the contour of multiple fractures fragments and articular depression into one template. Xie et al. apply fracture mapping to categorize fracture morphology 3D. The contour of the fractures fragments and articular depression are illustrated in 3D maps [13]. These 3D fracture maps can reveal recurrent fracture patterns, provide (limited) information on soft-tissue injury, and underscore the inadequate appreciation by the most commonly used classification systems of fracture morphology, especially of PTPF[13, 20]. In addition, 3D fracture maps prevent misclassification of oblique posterolateral fracture lines in Schatzker type I or II tibial plateau fractures. Furthermore, 3D fracture maps distinguish classical posteromedial shear fractures from posterior shear-type fractures that do not fit into the Schatzker classification [17,21].

Clinical significance

New insights into fracture morphology significantly contribute to a better understanding of PTPF, which is crucial in defining treatment strategies. Molenaars et al. have shown that as much as 85% of all tibial plateau fractures with a posteromedial fragment, would possibly benefit from a non-standard customized lateral plating or additional medial or posterior plating [22]. Moreover, according to Kfuri et al. information on orientation of the main fracture plane should guide the plate application (i.e. plate application parallel to fracture plane) [18]. However, some major limitations should be noted. One-dimensional simplification of complex intra-articular fractures used in fracture mapping does not always account for specific 3D fracture characteristics and patterns. Furthermore, in highly comminuted fractures with several fracture lines, the extensive denomination of all fracture components using fracture mapping or main fracture planes, can become very complex and unreliable. Moreover, reproducibility and intra- or inter- observer reliability is still inadequate, which raises concern on the validity in daily clinical practice.

Trauma mechanism

New classification systems

Based on the three-column classification, Wang et al. introduced the updated three-column concept, which incorporates trauma mechanism (flexion/extension and varus/valgus), in order to guide surgical decision making [8]. More recently, Hua et al. evaluated a more extensive injury-mechanism centered classification system, wherein six main fracture types were defined: lateral condylar fracture (valgus type), fracture dislocation (complex force type), simple medial condylar fracture (varus type), bicondylar fracture (extension type), posterior condylar fracture (flexion type) and anterior condylar compression fracture (hyperextension type) [23]. The main strength of this study is the attention to collateral injuries, such as avulsion fractures of the intercondylar eminence and fibular head. A strong association was found here between posterior condylar fractures and evidence of soft-tissue injuries (e.g. avulsion fractures of the intercondylar eminence) [23].

Merging fracture-mapping with fracture-mechanism classification, Xie et al. aimed to combine the best of both concepts[13]. Adding hyperextension to Wang' updated three-column concept, they defined six injury categories: force vector in the sagittal plane (flexion/extension/hyperextension) and coronal plane (valgus/varus). In conjunction with Hua et al. an association between flexion-varus fractures, and anterior cruciate ligament (ACL) injury was established [8,23].

Clinical significance

These trauma mechanism-based studies focus primarily on flexion/extension/hyper-extension and valgus/varus forces. It should be noted that force vectors other than in the axial plane, like rotation, translation, and forces anterior onto the tibia plateau are not considered to date. However, based on the recent studies, the simplification of force vectors into sagittal and coronal plane is assumed to account for the majority of tibial plateau fractures [8,13,23].

Limited reports on the updated three-column concept demonstrate good radiographic and functional outcomes[8]. However it should be noted that long-term follow-up studies are not available. Also, no significant difference was found in functional outcome scores and range of motion between the different fracture groups, indicating limited association between classification and prognosis for patients [8]. Other limitations of these new

classification systems are that split and depression type fractures are not distinguished. Furthermore, there is lack of attention to fracture orientation, which is often crucial in determining the need for additional plating, particularly in PTPF. Therefore, surgical guidance is still limited. Only the three-column classification has been adequately assessed for reliability, which is relatively high due to the simplicity of the classification system [24].
The mechanism-based interpretation provides a dynamic perspective to understand fracture morphology and concomitant soft-tissue injuries. PTPF are considered as the result of either a flexion or extension compression force vector in the sagittal plane, or a hyperextension force acting as a tension arc at the posterior cortex. As a consequence of the latter, a posterolateral ligamentous injury is likely and the fixation strategy is different.

Soft-tissue injury

Diagnosis

Concomitant injuries to the collateral ligaments, cruciate ligaments and menisci are common with tibial plateau fractures. Incidences of soft-tissue injuries range from 52% up to 73%, with medial collateral ligament, posterolateral corner and lateral meniscus injury being most frequent, followed by ACL injury [8,11,25–28]. If left untreated, stability may be compromised, articular stress will increase, and early progression to osteoarthritis and joint collapse are inevitable. However, clinical detection of these lesions in the acute phase of the trauma can somehow be difficult to impossible due to pain and swelling. Although MRI is regarded as the gold standard to identify soft-tissue injuries, its routine use in tibial plateau fractures is limited by higher cost and limited availability ad hoc. In far most hospitals, plain radiographs and CT scans are part of the standard preoperative work-up. Therefore, great efforts were made to develop parameters based on preoperative plain radiographs and CT images, to predict soft-tissue injuries.

Predicting soft-tissue injury

Lateral tibia plateau depression and widening are regarded as important predictors of lateral meniscal tears. Although the thresholds for articular depression and fracture gap vary across literature, ranging from 6-14 mm and 5-10 mm respectively, most studies seem to agree that large displacements warrant high suspicion for a meniscal tears [29–36]. Though plenty of studies report on lateral meniscal injury, ligamentous injury is less well described, as only two studies report on radiographic parameters that predict ligamentous injury. Spiro et al. described an association between increased tibial plateau fracture depression and ACL lesions, and Kolb et al. found a significant effect of increasing lateral plateau widening on the incidence of lateral collateral ligament tears [31, 37]. Moreover, Mui et al. demonstrated that CT evaluation of the ligament contours is a reliable assessment, as torn ligaments could be identified with 80% sensitivity and 98% specificity. Smooth visible ligament contours without obscuration by increased attenuation in adjacent soft-tissues suggested intact ligaments [32].

The value of the Schatzker classification in predicting soft-tissue injuries is debatable. Most authors suggest that it is not suitable to estimate the probability of soft-tissue injuries in acute tibial plateau fractures, since they were unable to establish a significant association with meniscal or ligamentous injuries [31,34,36]. However, Hao-Chen et al. observed a greater risk of ACL avulsion fractures in patients with high-energy-pattern fractures types (Schatzker type IV-VI) (Figure 1), and also Stannard et al. found that ligament injuries occur more frequently in these groups [10,33]. Moreover, Chang et al. described higher injury rates for bucket-handle meniscal tears in type VI fractures [35].

Diagonal lesions are commonplace in knee sports medicine, however the recurrent patterns of a tibial plateau fractures and concomitant soft-tissue injury, are not concluded in the literature yet. The injury force mechanism theory is based on the understanding of 3D fracture morphology, which allows us to predict soft-tissue injuries. It gives us a more thorough understanding of PTPF due to forces on the posterior tibia plateau. PTPF are frequently associated with ACL avulsions due to flexion- varus forces and are accompanied by posterolateral ligamentous injury as a consequence of hyperextensions forces acting as a tension arc at the posterior cortex [8,13,23].

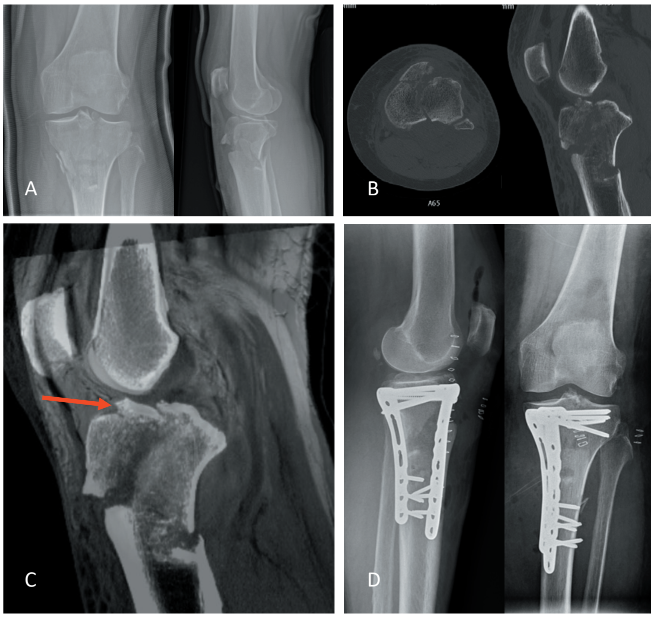

Figure 1:
A 72 year old female sustaining a left-sided tibial plateau fracture due to a fall with a motor scooter. Standard X-rays (anteroposterior and lateral, A), preoperative CT (axial and sagittal, B) and MRI were performed. Fracture morphology indicates a flexion-varus trauma. CT/MRI fusion images (C) clearly reveal the presence of an anterior cruciate ligament (ACL) avulsion fracture without ACL rupture (red arrow). Furthermore, patellar avulsion fracture, total avulsion of distal medial collateral ligament insertion and partial tear of lateral collateral ligament with associated posterolateral corner injury were detected. Timing of surgery was delayed for 8 days until clinical resolution of swelling. During surgery with dual plating, specific care was taken for fixation of ACL footprint and medial collateral ligament avulsion fragments (suturing). Standard postoperative X-rays in lateral and anteroposterior view showed good overall reduction and stable fixation (D). Postoperative care consisted of progressive mobilization (flexion /extension) with varus-valgus stabilizing brace, and 8 weeks plantar touch (non-weight bearing).

Clinical significance

The question remains whether early detection of these soft-tissue injuries will alter the treatment strategy, since the effect of these injuries on the outcome remains controversial[26]. Moreover, consensus about the need for operative treatment of soft-tissue injuries in tibial plateau fractures as well as on the timing of operative treatment is lacking. Available evidence on soft-tissue injury management is often based on isolated soft-tissue injuries without the presence of a tibial plateau fracture [38,39]. Reconstruction of cruciate ligament tears is usually deferred after fracture consolidation. Due to the anatomic properties of the medial collateral ligament, even high-grade sprains might not require surgery, though some authors do recommend reconstruction [40–42]. In contrast, lateral and posterolateral ligamentous injuries seem to be less forgiving if left untreated [11,27]. Meniscal tears are generally repaired or debrided acutely to maintain knee joint stability and congruence, and to minimize articular contact pressure, thereby preventing the development of post-traumatic osteoarthritis. Nevertheless, there are insufficient treatment guidelines, due to the lack of follow-up data on soft-tissue repair in large cohorts of tibial plateau fractures [43–45].

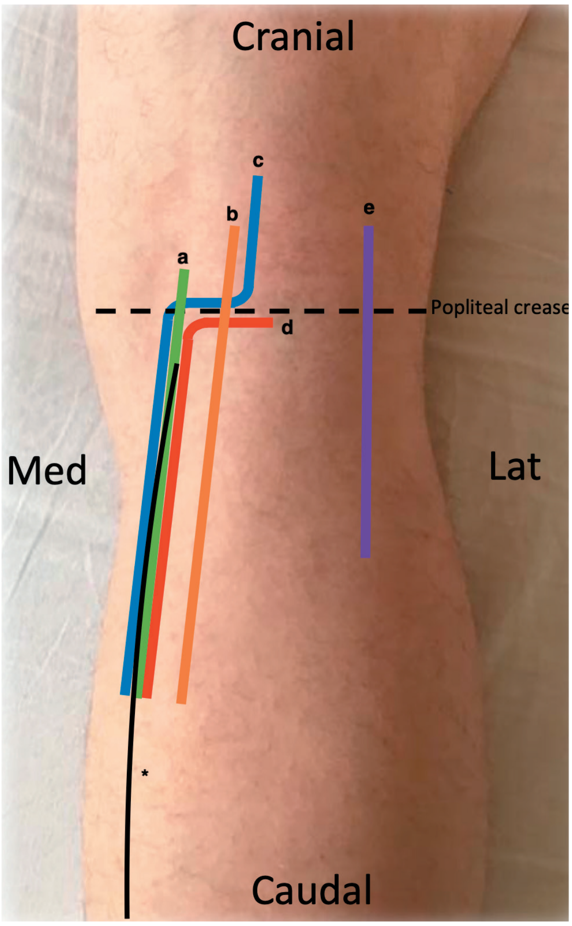

Figure 2: Posterior approaches of the tibia plateau.
a, Lobenhoffer or direct posteromedial approach (green line); b, 'FCR' or direct posterior approach (orange line); c, S-shaped posteromedial approach (blue line); d, posteromedial reversed L-shaped approach (red line); e, posterolateral approach (purple line). The medial border of the medial head of the gastrocnemius muscle indicated by the black line. The posteromedial approach has been described by several authors under several names and in different configurations [56-59]. The inverse L-configuration allows for more visualization towards the lateral aspect of the posterior articular surface [47]. Careful creation of a fasciocutaneous flap will function as protection for sural structures. Berwin et al. proposed a more lateral incision to increase visualization towards the lateral tibial aspect, however with increasing risk of damage to the sural structures [57]. All described approaches dissect along the medial border of the gastrocnemius muscle, in order to retract it laterally. Some authors propose transection of the medial gastrocnemius tendon (leaving sufficient stump for reattachment) in order to gain further exposure [55,56]. The popliteus muscle is longitudinal incised at the medial border and dissected off posterior wall. Careful dissection below the popliteus muscle and its retraction will protect the popliteal neurovascular bundle. Only blunt retractors should be used and traction should be minimized to prevent damage to the anterior tibial artery and popliteal neurovascular bundle.

Surgical management and perspectives

Approach consideration

Surgical planning should include a strategy for all affected columns and concomitant soft-tissue injury in a step-by-step manner. Regarding PTPF, there are multiple posterior approaches described in the literature (Figure 2). Recently, Krause et al. introduced a surgical approach-specific map of the tibial plateau providing information on specific visualization of the articular surface for different approaches [46]. However, the direct posterior approach and posteromedial reversed L-shaped approach (PRLA) were not addressed. In most cases the PRLA is sufficient to provide posteromedial and posterolateral buttress without the need to open the posterior joint capsule [47]. Subsequently, articular reduction can be achieved either through a posterior cortical window with the use of pusher, fluoroscopy or dry arthroscopy (fracturoscopy). Pierrie et al. demonstrated that combining a posteromedial and anterolateral approach, provides sufficient articular exposure of both the posterior aspect and lateral joint surface of the tibia plateau (Figure 3) [48]. However, exposure of the posterolaterocentral tibia plateau (according to the 10-segment classification) remains difficult [49]. The posterolateral or extended anterolateral approach (including a lateral femur condyle osteotomy) might be a good alternative here [50, 51]. A comprehensive treatment algorithm for these posterolateral fractures has been proposed by Cho et al. with specific interest towards rim plating[49]. However, no long-term follow-up is available to support these protocols. Moreover, treatment and approach choices for these posterolateral fractures should be tailored to possible other approaches used during definitive surgery.

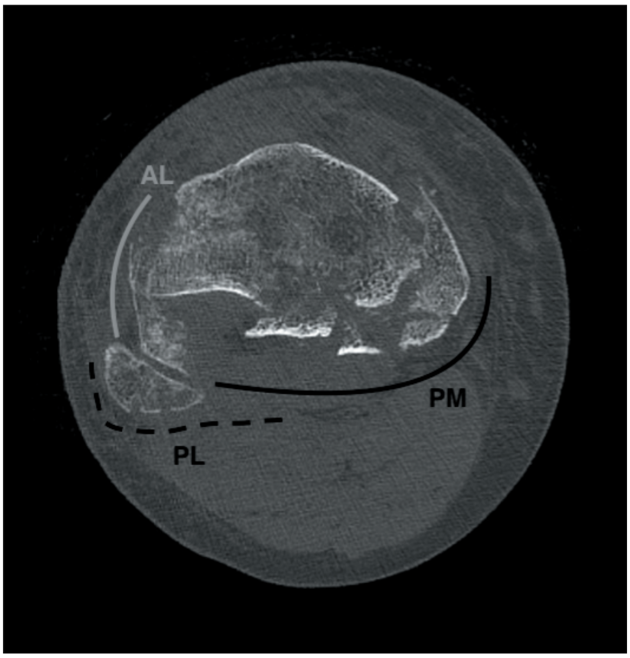

Figure 3:
Schematic exposure of the proximal tibia as demonstrated by Pierrie et al. for different surgical approaches[48]. AL, anterolateral approach (grey line); PL, posterolateral approach (black dashed line); PM, posteromedial approach (black line).

So why address PTPF?

1. Cadaveric studies have clearly indicated the unstable nature of posteromedial fractures during motion of the knee, with and without weight-bearing[52, 53].
2. Multiple outcome studies have indicated the important prognostic impact of sagittal malalignment; given the risk of secondary displacement, stabilization and restoration of sagittal alignment is very important in PTPF[3, 4, 54].
3. According to Wang et al., posterior fixation is based on trauma mechanism and column classification and the main principle being the need for buttress plating on the compression side of the fracture pattern.[8] However, previously we have shown that there is only minimal impact on outcome regarding PTPF using the column concept. Therefore, it was hypothesized that the simplification of fracture morphology in just 3 column groups insufficiently represents all treatment choices a surgeon makes during preoperative planning[5].
4. Recently implicated 'main fracture planes' imply that the direction of the fracture should guide plate osteosynthesis. Fracture mapping clearly shows the high frequency of coronal fractures ranging up to 85% in Schatzker types IV-VI, with possible benefit of additional posteromedial or posterior fixation[18, 20, 22]. Kfuri et al. proposed that the location of a buttress plate should be parallel to the main fracture plane in each quadrant. This further underscores the need for posterior buttress plating in coronal fracture patterns[18].
5. PTPF are associated with high energy trauma and specific soft-tissue injuries depending on the diagonal injury pattern [13]. Therefore, addressing these concomitant soft-tissue injuries simultaneously seems obvious.
6. Posterior approaches have clearly shown to be safe and feasible in order to address and fixate PTPF with good clinical results[5, 8, 55, 56]. Figure 4 shows a demonstrative case regarding a three-column fracture using triple plating.

Evolving perspectives

In tibial plateau fractures, research has evolved over the previous year's towards a more trauma mechanism-based view. In ankle fractures, the trauma mechanism based Lauge-Hansen classification has been used for many years in guiding treatment and predicting instability. This system is built on a comprehensive understanding of trauma mechanism and interplay between fracture morphology and ligamentous injury. One of the key aspects in such a concept is the in-depth appreciation and diagnosis of soft-tissue injury. Xie et al. introduced the diagonal injury pattern, integrating the trauma mechanism based three-column classification and associated ligamentous injuries[13]. A thorough understanding of fracture morphology, trauma mechanism and ligamentous injury can lead to further integration of diagonal tension-compression principles. To date, the impact of residual ligamentous instability in tibial plateau fractures remains for the most part unclear. Insufficient evidence is available to guide decision making for ligamentous stabilization procedures and their optimal timing. In most hospitals, a systematic preoperative MRI is not yet part of standard work-up in tibial plateau fractures. Hence, intraoperative assessment and recording of soft-tissue injury is crucial.

Further research should focus on diagnosis and classification of concomitant soft tissue (i.e. ligamentous) injury in order to guide future treatment protocols and positively affect functional outcome. Ultimately, the goal should be a comprehensive treatment concept which incorporates fracture morphology, trauma mechanism and soft-tissue injury.

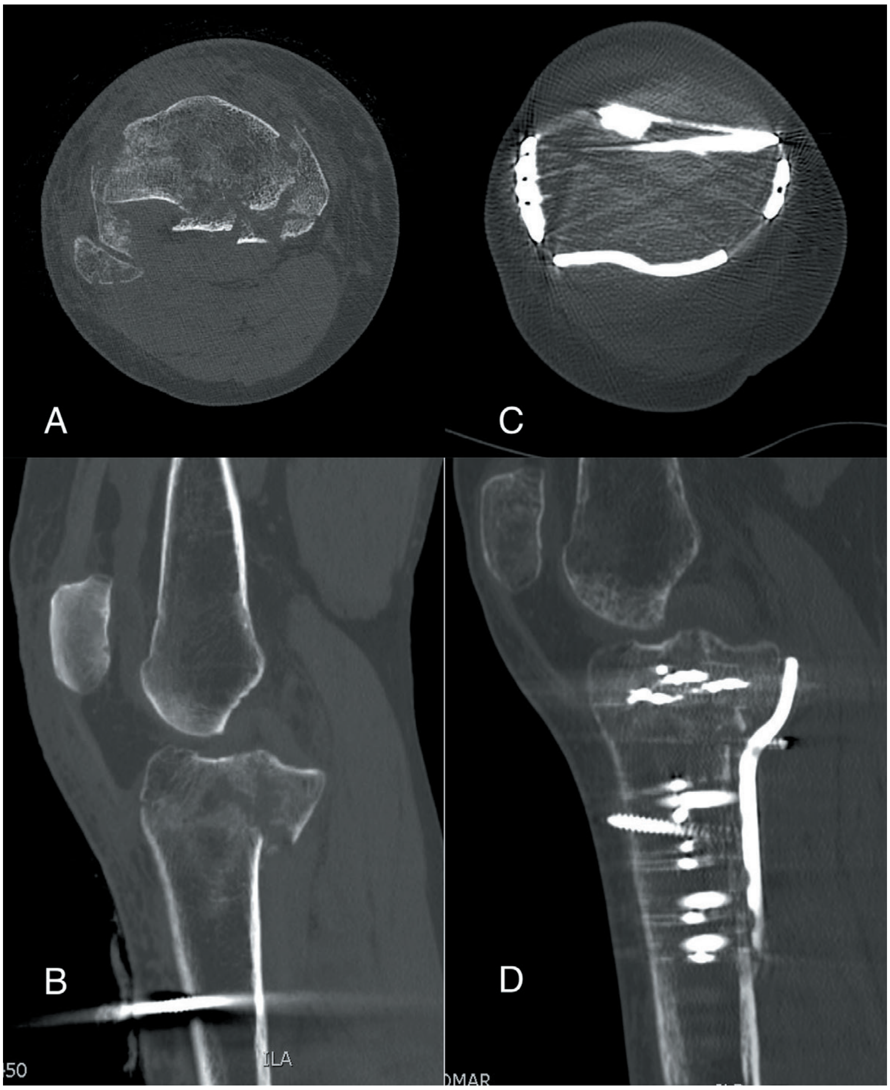

Figure 4:
This case presents a 59 year old female who sustained a unilateral accident with her bicycle. Preoperative CT-scan shows a three-column tibial plateau fracture with severe comminution. A major coronal fracture line was observed with complete separation of the posterior fracture components in axial and sagittal view. (A,B) Posterior fracture fixation was performed in prone position firstly. Secondly the patient was turned and additional medial and lateral approaches were performed for triple plating. Postoperative CT-scan at three months follow-up showed adequate reduction and buttress using the WAVE proximal tibia plate (7S medical, Switzerland) of the whole posterior column reaching the posterolateral corner. (C,D)

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CHAPTER 8

Posterior tibial plateau fracture treatment with the new WAVE posterior proximal tibia plate: feasibility and first results

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Published in:

European Journal of Trauma and Emergency Surgery (2021)
doi: 10.1007/s00068-021-01639-7

Abstract

Introduction:

Operative management of posterior tibial plateau fractures (PTPF) remains challenging. The treatment goal is to restore the alignment and articular congruence, and providing sufficient stability which allows early mobilization. The purpose of this study was to assess the feasibility and safety of the newly developed WAVE posterior proximal tibia plate.

Methods:

Between October 2017 and June 2020, 30 adult patients with a tibial plateau fracture and posterior involvement were selected for treatment with a WAVE posterior proximal tibia plate. Patient reported outcome was assessed using the Knee injury and Osteoarthritis Outcome Score (KOOS) at time of injury (pre-injury) and at one-year follow-up. Radiological outcome was evaluated with CT-imaging.

Results:

Twenty-eight patients were eligible for treatment with the new implant (3 'one-column', 10 'two column' and 15 'three-column' fractures), whereas in 2 patients anatomical fit was insufficient. KOOS results showed fair outcome scores at one year, with a large negative impact compared to pre-injury levels, however, a trend towards better results compared to a previous PTPF reference cohort. Radiological follow-up showed insufficient posterolateral buttress in 2 cases and residual articular step-off (>2mm) in 7 patients, of which five were classified as three column fractures.

Conclusion:

Management of PTPF using the WAVE posterior proximal tibia plate is feasible and safe with satisfactory clinical and radiological results after one year. Nevertheless, there is a learning curve regarding optimal implant positioning in order to achieve the maximum benefit of the implant.

Introduction

Posterior tibial plateau fractures (PTPF) are increasingly recognized as an important prognostic factor [1–3]. In parallel, there is growing awareness to treat PTPF, since PTPF and subsequent sagittal malalignment predispose for significantly worse patient reported outcome scores [3]. Posterior column fractures are well depicted according to the three-column classification, introduced by Luo et al. in 2010 [4]. This classification has proven very helpful and reliable in the preoperative planning and treatment of tibial plateau fractures (TPF) [5]. According to the revised three-column classification approach, the posterior border of the lateral column lies medial instead of anterior of the fibular head (Figure 1) [6]. CT imaging has proven indispensable in classification and preoperative planning, with possible further beneficial effect of 3D imaging techniques [7]. Lateral column TPF extending into the posterolateral corner are mostly sufficiently treated via a single lateral (lazy-s) approach, whereas posterior column fractures (medial of the fibular head) should be treated via a posterior approach [1, 5, 6].

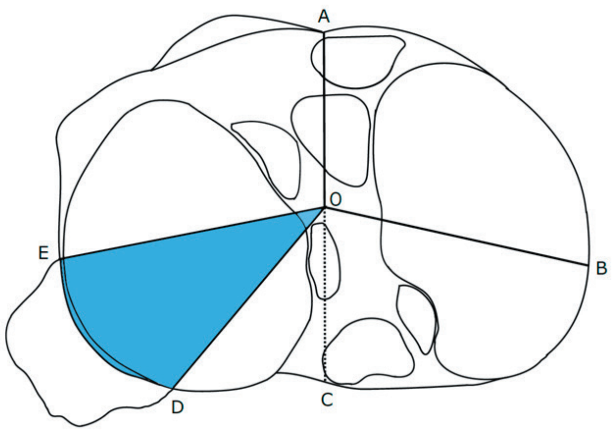

Figure 1: Revised three-column classification.
According to the revised three-column classification, lateral column fractures that extend into the posterolateral corner (blue area - OED), are defined as extended lateral column fractures (OAD). Fractures medial of the fibular head are referred to as posterior tibial plateau fractures (PTPF) (OBD) [6].

Various approaches have been described for reaching the posterior aspect of the tibia plateau, posterolateral, direct posterior and posteromedial, all with their benefits and drawbacks [1]. The posteromedial reversed L-shaped approach (PRLA) however, has been shown to be elegant and straightforward, and provides sufficient exposure of the entire posterior aspect of the proximal tibia [8, 9]. The WAVE posterior proximal tibia plate (7S-Medical, Oberkirch, Switzerland) is a newly designed implant in line with this approach with an identical inverted L-shaped configuration. The plate is designed in such a way that its horizontal arm provides both posteromedial and posterolateral buttress, due to its anatomical (epiphyseal) fit (Figure 2). Hence, PTPF that extend towards the medial border of the fibular head can therefore be treated via a single PRLA (Figure 3). This may avoid unnecessary complications associated with extensive (combined) posteromedial and posterolateral approaches. The PRLA is also known as the Burks and Schaffer approach (1990) for the treatment of posterior cruciate ligament avulsions [10]. Since the PRLA is straightforward, safe and easy to master, together with this new implant it could further lower the threshold for the operative management of PTPF.

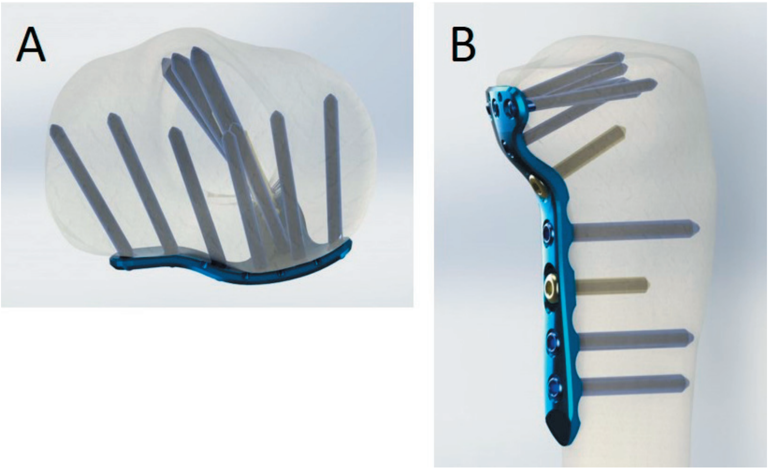

Figure 2: The WAVE posterior proximal tibia plate (7S-Medical, Oberkirch, Switzerland).
A. Axial view, B. lateral view. This plate is designed with an 12° diaphyseal axial twist, an elongated large fragment screw hole for positioning of plate, and buttress and large fragment locking holes for load transfer; an additional 15° metaphyseal axial twist with a large fragment screw hole to possibly achieve bone-plate compression; horizontal epiphyseal arm for posteromedial and posterolateral buttress with small fragment divergent locking screw holes for articular support.

The goal of this study was to assess the feasibility of the WAVE posterior proximal tibia plate for PTPF. To that end we aimed to investigate in a case series, its clinical applicability in terms of soft-tissue friendliness (i.e. required degree of soft tissue dissection), appropriate anatomical fit and thus the ability of fracture reduction and adequate fracture fixation.

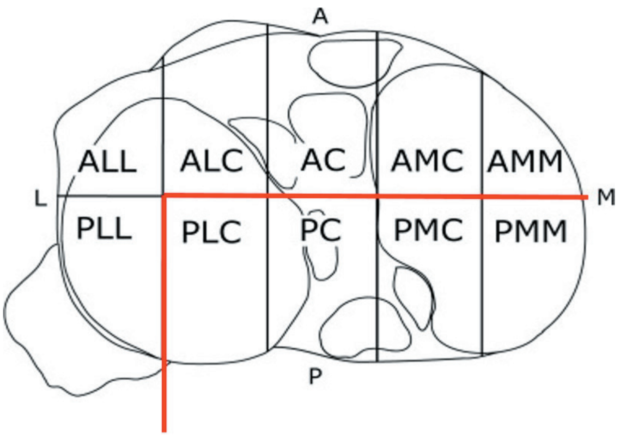

Figure 3. Ten segment classification as introduced by Krause et al. (2016).
Tibial plateau fractures affecting the posterior wall posteromediomedial (PMM), posteromediocentral (PMC), posterocentral (PC) and posterolaterocentral (PLC) can be addressed using a single posterior reversed L-shaped approach (PRLA) [20].

Patients and methods

Patients

Between October 2017 and June 2020, 30 adult patients were treated with a WAVE posterior proximal tibia plate for a single posterior column, two column, or three column TPF at the Department of Trauma Surgery of the University Hospitals Leuven. In all patients the posterior column was involved. Patients in which both the posteromedial and posterolateral part of the posterior column were affected were eligible for a WAVE posterior proximal plate (Figure 1). Based on the trauma mechanism, either a flexion/(hyper-)extension and valgus/varus forces, TPF were classified as either posterior, lateral or medial column fractures, wherein a column fracture is defined as a disruption of the cortex combined with an articular depression of each respective column [4, 5]. All patients were both operated and postoperatively assessed during the entire follow-up by the same trauma surgeon (HH). All patients got a metal artefact reduction (MAR) CT immediately postoperative as well as during further follow-up. This study was completed in compliance with national legislation and the ethical guidelines of the University Hospitals Leuven.

Surgical technique

All patients were evaluated and treated according to the three-column concept [5]. All lateral plates used were VA-LCP lateral proximal tibia plates (DepuySynthes). All medial plates used were LCP medial proximal tibia plates (DepuySynthes). The PRLA is performed in prone position. Depending on whether or not the lateral and/or medial column require open reduction and fixation, the patients are turned into a supine position, subsequently. The inverse L-shaped configured skin incision starts at the center of the popliteus fossa, running 3-4 cm medial parallel to Langer' lines, and curves down parallel to the midline of the calf (Figure 4A). Attention should be paid to the saphenous nerve (medial), and sural nerve and the lesser saphenous vein (central). Subsequently, a full thickness fasciocutaneous flap is retracted laterally (Figure 4B). After blunt dissection, the medial head of the gastrocnemius muscle is retracted laterally and the popliteus muscle exposed (Figure 4C). Next, the posterior facet of the proximal tibia is exposed through a sharp longitudinal incision at the posteromedial margin of the popliteus muscle, followed by dissecting the popliteus muscle off the bone from medial towards lateral (Figure 4D-E) [12]. Homann retractors should be placed just cranial and caudal of the fibular head. A Homann retractor on top of the fibular head carries the risk for crushing the common peroneal nerve. Placement too caudal can cause damage to the anterior tibial artery that perforates the tibiofibular septum approximately 4 cm caudal of the proximal tibiofibular joint.

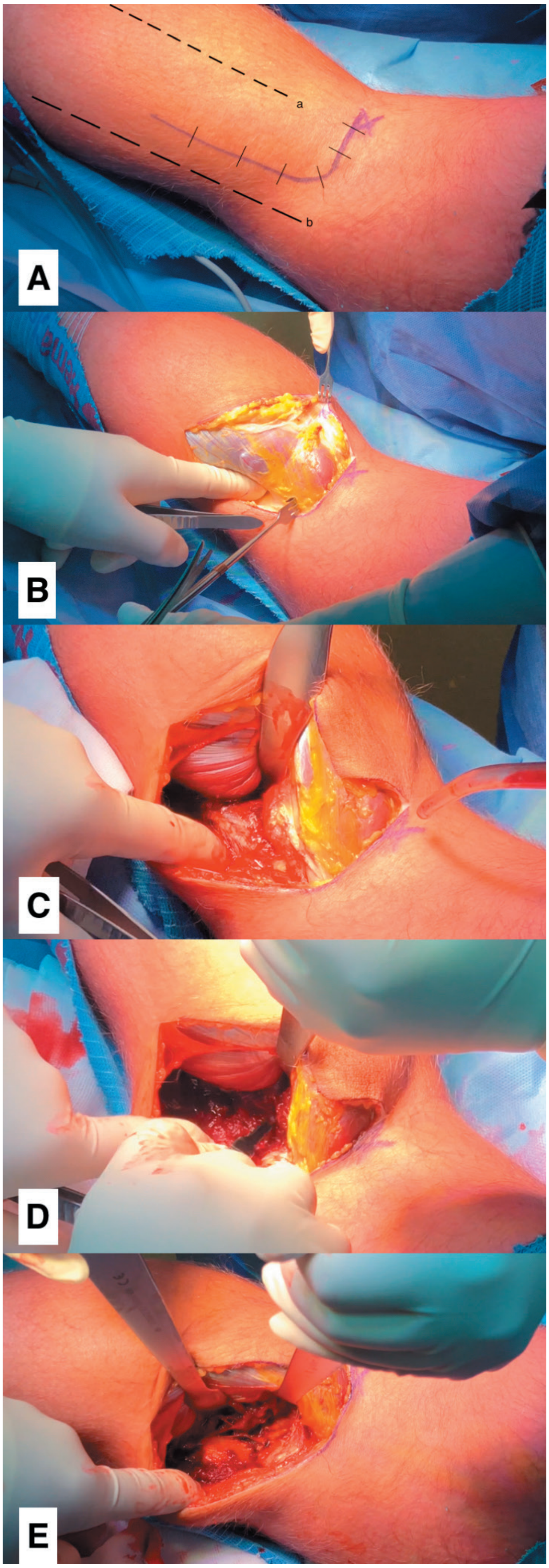

Figure 4. Posterior reversed L-shaped approach (PRLA).

A. Left knee, marking the reversed L-shaped skin incision, starting in the center of the popliteus fossa parallel to the Langer lines. It continues 3-4 cm to the medial corner of the popliteal fossa and then bends distally approximately 10-15 cm, parallel to the midline of the calf. Care should be given to avoid damage to the sural nerve and lesser saphenous vein (a) and the saphenous nerve (b). Note: it is useful to apply cross mark(s) in advance in order to be able to close the skin sufficiently after finishing the procedure.

B. A fasciocutaneous flap is lifted and retracted laterally. Attention should be paid to protect the saphenous nerve and vein. The interval between the popliteus muscle and gastrocnemius muscle is developed bluntly from distal to proximal with the medial caput of the gastrocnemius muscle and neurovascular bundle safe behind a retractor. Traction from the gastrocnemius muscle is released by flexing the knee

C. The tendon of the medial head of the gastrocnemius muscle is dissected further free (left intact though) and retracted laterally using a stump retractor to achieve good exposure of the posterior aspect of the popliteus muscle. The retractor can be placed carefully over the lateral edge of the popliteus muscle immediate caudal of the fibular head, in order to prevent vascular damage to the anterior tibial artery. The tibial neurovascular bundle lies between the medial and lateral caput of the gastrocnemius muscle.

D. The popliteus muscle is incised longitudinally at the posteromedial corner of the tibia from distal to proximal, and dissected from the posterior facet of the proximal tibia from medial to lateral.

E. The blunt retractor is replaced by two sharp ones flush over the bone and under the popliteus muscle, flush caudal and cranial of the fibular head to expose the posterior wall and fracture fragments.

Regarding fracture dislocation, reduction of the posterior wall is performed either directly or by applying the WAVE posterior proximal tibia plate (i.e. buttress). If necessary, elevation of the depressed joint surface can be established through the fracture with the use of a plunger and bone graft (Figure 5A, 5B). A posterior arthrotomy is not necessarily required. The WAVE posterior proximal tibia plate is positioned, temporally fixed using K-wires, and after checking the correct height using fluoroscopy, it is pulled to the diaphyseal bone using a large fragment cortical screw (Figure 5C). Additional locking screws are inserted in the tibial shaft for controlled load transfer. Finally, small fragment subchondral locking (rafting) screws, diverging from posteromedial are inserted depending on whether a secondary reduction of the medial or extended lateral column is necessary (Figure 5D). A video summary of the surgical procedure and technique was composed in 2018 for future reference [13].

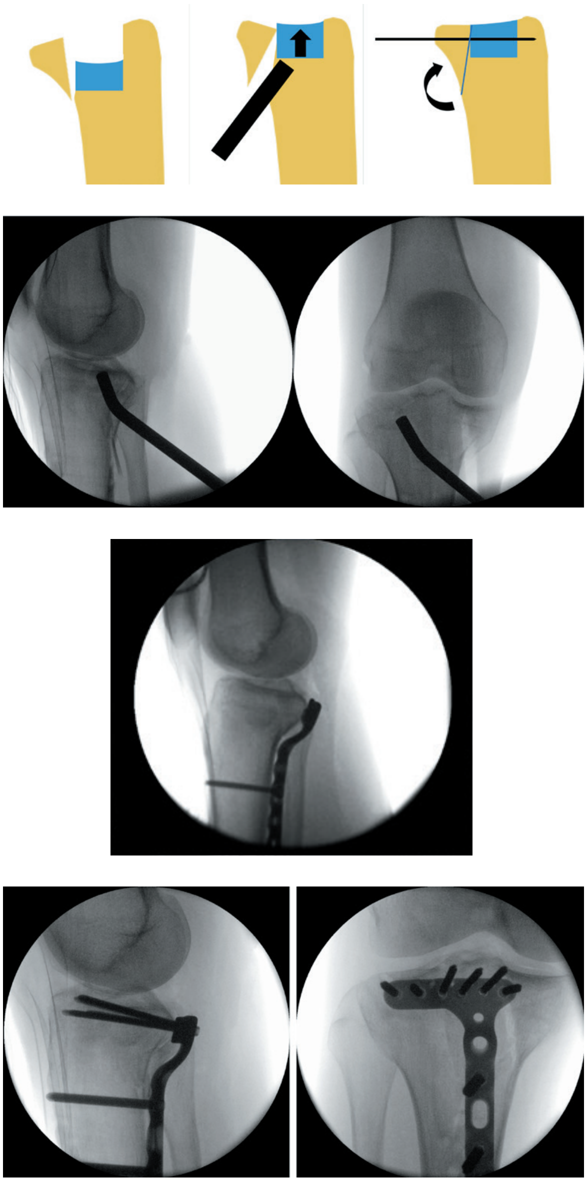

Figure 5. Indirect reduction technique and WAVE posterior proximal tibia plate application.
If buttress alone is not enough, first attempts can be made to reduce an associated articular depression by folding away the posterior fracture fragment (or opening the posterior cortex using a saw or drill) and inserting a plunger. (A, B) A posterior arthrotomy is not necessarily required. After reduction, posterior fracture fragment(s) are temporary fixated with K- wires and the reduction is verified using fluoroscopy. This buttress plate osteosynthesis starting with a large fragment cortical screw that will pull the plate to the bone and (further) reduce and restore the posterior wall. (C) Proximal locking screws (small fragment) are inserted in order to provide sufficient articular support. Depending on the need for further articular reconstruction of the existing extended lateral (or medial) column fractures, it can be decided not to use (all) the proximal locking screws. After application of the WAVE posterior proximal tibia plate fluoroscopy shows adequate reduction. (D) Articular congruence can be hard to evaluate intraoperative, therefore dry arthroscopy (i.e. fracturoscopy) or intraoperative CT might be beneficial here.

Outcome assessment

Functional outcome and general health status were assessed using the standardized Knee injury and Osteoarthritis Outcome Score (KOOS) [14]. This validated patient reported outcome measure consists of five subscales; symptoms, pain, activities of daily living, function in sport and recreation and knee related quality of life. Each subscale is presented as a normalized score (100 indicating no symptoms, 0 indicating extremely severe symptoms) and no summarized KOOS score can be constructed due to heterogeneity of the subscales [14]. All patients were asked at presentation to score their functioning before the accident. At approximately one year postoperatively, another KOOS score was obtained. Clinical follow-up in the outpatient clinic with assessment of articular stability and range of motion (using goniometer) was continued as long as deemed medically necessary.

Radiological assessment

CT-imaging using metal artefact reduction was performed in all patients for evaluation of quality of the reduction on postoperative day 1 or day 2. Reduction was assessed and marked as failed if the articular congruence (gap and/or step) exceeded 2mm. Plate positioning was assessed. In the sagittal plane the contour of the plate should match the contour of the proximal tibia metaphysis. In the coronal plane the horizontal arm should reach the superior medial border of the fibular head.

Statistical analysis

Statistical analysis was performed using IBM SPSS 26.0 (SPSS Inc. Chicago, IL). Postoperative KOOS outcome scores (at one year) were compared to a reference group using the Mann-Whitney U test for nonparametric continuous variables. Demographics are expressed as median and the respective interquartile range (IQR). A significance level of <0.05 was accepted for all tests.

Results

A total of 30 consecutive patients that underwent application of the WAVE posterior proximal tibia plate via PRLA were initially included. Median age was 54 (IQR 44-61) years, concerning 19 male and 11 female patients. Ninety percent (n=27) suffered a low energy trauma, mainly bike accidents and falls. Regarding the trauma mechanism, 26 patients sustained a flexion trauma, of which 17 were classified as flexion-valgus, 2 as flexion (unspecified) and 7 as flexion-varus TPF. Three patients sustained an extension trauma and in 1 patient a hyperextension trauma was noted. One third of the patients was treated according to a delayed staged surgery protocol (external or staged internal fixation) at 7 (IQR 4-11) days. The remaining 20 patients got the definitive surgery after 3.5 (IQR 2-6) days. Two patients with a minimal contoured posterior proximal tibia metaphysis, in which no adequate buttress using the WAVE posterior proximal tibia plate could be obtained intra-operatively (Figure 6), were treated with 2 conventional LCP (DepuySynthes) plates instead of a WAVE posterior proximal tibia plate. These patients were excluded from further follow-up in this study.

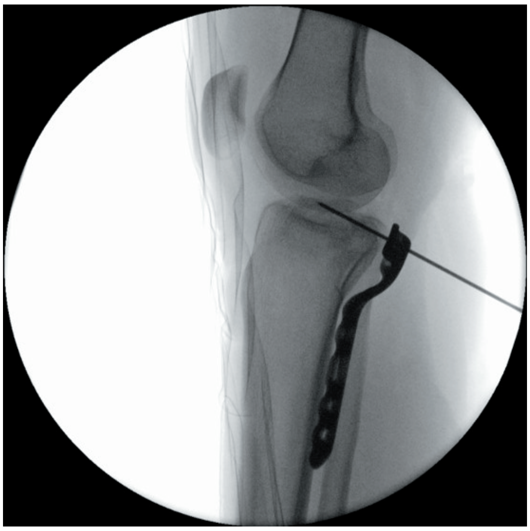

Figure 6: Steep proximal tibial contour and insufficient buttress.
2/30 Patients (both female) showed a less contoured posterior proximal tibia metaphysis, where the posterior proximal metaphyseal curvature of the WAVE posterior proximal tibia plate was larger than that of the patient. As a consequence, no epiphyseal buttress could be exerted using the WAVE posterior proximal plate.

Trauma mechanism and implants

All 'one column' (posterior column) TPF (n=4) were treated with a single WAVE posterior proximal tibia plate. All 'two column' flexion-valgus TPF (n=5) and one 'two column' flexion-varus got dual plating (lateral *vs*. medial resp.), whereas 4 out 5 'two column' flexion-varus TPF got a single WAVE posterior proximal tibia plate only. One 'two column' extension-valgus fracture was treated with dual plating. Eight out of fifteen 'three column' TPF were treated according to the 3 column concept (i.e. triple plating). The remaining 7 'three column' TPF got dual plating (WAVE plate combined with lateral plate), concerning 6 flexion valgus and 1 extension valgus TPF.

Clinical outcome

Three patients were lost in follow-up, two of which after polytrauma with associated lower limb trauma. Figure 7 displays the KOOS scores (n=19) before and 12.2 (IQR 11.0-14.1) months after surgery, as well as the results of a reference cohort of PTPF [15]. Statistical analysis showed no significant difference between the study group and the reference group for any of the subscales (p=0.348, p=0.101, p=0.273, p=0.708, p=0.096; respectively symptoms, pain, activities of daily living, function in sport and recreation and knee related quality of life). During the last clinical follow-up of the remaining 25 patients, 11 patients showed a full range of motion of the knee, 9 patients showed a limited flexion deficit (135-110°) and 5 patients showed a slight extension deficit (5-10°). Seven patients had grade 2 (5-10mm) lateral instability, and a mechanical femoral-tibial axis valgization >5° compared to the contralateral side on full-leg x-ray. At 33 months after first surgery one of these patients underwent a total knee arthroplasty.

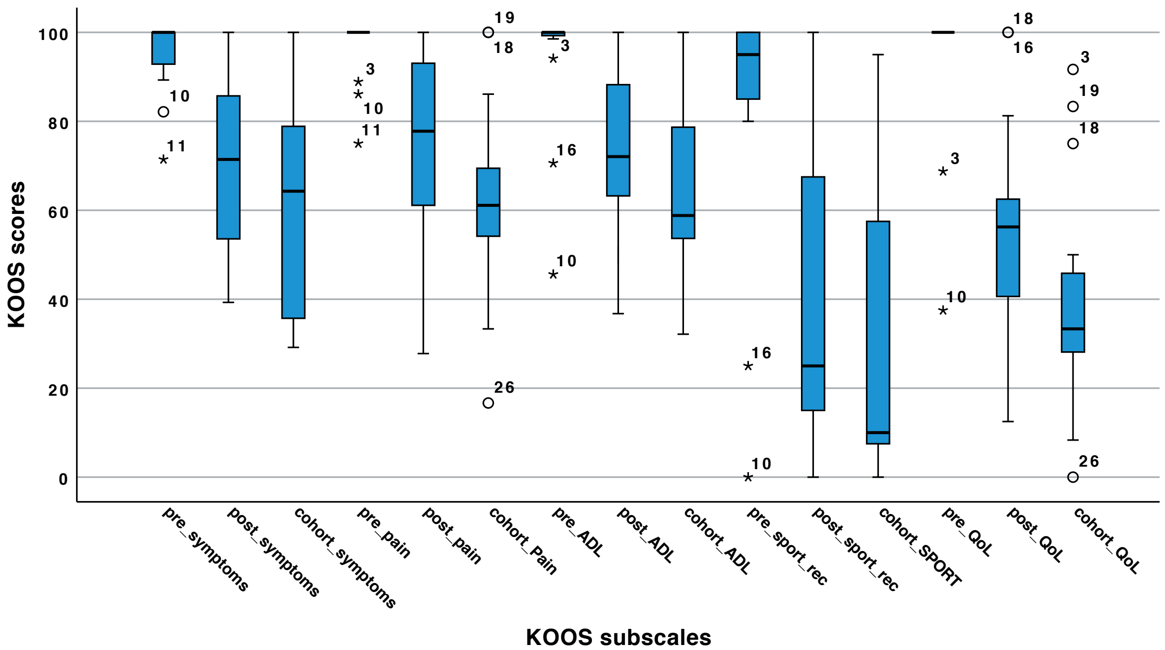

Figure 7: Boxplot KOOS subscale outcome scores.
Boxplot for all five KOOS subscale scores for pre-injury (noted as 'pre') and postoperative at approximately one year (noted as 'post') and reference cohort (noted as 'cohort'). [15] Median value is depicted by the horizontal black marking dividing the interquartile range (blue diagram). Outliers (value outside 1.5 to 3 times the interquartile range) are marked with '*o*'. Extremes (value outside 3 times the interquartile range) are marked with '*'. Abbreviations: KOOS, Knee injury and Osteoarthritis Outcome Score; ADL, activities of daily living; Sports_Rec, Sports and recreation; QoL, quality of life.

Radiological outcome

Last postoperative CT evaluation of the implant position, alignment, and articular congruence at 6.5 (IQR 3.1-9.4) months, revealed an adequate position and axial epiphyseal fit of the WAVE posterior proximal tibia plate in 21 patients, providing sufficient epiphyseal buttress both posteromedial and posterolateral. In 6 patients the WAVE posterior proximal tibia plate was applied either too lateral or medial, where in 2 patients the lateral tip of the epiphyseal arm was detached from the bone and therefore did not provide posterolateral buttress (Figure 8). The median lateral and medial posterior proximal tibia angle were respectively 11 (IQR 9-13) and 7 (IQR 5-9) degrees. In seven patients a residual articular step-off (>2mm) in either the lateral or medial tibia plateau was shown, of which 5 were three column fractures treated with triple plating.

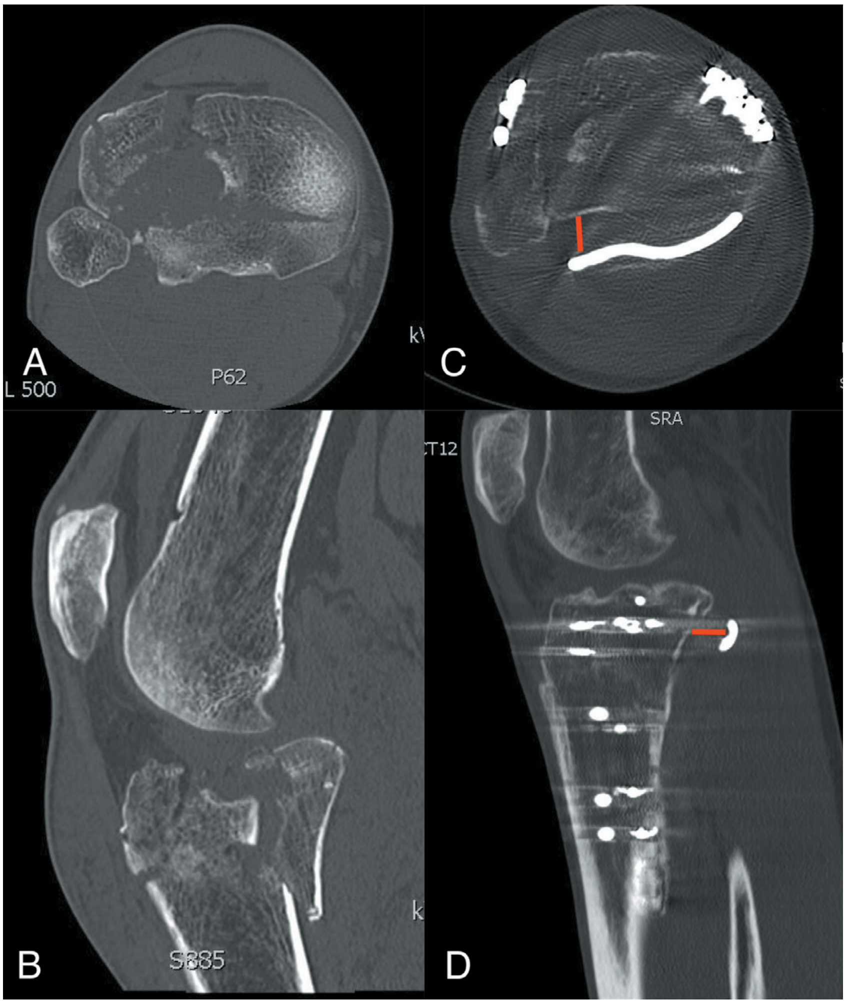

Figure 8: Clinical case with insufficient posterolateral buttress.
This 41 year old male sustained a three column fracture after a car accident and was transferred to a tertiary hospital. Preoperative CT-scan showed articular comminution of the lateral column and a large posterior fragment with a (main) coronal fracture line. (A, B) Triple plating of this three-column tibial plateau fracture was performed using a PRLA, medial and lateral (Lazy S) approach, respectively. Although postoperative CT-scan at three months showed adequate reduction of the posterior column, insufficient posterolateral buttress of the WAVE posterior proximal tibia plate (epiphyseal arm), was detected (marked red). (C, D).

Complications

In total, nine patients suffered from perioperative complications. Two patients sustained a posttraumatic and 2 patients an impending postoperative compartment syndrome requiring fasciotomy with secondary closure. Two patients developed a fracture related infection, of which 1 after fasciotomy for postoperative compartment syndrome [16]. Furthermore, one patient suffered from popliteal artery intima dissection due to severe peripheral arterial occlusive disease, eventually leading to transfemoral amputation. One patient experienced transient peroneal nerve neuropraxia. One patient was diagnosed postoperatively with pes anserinus syndrome and one patient with complex regional pain syndrome. Finally, one patient required a redo procedure due to inadequate reduction of the depressed posterolateral tibial plateau.

Discussion

The purpose of this study was to evaluate the feasibility the WAVE posterior proximal tibia plate for the treatment of PTPF. It was designed in line with the PRLA with an identical inverted L-shaped configuration, in order to treat posteromedial and posterolateral TPF simultaneously. Since the PRLA has been proposed as a straightforward and safe way to expose the entire posterior wall medial of the fibular head, we assume that this implant would simplify the operative management of TPF [8, 11].

As expected after TPF, a marked decrease in functional outcome and quality of life was noted at approximately one year postoperatively, compared to preoperative KOOS subscale scores. However, there was a clear tendency towards better results compared to a previous PTPF reference cohort with a median follow-up of 43.1 months (Figure 7) [15]. Furthermore, our results are in line with previously reported significant impact on sports and recreative activity [3, 8, 15, 17]. Prolonged follow-up showed concurrent increase in range of motion of the affected knee. In contrast, an extension deficit is associated with posterior knee surgery due to adhesions. Therefore, perioperative patient counseling and guidance is very important. In five patients a small extension deficit (5-10°) was seen. Since early mobilization (with plantar touch) can prevent major extension deficits, the authors recommend usage of varus-valgus stabilizing braces only in case of residual (ligamentous) instability, however with early full range of motion.

Radiological outcome, evaluated by residual articular gap or step >2mm showed a good quality of reduction in the vast majority of cases (21/28). This finding is promising, since previous PTPF studies have shown postoperative articular incongruence in up to 40% of cases [15]. Five (out of seven) cases with residual articular incongruence resulted from comminuted three column fractures. Evidently, in complex PTPF, anatomical restoration of the articular surface can be challenging as is true for all TPF.

TPF are generally associated with a relatively high complication rate (e.g. compartment syndrome, fracture related infection, neuropraxia), especially in cases with high energy trauma [2, 3]. However, complication rates for posteromedial approaches specifically, are low [8]. In our cohort, both postoperative compartment syndrome and fracture related infection were seen in two patients and one patient experienced transient peroneal nerve neuropraxia. These results are considered in line with the current literature [1-3, 8, 16]. However, one patient suffered from popliteal artery intima dissection eventually resulting in transfemoral amputation. It should therefore be noted that pre-existent peripheral arterial (occlusive) disease in the elderly is a risk factor when retracting the neurovascular bundle and it goes without saying that recognition of peripheral arterial disease in preoperative planning is crucial. Regarding infection, the PRLA has generally lower infection rates compared to lateral and medial approaches [1, 8].

The PRLA is a straightforward surgical approach. The soft-tissue injury is limited and extensive manipulation of the popliteal neurovascular bundle, such as in the direct posterior approach by Trickey, is avoided. Sufficient exposure of the entire posterior wall medial of the fibular head is achieved (Figure 1 & 3) [9]. In fact, medial column fractures can also be addressed via the PRLA by elevating the pes anserinus. By installing the patient in 'floating position', tilting the table and flexing the knee, it is also possible to combine an (antero-) lateral approach and PRLA without the need for reinstalling the patient [11, 18]. However, this procedure has several disadvantages. Forced knee flexion necessary for the exposure of the extended lateral column tibial plateau fracture increases the axial pressure at the posterior column and the risk for loss of reduction intraoperatively. Recognition of anatomy and interpretation of fluoroscopy can be difficult as well. Furthermore, the procedure can be challenging with severe comminution of the lateral plateau and in a compromised host (i.e. obesity). In the current study, none of the patients were operated in floating position. The vast majority was treated in prone position first and then turned in supine according to the paradigm that we first treat the more simple (cortical) fractures in order to restore the alignment and then the more comminuted (articular) fractures, for which we need the other column(s) as a foundation. Therefore, operating associated highly comminuted medial metaphyseal fractures in supine position (anteromedial approach) first, should be considered. Finally, in this cohort all 'one-column' (isolated posterior) fractures and 4 out 5 flexion-varus 'two column' fractures (posterior and medial split) could be treated with a single implant (WAVE posterior proximal tibia plate), in prone position only, thereby simplifying the treatment for such fractures.

The WAVE posterior proximal tibia plate was specifically designed to provide buttress and articular support of the posteromedial and posterolateral part of de posterior tibial plateau, as well as fixation of the intercondylar eminence. However, in two cases, perioperative evaluation showed an inadequate sagittal fit of the WAVE posterior proximal tibia plate (Figure 6A), as a result of which it could not perform its buttress function and 2 other regular implants were used here. As presented in a principal component analysis by Quintens et al. there is large anatomical variation at the level of the tibial plateau [19]. A steeper type tibial tuberosity complex is associated with a less pronounced posterior proximal metaphysis. Despite the axial contour and length of the horizontal epiphyseal arm of the WAVE posterior proximal tibia plate being adequate in all patients, in 6 patients the plate was applied either too lateral or medial. In two of these cases postoperative CT imaging showed insufficient posterolateral buttress, wherein the lateral end of the arm was detached from the bone (Figure 8), due to suboptimal positioning of the WAVE posterior proximal tibia plate too far medial. As a consequence, the combined 12° diaphyseal and 15° metaphyseal axial twist of WAVE posterior proximal tibia plate was not enough to compensate for this. This important insight will lead to better positioning in future patients.

The current study has some limitations. Firstly, for assessment of feasibility a study group of 30 patients is adequate. However, to assess for more generalized outcome and complications a larger cohort is needed. Secondly, since osteoarthritis is a long-term post-traumatic effect, this cannot be adequately evaluated during one-year follow-up. Moreover, the compared reference cohort has a longer follow-up period, therefore long-term osteoarthritis could be interfering with those results.

In conclusion, treatment of PTPF with the new WAVE posterior proximal tibia plate seems feasible. Our study shows satisfactory clinical and radiological results after one year. However, there is a learning curve regarding optimal implant positioning in order to gain adequate posterolateral buttress. With appropriate application of the WAVE plate, buttress of both the posteromedial and posterolateral tibia plateau can be accomplished. The proximal rafting screws diverging from posteromedial towards anterolateral, limit extended soft-tissue dissection, and allow for medial and lateral articular support as well as intercondylar eminence fixation. Furthermore, in far most cases of combined posteromedial and posterolateral TPF could adequately be treated with this single implant and single straight-forward approach. Early mobilization possibly with use of varus-valgus stabilizing braces should be promoted to reduce residual flexion and extension deficits. Nevertheless, further prospective cohort studies should investigate whether open reduction and internal fixation of posterior column fractures will improve long-term functional outcome.

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CHAPTER 9

General discussion and future perspectives

General discussion

Tibial plateau fractures (TPF) are generally caused by high energy trauma and the impact can be severe as demonstrated by numerous studies[1, 2]. In addition, several previous studies have indicated the possible negative impact of posterior tibial plateau fractures (PTPF)[3, 4]. The results of this thesis are in line with these findings and underscore the need for improvement in treatment of PTPF.

Diagnostics

In order to optimize treatment, the first step is adequate recognition and diagnosis of PTPF. The Schatzker classification is the most frequently used classification method and is based on anteroposterior x-ray imaging. Therefore, fractures in the coronal plane are frequently underappreciated[5, 6]. With growing availability, CT imaging has become the gold standard for preoperative evaluation of TPF and has proven beneficial in identifying PTPF[5]. In our study cohort of TPF between 2009 – 2014, 12.8% had no preoperative CT evaluation (Chapter 2). However, in the cohort with selected posterior fractures between 2009 – 2016 (Chapter 3), only 1 patient was excluded due to the absence of a CT. This indicates the existing shift in clinical practice towards CT evaluation of more complex fractures. The CT-based three-column classification (TCC) as proposed by Luo et al. has been validated and has shown high inter-observer and intra-observer reliability, especially compared to the AO/OTA and Schatzker classification [6–8]. We showed that according to TCC the incidence of PTPF is rather high (61.9%, Chapter 2) which might be explained by the frequent posterolateral corner involvement in lateral column fractures[4, 5, 9, 10]. However, these 'extended lateral column fractures' can be treated via a lateral approach only, especially since introduction of VA-LCP implants as stressed by Hoekstra et al. in the revised three-column classification approach (rTCC)[11]. Therefore, from Chapter 3 and onward, PTPF were defined according to rTCC in this thesis in order to more specifically select fractures that need separate/specific attention.

This thesis evaluates the possible benefit of 3D-CT reconstruction imaging in preoperative workup (Chapter 4). Interobserver agreement was moderate and did not differ with or without 3D-CT images. The study was conducted with 5 observers and although an increase in operative indication was seen in all observers (8.2% (OR 2.01, p=0.022)), the results were highly influenced by 2 observers with a low intra-observer agreement. Morphologic analysis of those cases with increased operative indication showed 12/13 cases with posterior and lateral column involvement, with 10 cases involving the posterolateral column exclusively. In the ten segment classification this area of interest has been denoted as 'postero-latero-central' and by Orapiriyakul et al. as the 'blind area', with both authors indicating the possible need for a posterior approach[9, 12].

Trauma mechanism and soft-tissue injury

Increasing interest has been shown for the role of trauma mechanism and its impact on fracture morphology, postoperative outcome and especially soft-tissue injuries[10, 13, 14]. Wang et al. provided the uTCC which incorporates trauma mechanism (flexion/extension and varus/valgus) in surgical decision making[10]. This classification of trauma mechanism is based on preoperative X-ray and CT-imaging. Most cases can be easily defined as varus of valgus trauma. However, in more extensive fractures with highly comminuted lateral and medial plateau and possible (sub)luxation of the knee the originating trauma mechanism can be harder to identify. Moreover, this classification of trauma mechanism does not specifically account for rotational forces during trauma. Studies by Gardner et al. and Stannard et al. show the high frequency of ligamentous and meniscal injury of up to 99% associated with TPF in general using magnetic resonance imaging (MRI)[15, 16]. Varus trauma (and medial column fractures) have been previously associated with several soft-tissue injuries (anterior cruciate ligament (ACL) tears, lateral collateral ligament (LCL) tears and posterolateral corner (PLC) injury)[14, 16, 17]. These injuries can lead to rotational instability and subsequent osteoarthritis. Yan et al., show the high incidence of soft-tissue injuries in medial condylar TPF (Schatzker type IV), especially regarding LCL, ACL and PLC given the frequent varus type injury in these fractures[18]. Although our results identify varus trauma and delayed-staged surgery (i.e. extensive soft-tissue injury) as important prognostic factors on postoperative outcome (Chapter 6), this cannot be directly linked to specific soft-tissue injuries since MRI is currently not part of standard preoperative investigations.

Surgical treatment

The evidence regarding the negative impact of posterior involvement in TPF has led to increasing interest in operative treatment of PTPF. Surgical planning, aided by all aforementioned diagnostics, should always incorporate all affected columns as well as possible soft-tissue injuries. Multiple posteromedial approaches have been described in the literature[12, 19]. Most of these are very similar and make use of the same dissection plane towards the posteromedial tibial surface. The posteromedial reversed L-shaped approach (PRLA) has been promoted as straightforward with sufficient exposure of both the posteromedial and posterolateral posterior aspect of the proximal tibia[20, 21]. In many cases of PTPF adequate buttress of the posterior column is necessary to restore alignment and articular congruence and provide adequate stability. Failure to recognize PTPF may lead to inappropriate utilization of treatment techniques resulting in worse outcome as also shown by other authors in recent years[22, 23]. Nevertheless, current available classifications do not provide definite evidence to support specific case selection for posterior plate osteosynthesis. The impact of implementation of uTCC principles was very clear in this thesis; posterior plate osteosynthesis more than doubled from 18% before 2014 to 38% afterwards(Chapter 3). However, still no significant benefit of posterior plate osteosynthesis or treatment as guided by the uTCC principles was found in PTPF in contrast to TPF in general (Chapter 2 and 3). These findings implicate a flaw within uTCC principles, possibly originating from the oversimplification in classification of three-column fractures. In surgical practice this means that these classifications can guide treatment, but definite treatment choices with case-by-case planning remain at the discretion of the trauma surgeon. The Wave posterior proximal tibia plate was developed with a corresponding reversed L-shape configuration identical to the PRLA. Furthermore, it was proposed that the diverging proximal rafting screws limit the need for extensive soft-tissue dissection, while gaining adequate buttress of the posteromedial and posterolateral tibial plateau. The results presented in Chapter 8 show satisfactory clinical, radiological and patient reported outcome after 1 year. In two patients, the implant was positioned too medial leading to insufficient buttress of the posterolateral plateau, underscoring the learning curve of the new implant. As seen in Chapter 4, treatment of posterolateral fractures with involvement of the 'blind area' remains highly debated and a posterolateral approach should also be considered[9, 12, 24–26]. However, in most cases of combined posterolateral and posteromedial TPF, adequate buttress was achieved with the WAVE posterior proximal tibia plate as a single implant.

Outcome

The extensive impact on functional outcome after TPF has been previously recognized and clearly described. Due to heterogeneity in study populations, classifications, fracture morphology and osteosynthesis techniques, specific factors influencing the outcome remain debated[1, 2, 27]. The Knee injury and Osteoarthritis Outcome Score (KOOS) is a standardized and validated tool for assessment of patient reported functional outcome and general (knee-related) health status. Furthermore, is has been validated for different languages (including Dutch, French and German) and population-based reference data is available[28–30]. The subscales can be independently compared between groups, calculation of a summarized compound score is not possible due to heterogeneity of the subscales. The advantage of independent subscale comparison is clearly visualized in the results of this thesis by identification of the low outcome scores reported on sports and recreational activities. We clearly identified PTPF, sagittal malalignment and complications as poor prognostic factors for patient reported outcome in Chapter 2. Although the implementation of uTCC treatment led to an increase in posterior plate osteosynthesis, no significant benefit on functional outcome was found in the study population(Chapter 3). Implementation of the newly developed WAVE posterior proximal tibia plate was deemed feasible (Chapter 8). However, no significant impact on postoperative outcome at 1 year was found in these 30 patients compared to a reference cohort. To assess for more generalized outcome and complications a larger cohort with longer follow-up is needed since osteoarthritis is a long-term post-traumatic effect. Also, the compared reference cohort has a longer follow-up period, therefore long-term osteoarthritis could be interfering with the results.

Sports activities and sports-specific movements put serious strain on the articular surface of the knee. These activities therefore possibly cause more complaints than lower impact activities in patients suffering from PTPF. In Chapter 5 an international multicentric cohort of 82 patients after operative treatment of TPF with posterior involvement was assessed. The results clearly show the detrimental effect on patients' sporting abilities with high numbers of unsatisfied patients (31% very disappointed, 28% disappointed). Previous studies found lower return to sports associated with increasing age[31, 32]. However, neither our study nor Kraus et al. found a significant difference between age groups[33]. These findings indicate the relativity of patient reported knee function outcomes with regard to patient specific demands. In other words, not every patient expects or needs the same knee functionality for satisfactory results. The results show better satisfaction rates and sooner return to activity for lower impact sports. Therefore, we emphasize the importance of appropriate patient counseling concerning long-term postoperative prognosis and realistic expectations with regard to sports and recreative activities.

Future perspectives

This thesis describes the frequency and impact of posterior involvement in TPF. The existence of PTPF and its relevance for patient and doctor is no longer subject of debate. However, the consequences for diagnostics, surgical treatment, functional outcome with regard to resumption of (sports) activities and long term prognosis deserve further research.

Diagnostics and soft-tissue injury

During workup, CT-imaging and no longer radiographs is and will remain the gold standard for all tibial plateau fractures. With the increasing availability of 3D-CT reconstruction and improvement of resolution the preoperative understanding of fracture morphology and with that preparedness to operate will increase. Currently used 3D-CT reconstruction consists of three-dimensional contour reconstruction. Segmentation and separation of different fracture components in 3D could be beneficial in understanding highly comminuted fractures. However, manual reconstruction methods can be laborious and require further automatization in order to gain practical applicability.

Classification of TPF remains difficult given the heterogeneous fracture patterns. A three-column classification is easy and reproducible and has guided towards recognition of PTPF. However, it seems inadequate to guide treatment in all cases and fails to incorporate trauma mechanism and soft-tissue injury. The recently adopted views on trauma mechanism give new insight together with fracture morphology, but still fail to address rotational force vectors. In complex TPF, including PTPF, exact fracture mechanism can only be reconstructed if soft-tissue injuries are accounted for. A classification combining fracture morphology, ligamentous injury and trauma mechanism could prove beneficial, just as it has for ankle fractures (i.e. Lauge-Hansen classification). However, the therapeutic consequences of performing preoperative MRI are still unclear. Future prospective studies with application of preoperative MRI to quantify soft-tissue injury patterns in relation to fracture morphology and trauma mechanism are needed. Moreover, these findings need to be evaluated for practical implications in specific treatment protocols for soft-tissue injuries (e.g. cruciate ligaments, meniscal injuries). This should firstly be implemented for all TPF but given the high impact of PTPF, these fractures potentially benefit the most from any improvement in understanding and/or therapy. In my view, this will eventually lead to standardization of the use of preoperative MRI in specific injury types.

Surgical treatment

Although some orthopedic trauma surgeons remain hesitant, several possible posterior approaches have been increasingly recognized as a valid treatment option, especially in complex TPF. Posterior approaches have clearly shown to be safe and effective in addressing PTPF. Several combinations of approaches are possible and can be used according to specific fracture morphology and operative plans. For example, PTPF with extension into the posterolateral corner and comminution can be addressed by either combining PRLA and lateral approach or a direct posteromedial (i.e. Lobenhoffer approach) combined with a posterolateral approach. The future trauma surgeon operating on PTF should always have multiple approaches in his/her toolbox in order to address all possible fractures.

Therefore, teaching of these approaches is a key element that deserves extra attention in the near future. Since turning the patient in prone position and back is needed for posterior approaches, considerate preoperative planning, clear communication and adequate training are important for all team members involved (e.g. surgeons, nurses, assistants and anesthesiologists). In other words, teamwork will make the proverbial dream work.

Newly developed intra-operative imaging techniques (e.g. CT and possibly 3D-CT) will further drive surgical precision in the future. In PTPF specifically, these techniques might improve fracture reduction and implant placement before turning the patient from prone to supine position (considering the fact that in most cases a prone-supine sequence is used). Moreover, arthroscopic assisted internal fixation (ARIF) has potential benefits in both aiding with fracture reduction as well as decreasing infection risk due to the minimal invasive technique. The reversed L-design of the WAVE posterior proximal tibia plate facilitates buttress of the posteromedial and posterolateral posterior tibial plateau. However, further improvement in implant design might be beneficial since there is significant anatomical variation in the contour of the posterior proximal metaphysis. Having multiple possible options in implant curvature combined with preoperative assessment will provide better anatomical fit. Moreover, intra-operative CT-imaging will also be beneficial with regard to correct implant placement since a learning curve seemed present with this new implant.

Outcome

Different patient reported outcome measures (PROM's) can be used in knee injuries. Since patient understanding is very important, questionnaires need to be validated not only in general but also for language. In retrospective cohorts of PTF, prospective gathering of PROM's can be influenced by length follow-up and patient related characteristics (e.g. pre-existing knee impairment). Furthermore, patient expectations can highly influence overall satisfaction rates. However, overall results clearly state the high impact of PTPF on patient reported outcome. Future studies regarding previously mentioned MRI protocols, implant improvements and diagnostic tools should try to implement prospective gathering of PROM's at dedicated timepoints during follow-up. If possible with baseline measurement at time of first presentation.

Postoperative radiological follow-up currently includes CT-imaging with metal artefact reduction (if available) in order to assess articular congruence and implant positioning. At this point it is unclear if postoperative MRI with metal artefact reduction could be beneficial in specific patients. Cases with unexplained unsatisfactory outcome, clinical instability or with suspected soft-tissue injury could benefit from further investigation. However, studies are needed here in order to associate eventual MRI findings with actual clinical problems and thereafter possible treatment options need to be assessed as well.

Our findings on sports related outcome and patient satisfaction should guide towards more adequate patient counseling in the future. In many medical fields where quality of life is possibly lost, patient centered support is expected and provided (i.e. oncological medicine). Although there is absolutely room for improvement in treatment of PTPF, many cases with extensive impact on knee function will remain. Therefore, future treatment protocols of these possibly invalidating fractures should incorporate expectational management and possible psychological follow-up regarding the loss of functionality.

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Chapter 9

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CHAPTER 10

Summary in English and Dutch

Summary

Over the last decade, increasing interest has gone out to tibial plateau fractures (TPF). At the same time the paradigm has shifted towards posterior tibial plateau fractures (PTPF) due to their possible negative impact on outcome. **Chapter 1** gives a general introduction on TPF and PTPF and describes the aims and general outline of this thesis.

In **Chapter 2**, the patient reported outcome in a retrospective cohort of 218 patients with a TPF, treated between 2009 and 2014, was evaluated and compared to all relevant treatment and patient specific characteristics. Treatment according to the updated three-column concept (uTCC) resulted in markedly better outcome scores. Incidence of posterior column fracture according to three-column classification (TCC) was found in 61% of patients. Posterior involvement, sagittal malalignment and postoperative complication were all independently associated with worse outcome scores.

In order to further investigate the impact of PTPF and posterior plate osteosynthesis on postoperative outcome, a cohort of 111 operatively treated patients who sustained a PTPF between 2009 and 2016 was selected. **Chapter 3** underscores the major impact of PTPF on functional outcome. Although the implementation of uTCC principles from 2014 was clearly shown to increase application of posterior plate osteosynthesis, no specific benefit could be demonstrated.

Three-dimensional CT reconstruction images are increasingly available. The impact of 3D-CT on preoperative surgical planning in PTPF was investigated in **Chapter 4**. Five observers were presented with CT images of 34 cases with TPF in 2 intervals. At the second evaluation 3D-CT reconstructed images were added. An increase of 8.2% of indication for posterior approach and fixation technique was found with added 3D-CT reconstruction. This increase was mainly present in patients sustaining posterolateral fractures.

Sports activities and sports-specific movements require adequate knee mobility and function. In **Chapter 5**, we assessed sporting abilities and patient satisfaction after operative treatment of PTPF. The results show the significant negative impact on reported sporting abilities with markedly low patient satisfaction rates. Low impact sports were shown to have better satisfaction rates and sooner return to activity. No differences between age groups were found, indicating the relativity of outcome compared to patients' demands. We stressed the importance of improving patient counseling on postoperative prognosis and expectations regarding sports and recreative activities.

In order to improve the understanding of outcome after PTPF, **Chapter 6** explores the impact of trauma mechanism. An international retrospective cohort of 145 operatively

treated TPF with posterior involvement was selected. Preoperative CT imaging was evaluated and trauma mechanism was defined and compared to patient reported outcome. Varus trauma and delayed-staged surgery were identified as poor prognostic factors for patient reported outcome.

In **Chapter 7**, all relevant literature regarding fracture morphology, trauma mechanism and soft-tissue injury is reviewed, leading to general recommendations on why PTPF should be addressed properly.

In **Chapter 8,** the feasibility and safety of a newly developed posterior implant was evaluated in a prospective cohort of 30 patients. Application of the 'WAVE posterior proximal tibial plate' via posteromedial reversed L-shaped approach was shown to give adequate buttress in most cases with satisfactory results after one year. A learning curve was seen with regard to optimal implant positioning.

Nederlandse samenvatting

Gedurende de laatste 10 jaar is er steeds meer aandacht voor tibiaplateaufracturen (TPF) gekomen. Tegelijkertijd is het besef gegroeid dat posterieure tibiaplateaufracturen (PTPF) het functionele eindresultaat mogelijk negatief beinvloeden. **Hoofdstuk 1** geeft een algemene introductie omtrent TPF en PTPF en beschrijft de doelstellingen en opzet van deze thesis.

In **Hoofdstuk 2** wordt van een retrospectief cohort (2009 -2014) van 218 patiënten met een TPF, de door patiënten zelf gerapporteerde resultaten beschreven en uitgezet tegen de meest relevante behandeling en patiënt gerelateerde kenmerken. Behandeling volgens het *updated three-column concept* (uTCC) resulteerde in duidelijk betere uitkomsten. De incidentie van posterieure pijler fracturen volgens de drie-pijler classificatie (TCC) was 61%. Een posterieure fractuur, een sagittaal malalignement en het optreden van (postoperatieve) complicaties bleken onafhankelijk van elkaar voorspellers te zijn van slechte uitkomst scores.

Teneinde het effect van een PTPF en posterieure plaat- en schroefosteosynthese op het postoperatieve resultaat te bestuderen, werd vervolgens een cohort van 111 operatief behandelde patiënten (2009 -2016) met een PTPF geselecteerd. **Hoofdstuk 3** bevestigt de negatieve impact van een PTPF op het functionele resultaat. Hoewel de implementatie van de uTCC principes vanaf 2014 hebben geleid tot een duidelijke toename van posterieure plaat- en schroefosteosynthese, kon geen functioneel voordeel worden aangetoond.

Driedimensionale CT reconstructies zijn steeds vaker beschikbaar. De impact van 3D-CT reconstructie op de preoperatieve planning in PTPF werd onderzocht in **Hoofdstuk 4**. CT beelden van 34 casussen met TPF werden in twee tijden aangeboden aan vijf beoordelaars. Tijdens de tweede evaluatie van de beelden werd een 3D-CT reconstructie bijgevoegd. De operatieve indicatie voor een posterieure benadering met osteosynthese nam toe met 8,2% na toevoeging van 3D-CT reconstructiebeelden. Deze toename was overwegend te zien bij patiënten met een posterolaterale fractuur.

Sportactiviteiten en sport-specifieke bewegingen vereisen een goede kniefunctie. **Hoofdstuk 5** beschrijft de sportcapaciteiten en patiënttevredenheid na de operatieve behandeling van een PTPF. De resultaten tonen een significant negatief effect op het kunnen uitoefenen van sport met een uitgesproken lage patiënttevredenheid. De zogenaamde 'lage impact sporten' toonden een hogere tevredenheid en een snellere hervatting. Hierbij werd geen leeftijdsverschil gezien, wat er op wijst dat het functionele resultaat ondergeschikt is aan de verwachtingen van de patiënt. We benadrukken derhalve het belang van goede patiëntenvoorlichting aangaande postoperatieve prognose en de verwachtingen met betrekking tot het uitoefenen van sport en recreatie.

Teneinde het functionele resultaat na een PTPF beter te kunnen duiden, beschrijft **Hoofdstuk 6** de invloed van traumamechanisme. Retrospectief werd een internationaal cohort van 145 operatief behandelde patiënten met een PTPF geselecteerd. De preoperatieve CT beelden werden beoordeeld en het traumamechanisme werd vastgesteld en nadien vergeleken met de uitkomsten. Het varustrauma en een gefaseerde operatieve behandeling (i.e. gecompromitteerde wekedelen) bleken onafhankelijke voorspellers van een slecht resultaat te zijn.

Een review van alle relevante literatuur in **Hoofdstuk 7** beschrijft de relatie tussen fractuurmorfologie, traumamechanisme en wekedelen letsels. Dit leidt tot de aanbevelingen om PTPF chirurgisch te behandelen.

In **Hoofdstuk 8** evalueren we de haalbaarheid en veiligheid van het gebruik van een nieuw implantaat voor de behandeling van PTPF in een prospectief cohort van 30 patiënten. Het gebruik van deze 'WAVE posterieure proximale tibia plaat' via een posteromediale benadering (*posteromedial reversed L-approach*) toonde in veruit de meeste patiënten een adequate posterieure afsteuning met doorgaans bevredigende resultaten na een jaar. Wel werd een leercurve waargenomen met betrekking tot een optimale positionering van het implantaat.

Appendices

List of publications

This thesis

van den Berg J, De Boer AS, Assink N. Trauma mechanism and patient reported outcome in tibial plateau fractures with posterior involvement. *Knee. 2021 Apr 10;30:41-50. doi: 10.1016/j.knee.2021.03.011. Online ahead of print.*

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Quintens L, **van den Berg J**, Reul M, Van Lieshout E, Nijs S, Verhofstad M, Hoekstra H. Poor sporting abilities after tibial plateau fractures involving the posterior column: how can we do better? *Eur J Trauma Emerg Surg. 2021 Feb;47(1):201-209. doi: 10.1007/s00068-019-01220-3. Epub 2019 Aug 31.*

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van den Berg J, Reul M, Nunes Cardozo M, et al. Functional outcome of intra-articular tibial plateau fractures: the impact of posterior column fractures. *Int Orthop*. 2017;41(9):1865-1873. doi:10.1007/s00264-017-3566-3.

Other publications

hoekstra H, Vanhees J, **van den Berg J**, Nijs S. Extended lateral column tibial plateau fractures. How do we do it? *Injury. 2018 Oct;49(10):1878-1885.* doi: 10.1016/j.injury.2018.07.027. *Epub 2018 Jul 27. Erratum in: Injury. 2018 Nov 3.*

Monteban P, **van den Berg JD**, Van Hees J, Nijs S, Hoekstra H. The outcome of proximal fifth metatarsal fractures: redefining treatment strategies. *Eur J Trauma Emerg Surg. 2018 Oct;44(5):727-734.* doi: 10.1007/s00068-017-0863-x. *Epub 2017 Oct 12.*

van den Berg JD, Monteban P, Roobroeck M, Smeets B, Nijs S, Hoekstra H. Functional outcome and general health status after treatment of AO type 43 distal tibial fractures. *Injury*. 2016;47(7):1519-1524. doi:10.1016/j.injury.2016.04.009.

PhD Portfolio

General Courses

- Good Clinical Practice (9/2020)
- Central lecture research integrity (3/2020)
- Verdere inzichten in klinisch wetenschappelijk onderzoek
- Lecture stralingsbescherming

Seminars and Workshops

- Advanced Trauma Life Support (ATLS)
- AO Beginner's course

Oral Presentations

EFORT congress 2019 – Lissabon

- Reversed L-Concept For The Treatment Of Posterior Column Tibial Plateau Fractures: The Quest For Intelligibility
- Posterior Tibial Plateau Fractures And The Impact Of Trauma Mechanism

EFORT congress 2017 – Vienna

- The outcome of operative treatment of AO type 44 ankle fractures: role of posterior malleolus fractures and syndesmotic injuries.

EFORT congress 2016 – Geneva

- Functional outcome and general health status after treatment of AO type 43 distal tibial fractures.

Poster Presentations

EFORT congress 2019 – Lissabon

- Poor sporting abilities after tibial plateau fractures involving the posterior column: how can we do better?

ECTES congress 2017 – Boekarest

- Functional outcome of intra-articular tibial plateau fractures: the impact of posterior column fractures.

EFORT congress 2017 – Wenen

- Functional outcome of intra-articular tibial plateau fractures: the impact of posterior column fractures.

Traumadagen 2016 – Amsterdam

- Functional outcome and general health status after treatment of AO type 43 distal tibial fractures.

Curriculum Vitae

Juriaan David van den Berg was born on the 31st july 1988 in ’s Hertogenbosch. He attended secondary school at the Karel De Grote College in Nijmegen from 2001 till 2007.

After travelling around the world to Australia he started the Bachelor Technical Medicine at the University of Twente in Enschede in 2018. During an internship in the cardiothoracic surgery department in Maastricht his interest in surgery started to grow. After passing the admission exam for Belgium he started the Bachelor of Medicine at the Catholic University of Leuven in September 2011.

During his studies he developed an interest for research and started working as a Student Researcher in the field of Skeletal Biology, Abdominal Transplantation and from 2015 onwards at the Traumatology department of the University Hospitals Leuven. He was a board member of the ‘Leuvense vereniging voor student-onderzoekers’ (LVSO) for two years.

Under supervision of prof. dr. H. Hoekstra (Traumatology Department, University Hospitals Leuven) he conducted his first studies on the topic of proximal tibia fractures. During the following years several studies followed including multicentric and international collaborations. This lead to the start of the jointly supervised doctorate program by prof. dr. M.H.J. Verhofstad and prof. dr. H. Hoekstra (of the Erasmus University Rotterdam and the Catholic University of Leuven respectively).

In 2018 he received his Master’s degree in Medicine (magna cum laude) at the Catholic University of Leuven. He has since started his general surgery residency training at the University Hospitals Leuven (prof. dr. P. De Leyn), AZ Turnhout (dr. G. Daenen) and AZ Klina (dr. P. Delvaux).